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DIVISION OF THE
STATE GEOLOGICAL SURVEY
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URBANA

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FIFTH ANNUAL MINERAL INDUSTRIES CONFERENCE

Recent Scientific and Industrial Developments Significant to the Mineral Industries of Illinois

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National Crushed Stone Association
National Lime Association
State Department of Mines and Minerals
State Division of Highways
St. Clair-Madison County Coal Operators' Association
Western Society of Engineers

ILLUSTRATIONS

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[1] The manuscript on "Production of Beidellite Clay and Its Uses", by J. L. Essex, Chief Engineer, Illinois Clay Products Co., Chicago, was not submitted for publication.

[2] The paper "Decolorization of Southern Illinois Silica" by J. S. Machin and F. V. Tooley has been published since the conference by the State Geological Survey as Report of Investigations No. 47.

The manuscript on "Use of Geophysical Apparatus in the Prospecting of Industrial Mineral Deposits" by H. A. Buehler, State Geologist, Missouri Geological Survey, was not submitted for publication.

RECENT SCIENTIFIC AND INDUSTRIAL DEVELOPMENTS SIGNIFICANT TO THE MINERAL INDUSTRIES OF ILLINOIS

INTRODUCTION OF CLYDE E. WILLIAMS

By

M. M. Leighton

Chief, Illinois State Geological Survey

Five years ago, these Annual Mineral Industries Conferences were organized to meet a need for a closer comradeship between those engaged in the mineral industries of the State and those who are members of the scientific research agencies here at the University, whose work pertains to mineral resources and the products.

There are two very important and fundamental reasons why close comradeship is desirable. In the first place, those who are engaged in the mineral industries should have an opportunity to learn first-hand of the results of the research work of the scientific agencies. In the second place, those who are active in research should have an opportunity to learn of the problems that are continually facing the mineral industries in their successful operation.

It was believed that if these two purposes could be accomplished it would advance the welfare of the mineral industries and would be invaluable to the work of the scientific agencies in keeping their programs of research properly oriented.

The success of these conferences speaks definitely as to the soundness of the plan and of the realization of the objectives.

The program for this conference has developed into a most attractive one. All of those who are to appear on the program are authorities in their fields. Their willingness to accept our invitations has been truly remarkable, and I wish to take this opportunity of expressing the thanks and appreciation of the sponsors.

This program has been shaped around the central theme of the scientific and industrial developments that have recently been made which are of special significance to the mineral industries of Illinois. The opening number of our Conference will sound the keynote for the Conference and will give food for thought during the coming year. Our principal speaker is widely and favorably known among the mineral industries and his knowledge and opinions command our respect. Occupying the position of Director of Battelle Memorial Institute of Columbus, Ohio, his daily responsibilities bring him into intimate touch with the problems of industry. It is therefore with pleasure that I have this privilege of introducing our principal speaker, Mr. Clyde E. Williams.

RESEARCH IN THE MINERAL INDUSTRIES

By

Clyde E. Williams

Director, Battelle Memorial Institute, Columbus, Ohio

INTRODUCTION

I was happy to receive Dr. Leighton's invitation to be with you at this conference, not only because of my friendship for Dr. Leighton and his staff and my admiration for the accomplishments of the three groups sponsoring this meeting, but also because of my keen interest in the theme of the conference.

I recall that in the dark days of the depression when national and state institutions and industries generally were retrenching and even terminating research and development work, the State of Illinois gave its Geological Survey an increased appropriation. Whereupon the Survey capitalized its opportunity and built up one of the finest institutions of its kind in the country. The developments that already have resulted from the work of this institution have proved the wisdom of this action, and the people of the State will continue to realize upon its value increasingly as the years go by.

By spending important sums continuously for scientific research in the field of mineral industries, this State, so rich in natural resources, will make doubly sure that its people will continue to enjoy the better things in life.

PURPOSE OF RESEARCH

Man has always striven, consciously or not, to get more comfort and enjoyment out of life; to acquire more and better things to wear and eat and enjoy; to find greater security, better health and longer life; and to secure improved transportation and greater ease of communication with his fellow men. The progress man has made down through the ages has been due to this desire plus an inventive ability. In fact, it is inventive ability that characterized early man and provided him with the means for besting his enemies. It used to be said that "Necessity is the mother of invention," but isn't it true that desire for better things creates the necessity, and hence, that the phrase should be "Desire is the mother of invention?"

So research has always gone on, only now the rate of invention is more rapid and the time lapse between the invention and its wide use has been

greatly reduced. Heretofore, invention was more often a hit-or-miss affair rather than the result of carefully planned and executed research that it is today. Such planning and execution can now be done in a business-like manner by trained men having facilities and tools to speed up and insure results. Business executives are sympathetic toward research, and financiers support it because they know that it pays.

KINDS OF RESEARCH

There are many types of research and many methods for classifying it. In the case of the mineral industry, two broad classifications may be made, namely, (1) research into methods of discovery, mining, preparation and smelting of minerals, and (2) use research, which may take the form of increasing old uses in established industries, substituting one product for another, or developing entirely new uses. Research also may be broadly classified as fundamental and practical. Fundamental research consists in finding facts that may or may not have a practical application, while practical research consists in the application of fundamental knowledge to effect a useful result.

An executive of a large corporation once told me that he was interested in only one kind of research, that is "dollar" research. By that he meant research designed to make money for his company. After all, this definition stated somewhat more broadly, is the object of all research, that is, research designed to effect a selfish end. This selfish end may be the acquisition of more money, the betterment of living conditions, the increase in the enjoyment of life, or the improvement of health. Even fundamental research of the most theoretical or academic type stands a chance of being applied practically, though the research worker may not have in mind any such practical application. In fact, it is usually unwise that the fundamental research worker's mind be limited by practical considerations but better that it be given full scope to develop scientific facts without regard to their practical usefulness. For economy's sake, it is often necessary to choose among the multitude of fundamental problems available those which lie in fields wherein practical developments are needed.

Practical research, for the most part, is aimed at the solution of a commercial problem. One branch of practical research that borders on fundamental research is what may be called pioneering practical research. Such research is speculative, and it is gone into with the realization that successful results may not be forthcoming. Pioneering research is of preliminary surveying nature carried out on a small scale and often by a more scientific group of workers than is the practical or engineering type.

Until recently, most of the fundamental research, and, to a large degree, the pioneering practical research, were carried on by universities and state

and federal institutions. Now many progressive industrial organizations are engaged in this type of research as well as in practical commercial research.

I believe that research supported by state and federal agencies should consist largely of the fundamental and pioneering type, leaving it to the industries to carry on the practical type of investigations. Where industry can sponsor research in such institutions and its representatives can maintain close contact with the research workers, practical investigations may be carried on advantageously both to the sponsor and to the worker. It is always helpful to the scientist to have his attention directed toward the practical side of problems, and it is equally helpful to the industrialist to be exposed to the vision and scientific atmosphere existing in these governmental institutions.

I was happy to learn from Dr. Leighton that the function of the Illinois Mineral Industries Committee is to promote interest in the scientific study of the problems of the mineral industries. It also has been a satisfaction to me in following the progress of the work of the Illinois State Geological Survey to observe that the research investigations have been of a highly fundamental and scientific character, and that its practical investigations have been truly pioneering. Undoubtedly, this work already has proved of great value to the mineral industries of the State. I say "already," even though the Survey has been in active operation for many years, because it is not to be expected that this type of work can be capitalized in a short time. Research is the means for providing against the future. It is the first seed planted which will grow and multiply in proportion to the care it is given. Research no longer is a hit or miss, cut and try operation; it can and should be well planned and carried on by trained experts using modern methods and equipment developed for the task at hand.

The State of Illinois is bountifully supplied with mineral reserves. Already it ranks high among the states as a producer of fuels and non-metallic minerals—raw materials that form the basis for many industries. And who can say what hidden resources may be discovered or what new markets may be developed as a result of research?

COAL

The most basic of all minerals perhaps is coal, and the State of Illinois is blessed with large reserves of this valuable resource which has the great advantages of low cost production and of occurrence adjacent to large centers of population and industrial activity. It will always find a ready market. Through the steady improvement in methods of mining and preparation, the cost of coal should be steadily decreased and its value increased. Great advancement in the cleaning of coal has been made in recent years, and great possibilities for further improvement lie immediately ahead. Effort is directed not only toward improvement in the quality of coal, but also toward the recovery of fine coal, much of which is now being lost. The extraction

of pyrite from coal is now economically feasible in some fields. Wide-spread use of this practice will provide an important return to those operating properties that contain large quantities of this valuable by-product.

Research and development have effected many improvements in the combustion of coal. Smoke in industrial units can be largely eliminated. We know how, but do not always do it. Attack is now being made upon the fly-ash nuisance, and we can look with confidence on the prospects of a solution of this problem. Through improved knowledge of combustion, the efficiency in locomotives and large heating plants has been greatly increased. For example, it is now possible in a modern power plant to make a kilowatt hour of electricity with as little as one pound of coal. This improvement in efficiency naturally means a lower consumption of coal for each power unit developed. It does not, however, necessarily mean that less coal will be used. Such improvement in efficiency increases the value of coal, and thus helps it in its fight against competitors as well as makes possible its sale at higher prices. In the domestic heating field, opportunities exist for eliminating smoke and fly-ash, for automatic firing and removal of ash, and, in general, for giving to coal the same advantages of cleanliness and convenience that exist for oil and gas. There is a possibility that the greater efficiency in the use of coal will pay for the added expense of securing these advantages.

Illinois coal has excellent combustion characteristics and is especially suitable for combustion on small underfeed stokers. Research is resulting in the development of domestic stokers that will increase the value of this coal in relation to other forms of fuel. The disadvantage of weathering or oxidation on standing which is characteristic of this type of coal in all probability can be eliminated by oiling or by some other form of pretreatment of coal before shipment is made. Its inability to form a suitable metallurgical coke, under present practice, has kept it from enjoying one great market, i.e., for coke in the steel industry. Some day, it is hoped, research will develop methods by which this coal can be used for the reduction of iron ores. The development of cheap and effective methods of briquetting fines will bring a larger return per ton of coal mined.

Until recent years, the use of coal as a chemical raw material has been largely overlooked. Now the great chemical companies are producing, almost by magic, such wonderful products as synthetic plastics and rubber using coal as a basic raw material. This is indeed a romantic field of endeavor, and although it is not expected that this use will develop a relatively large outlet for coal in the near future, it will lead to increased employment in the chemical industries and the manufacture of many useful products.

The next revolutionary method for using coal for the generation of heat undoubtedly will be as gas, either generated at the mine and transmitted to

centers of consumption in pipe line, or generated at large centers of consumption and piped in existing transmission lines to the user. Following, and to my mind this is a long long way off, the next step will be the liquefaction of coal and the use of the resultant oil for the same general purposes for which petroleum is now used. Some geologists tell us that oil will be scarce within the next ten years. Although this may be far too pessimistic, or optimistic if you are a coal man, yet we do know that the rate of discovery of oil is now less than the rate of production. As a result, oil will become more valuable, and the essential uses to which it is now put, that is, in gasoline and lubricating oil, will require that more and more of the raw oil be converted into these commodities. Continual advancement in this direction is being made through cracking and to a lesser extent, by hydrogenation of oil. As this requirement increases, less oil will be available as a fuel for competition with coal.

PETROLEUM

The development of the petroleum producing industry into the nation's third largest mineral industry in point of value of production, which has taken place virtually in the present century, is an excellent example of how the destiny of an industry can be changed by a discovery that is wholly unexpected and outside of the industry. Too many of us look upon the production of petroleum as a young industry. It is reported, however, that the Persians burned oil two thousand years ago, and still the annual production of petroleum at the beginning of this century was only 63 million barrels. Its principal use was as a source of oil for lamps and for lubricants. The development of the automobile, which was handed to the oil industry at no expense, caused the phenomenal increase in the output of petroleum in this country to about one billion barrels last year. We must give the oil industry credit, however, for making the most of its opportunity by developing new gasolines and lubricants speedily and effectively. The automobile industry could never have reached its present state of development without this assistance.

IRON AND STEEL INDUSTRY

Although Illinois does not produce iron ore, it does have within its borders and in the states contiguous to it a huge iron and steel producing industry which uses vast quantities of raw materials other than iron ore such as coal, clay, limestone, sand, fluorspar, oil and gas. This industry is a great asset to the mineral industries of the State. The production of steel represents a constantly recurring use for the raw materials entering into its manufacture. It is so large that the annual consumption of raw materials entering into its manufacture, even though used in relatively minor quantities, i.e., in pounds per ton, mounts to huge quantities in a year. This large potential use of raw materials in iron and steel production should present an

ever present goal in the minds of research workers to find new applications for metals and minerals, even though used in relatively small amounts per ton of iron or steel. New uses for steel are being developed rapidly, and the production of steel undoubtedly will continue to increase for many years to come. Although, owing to the shorter life of products made from steel and the resultant early return of the scrap to the market, steel scrap may be used in increasing amounts. The rate of consumption of the raw materials other than iron ore entering into the manufacture of steel will continue to increase.

LIMESTONE

For the iron blast furnace, the open-hearth steel furnace, cupola, and other metallurgical operations, limestone or lime is the flux *par excellence.* Likewise, in mortars used in the building industry, lime is almost without a rival. Limestone also makes up an important constituent in the charge to the portland cement kiln. For these uses research into better methods of preparation and improvement of the desired qualities of the product for a given use will continue. Lime enters into many chemical manufacturing operations and as new products are developed, will find an increasing use.

The mineral wool industry may prove a boon to limestone just as the development of the automobile changed the aspect of the oil industry. The production of this valuable insulating material is being increased at an astonishing rate. Owing to the wide distribution of raw materials used in its production and the high cost of shipment of the finished light-weight material, plants are springing up all over the country, and one can expect to see mineral wool plants almost as wide-spread as iron foundries. It is highly probable that this industry may account for an important percentage of the limestone output of this State, and as a further advantage to the industry, a lower grade stone may be advantageously used. The Illinois Geological Survey has done a very creditable piece of research work in this field.

SILICA SAND

Just as "a prophet is not without honor save in his own country," so the magnitude of the Illinois silica sand industry and the excellent quality of the product are not appreciated by the people of this State. I venture to state that hardly a steel foundry organization in the United States does not know about or use "Ottawa" sand. The same may be said for the glass industry. Owing to its unusual physical properties, excellent size classification and low production cost, "Ottawa" sand enjoys a wide market in the foundry, both as a molding sand and as a sand blasting material. Its high purity makes it desirable as the major constituent in the furnace mixture for making glass and its physical properties make it an excellent agent for the polishing of glass. These uses account for a large consumption. Developments in

the glass industry are coming fast; new uses, as a result of research work, bid fair to increase the output of glass to an enormous degree. Your silica resource will be an important factor in making these developments possible, and not only will the mineral industry profit, but industrial activity within the State will be increased by the further building up of the glass industry.

Improved methods of preparation and especially of purification to bring this material to an even more desirable form undoubtedly will be developed through intelligent research.

FLUORSPAR

The steel industry is fortunate in that the valuable flux, fluorspar, occurs in the State of Illinois so near to many steel-making operations. Fluorspar manufacturers in this State have done fine work in producing an excellent grade of fluorspar by modern cleaning methods. Producers, however, should be ever watchful that substitute materials may not be proved to be more useful than fluorspar, and should strive through research to improve the quality of the product, decrease its cost and demonstrate its utility. Fluorspar also is used in lead refining and in the chemical industry. It is a useful reagent that deserves the attention of research workers.

CLAY AND CLAY PRODUCTS

Clay and products made from it enjoy a multitude of uses. The iron and steel industry is an ever hungry customer. Research has it in its power to improve the refractory quality and the workability of clay so that clays once considered unsuitable for refractories, pottery, and other uses might be economically converted into products satisfactory for these purposes. Light-weight refractories made from clay by the incorporation of pores within the body are being rapidly developed and found advantageous in increasing the efficiency of metallurgical and other heat-generating furnaces. The use of light-weight aggregates in cement construction for decreasing the weight of structures is rapidly coming to the fore. Clay, made hard and porous by various methods, thus has a new and large market opened up for it. The use of light-weight brick for building construction has not yet arrived in this country, but when it does arrive and costs of construction are consequently lowered, more structures will be built, and an increased market for clay will be made available. For this reason, research and development work into the development of light-weight units from clay should be fostered.

PORTLAND CEMENT

Illinois ranks as one of the largest producers of portland cement in the United States. As a result, not only are large markets available for limestone and shale entering into the manufacture of cement and for gravel and other

aggregates used in the production of concrete, but low cost construction of highways, buildings, and bridges is made possible. The cement industry is constantly improving its products, making faster setting and stronger cement as well as opening up new uses for this remarkable material. Many opportunities exist for additional developments.

SUMMARY

The Illinois operators in the mineral industry have done an excellent job in making available the rich natural resources of this State to the industries of the State and the Nation. Continued growth of these manufacturing industries will insure a healthful life for the mineral producing industries. Since our modern industrial life has made business a competition of initiative and resourcefulness, I beseech you to continue and even to increase your support of the fundamental and pioneering types of research that are the life blood of your great industry.

CURRENT DEVELOPMENTS IN COAL

FUEL OIL AS A COMPETITIVE FACTOR IN THE DOMESTIC FUEL MARKET*

By

W. Y. Wildman

Managing Director, Illinois Coal Traffic Bureau, Chicago

An intelligent study of the question, "Competition of Fuel Oil and Coal in the Domestic Market," calls for a division of the subject matter into three natural parts; (1) competition as it was in the past; (2) as it is now; and (3) as we can expect it to be in the future.

COMPETITION IN THE PAST

The oil burner, which originally was of the conversion type, first became an important factor in the domestic heating field about the time of the World War. Initially, it met with indifferent success, as burners were not only expensive but generally noisy, sometimes odorous, and frequently got out of order. Coal prices were high, however, and as the burners offered automatic heat, which was an innovation, except in those localities where cheap natural gas was available, they became increasingly popular as a result of an intensive advertising and selling drive. This was particularly true in the boom years ending with 1929. In the meantime, of course, reduction in price and improvement in design added to the oil burner's popularity. Up until this time, coal could not put up any argument against oil except that of economy, and the majority of installations were made in homes where the owner felt perfectly willing to pay the difference in cost in order that he might secure the convenience of automatic heat.

It is probably true that in this middle western region, a majority of the homes in which oil burners have been installed, previously burned anthracite coal, coke, or a high grade eastern bituminous coal. A relatively small number were burning a medium grade bituminous coal such as mined here in Illinois, and consequently, the Illinois producer has not suffered to any great extent because of oil competition in the domestic field. From 1930 to 1932, oil burner sales fell off, as might be expected, but shortly afterwards again gained impetus with the result that sales in 1936 were by far the largest

* This paper has been published since the Conference in Coal-Heat, vol. 32, no. 4, p. 28, 1937; The Black Diamond, vol. 99, No. 10, pp. 27-28, 1937, and in the Northwest Coal Dealer, number unknown.

in history. This showing was made in spite of heavy sales of gas conversion burners here in the West, and in spite of a new and formidable competitor in the field—the domestic stoker. This brings us up to a discussion of the competition of fuel oil and coal under present conditions.

COMPETITION AT THE PRESENT

According to reports of the Bureau of Census, there are 11,294,603 one and two family homes in the United States equipped with central heating plants at the present time, and on January 1, 1937, there were 1,349,401 domestic oil burners in use. One company alone, advertises total sales of 250,000 units. On the above basis, it will be found that one out of every 8.4 centrally heated houses in the country is heated with oil. Assuming an average coal consumption of twelve tons to the home per annum, it will be seen that the domestic oil burner is responsible for the displacement of over 16,000,000 tons of coal or its derivative, coke. For reasons hereinafter outlined, the Middle West has always been an excellent market for automatic heating devices of all kinds. In the five states of Illinois, Iowa, Missouri, Wisconsin, and Minnesota, comprising the principal market for Illinois coal, on January 1, 1937 there were 305,775 domestic oil burner installations in the 2,155,758 one and two-family urban homes which are equipped with central heating plants. This is a ratio of one to seven as against one to 8.4 for the country as a whole.

Again using the purely arbitrary figure of twelve tons per annum to the home, it will be found that the equivalent coal consumption amounts to over 3,600,000 tons annually. According to reports of the United States Bureau of Mines, the consumption of heating oils in the State of Illinois alone, in the year 1935, amounted to 8,324,000 barrels. This exceeded by far the consumption in any other state in the Union, except New York. On a heat basis, measured by British thermal units, a ton of coal is equivalent to four barrels of oil. Using that figure the heating oil consumption of Illinois in 1935 was equivalent to 2,081,000 tons of Illinois coal. For the five states of Illinois, Iowa, Missouri, Minnesota, and Wisconsin, the consumption of heating oils in 1935 amounted to 15,200,000 barrels, or the equivalent of 3,800,000 tons of coal. Unquestionably, the consumption in 1937 will be considerably greater because of new installations made since 1935.

The producer of coal, and especially the Illinois producer, is not so much concerned over losses of tonnage in the past as he is in holding his present market, and if possible, increasing it in the future. Competitive conditions have changed very materially in the last two or three years as a result of great improvements made in the small domestic stoker. Up until the time that the domestic stoker emerged from the experimental stage into a commercially practical automatic heating device, coal could offer no argument

against oil except that of economy. Now, however, coal promises to soon become the dominant factor in the automatic domestic heating field. The stoker has taken the country by storm, and sales are continuing to increase at a rate that is most gratifying to the coal people. According to Bureau of Census reports, the sale of small sized domestic stokers using up to 60 pounds of coal to the hour amounted to 6,783 units in 1932; 14,212 units in 1933; 23,214 units in 1934; 41,126 units in 1935; and 76,376 units in 1936. Sales for the first eight months of 1937 were 43.4 per cent over sales for the corresponding period of 1936, so a total of over 100,000 units for the full year can reasonably be expected. On this basis, there will be a total of 261,711 units in use on January 1, 1938 that are less than six years old. As stated before, oil burner sales in 1936 were the largest in the history of industry; but let us look at the changing ratio of oil burner sales to domestic stoker sales. In 1932, the sale of conversion oil burners outnumbered domestic stoker sales by 10 to 1; in 1933, by 6 to 1; in 1934, by 4 to 1; in 1935, by 3.2 to 1; and in 1936, by 2.9 to 1. If stoker sales hold up for the balance of 1937, as well as they did for the eight months ending August 31, sales for the year will aggregate 109,523 units. The sale of oil conversion units in the first six months of 1937 exceeded those for the corresponding period of 1936 by 37.9 per cent. At the same rate of increase, sales for the full year of 1937 will amount to 270,306 units. On this basis, the sale of oil conversion units for the country as a whole in 1937, will outnumber the sale of domestic stoker units by a ratio of 2.5 to 1. The probabilities are that the ratio would be very much less in the Middle West, as this area is losing ground as a market for oil burners as compared with the country as a whole, but it's the most fertile ground for domestic stoker sales. Although total oil burner sales for the country increased 49.3 per cent in 1936 over 1929, sales in representative key markets in the Middle West increased only 35 per cent over 1929.

There are five principal factors that normally would influence one in the choice of a fuel and a method of firing, namely,—dependability, cleanliness, convenience, noise, and economy.

From the standpoint of dependability, there can be little choice between fuel oil and coal, both are dependable. Chances of a failure of supply of either fuel are quite romote. From the standpoint of cleanliness, oil might be preferred to coal burned in a hand fed boiler, but would have no advantage over coal burned in a domestic stoker. Modern stoker coal is dustless and is burned practically without smoke. There is some oil film that permeates the house and the neighbor's house as well with most oil burners. From the standpoint of convenience, oil holds a big advantage over hand fired coal, but only a slight advantage over coal burned in a stoker, and particularly,

in a stoker of the bin food type. From the standpoint of noise, there would be little difference either way, the balance probably being in favor of coal. From the standpoint of economy, coal's position is far in front.

The best grades of southern Illinois stoker coals now sell in the Chicago market at $6.30 a ton in four ton lots, and $5.75 a ton in 100 ton lots. Fuel oil suitable for use in the average oil burner sells for 7 cents a gallon. In order to make a comparison of relative heat values, it is necessary to reduce both coal and oil to a B.t.u. basis. Southern Illinois stoker coal will average 12,000 B.t.u. to the pound or 24,000,000 to the ton. Based on a price of $6.30 a ton, the consumer of coal receives 38,100 B.t.u. per penny delivered. Ordinary No. 2 fuel oil, the accepted oil for a conversion burner, contains approximately 140,000 B.t.u. per gallon which is equivalent to 20,000 B.t.u. per penny. It is generally agreed that coal can be burned in a modern domestic stoker with approximately the same degree of efficiency as can fuel oil in a conversion burner. On this promise, the present cost of heating a house in Chicago with oil in a conversion burner is 90 per cent greater than the cost of heating with a stoker burning southern Illinois coal. It is safe to assume that the average cost of heating a Chicago home with a conversion oil burner is in the neighborhood of $175.00 a year. The same home could be heated with a modern stoker burning southern Illinois coal for approximately $92.00 a year, or at a saving of $83.00 a year. With a larger house, the saving would be greater, and with a smaller house less.

While, in all fairness, it must be admitted that the electric power cost is somewhat greater with a domestic stoker than with a conversion oil burner, the difference in cost is quite insignificant.

Under the heading of economy, something should be said about the original installation costs. It is probably true that the installation cost of a good stoker is still somewhat higher than the cost of a good conversion burner. The difference, however, is not great, and particularly, on a ten-year amortization basis. Furthermore, with stoker manufacturing increasing in volume the way it is, reductions in stoker prices in the near future can reasonably be expected. Servicing charges on oil burners would probably be as great or greater than on a stoker.

Another factor that should be given some weight is the one of safety. On this score, of course, coal has the better of the argument. An additional argument in favor of coal is the fact that it gives a continuous heat and is generally considered better from a health standpoint than an intermittent heat such as oil or gas. A certain retail coal association, in advertising the merits of coal versus oil or gas, has made much of the point that one gets "layer cake" heat with oil or gas, meaning a wide variation between the floor temperature and the temperature in the zone of a person's head when sitting or standing.

From the standpoint of dependability, cleanliness, and noise there is little choice between the two fuels. Fuel oil has a slight advantage from the standpoint of convenience, but coal holds a tremendous advantage from the standpoint of economy. It therefore resolves itself into this—the man who is deliberating between the choice of a conversion oil burner and a coal stoker must decide whether it is worth $83.00 a year for the slightly greater convenience he secures through the use of an oil burner over that which he would enjoy with a modern stoker. An increasing number of people are becoming convinced that this added convenience is not worth that much, and many of the stoker installations today are replacing the older type conversion oil burner.

COMPETITION IN THE FUTURE

I have made the statement that, in my opinion, coal is destined to be the leading fuel in the automatic heating field in the near future. The popularity of coal, oil, or gas, depends to a great extent on the proximity to supply. In the heart of the great oil and gas fields of the Southwest and Far West, coal will never be very much of a factor so long as the other fuels continue to be available at relatively low prices. The situation is entirely different, however, in the Middle West market where Illinois coals are sold.

No section of the country offers as great a field for automatic heating devices as does the Middle West. This is proven by sales of all types of burners (oil, gas, and coal) during recent years. It is estimated that 46.7 per cent of the stoker installations of the country have been made in the Middle West area. There are two principal reasons for this—first, because 45.2 per cent of American homes with central heating plants are located in this area; and second, because of the tremendous advertising effort that has been put forth here in recent years selling the public on automatic heat. Natural gas is a relatively new fuel in such states as Illinois, Iowa, and Minnesota. During the past five years, the large gas companies have spent millions of dollars advertising gas as the ideal automatic fuel. This has sold many gas burners it is true, but it also has had the effect of making the public at large think in terms of automatic heat. Millions of dollars have also been spent for advertising by the oil burner people, by the stoker manufacturer, and coal people expounding the merits of their product with the same effect of building up "automatic heat consciousness" in the mind of the public. Millions of dollars are now being spent annually for advertising by the coal producers of the country and by the stoker manufacturers in a nationwide advertising campaign which is expected to add further stimulus to stoker sales.

The popularity of either fuel in the future will depend to some extent on the relative costs of coal and oil. Oil prices have not fluctuated very

widely during the past six or seven years, the average being very close to seven cents a gallon for the better grades, with a slight tendency upward in recent years. This oil sells for 3⅝ to 3¾ cents a gallon in tank car lots, F.O.B. Group 3, Oklahoma. The transportation cost to Chicago is $0.238 a gallon, making delivered costs slightly over 6 cents a gallon. The retailer's margin is about a cent a gallon. An increase in the price at the refinery of even 25 per cent would increase the retail price only 13 per cent. Some people hold to the thought that with limited crude production and an ever increasing demand for gasoline for motor fuel, it will be necessary to increase the amount of crude distilled through the cracking process which will mean a lesser percentage of fuel oil distilled, and hence higher prices. This is not apt to occur during the next three or four years, but may be a factor after that.

In the distillation of crude oil there are three major products, gasoline, distillate fuel oil, and residual fuel oil. By means of the so called cracking process, it is possible to materially increase the gasoline yield with a resultant decrease in the fuel oil yield. With gasoline selling for upwards of five cents a gallon at the refinery, and fuel oil selling from 2 cents to 4 cents a gallon, it would seem that a refiner would be interested in securing a maximum gasoline yield. To a certain extent this is true, but the refiner is put to considerable additional expense in recharging the fuel oils to the stills under the cracking process, so the higher gasoline yield results in a greater cost per gallon. Domestic fuel oil is fast becoming a major product, and at present prices is a distinct commercial asset to the refiner. Even though more and more crude oil is being refined through the cracking process, with a resultant higher gasoline yield, the percentage of the domestic fuel yield has also increased. In 1930 the domestic fuel oil yield was 8.79 per cent; in 1933, 9.16 per cent; in 1936, 11.80 per cent; and in January 1937, reached 14.14 per cent. The answer is that greater gasoline and heating oil yield has been at the expense of the heavy residual fuel oils which are essentially a by-product and return to the refiner a very small amount per gallon. In 1930, the yield of residual fuel oil per barrel of crude refined was 31.4 per cent, and in 1936, 26.7 per cent.

Another fact that should not be overlooked is that the peak demand for gasoline is in the summer, while the peak demand for domestic fuel oil is in the winter. Refinery operation is very flexible, so it is possible to obtain a higher gasoline yield during the summer months and to obtain less gasoline and more domestic fuel oil during the winter months. For these reasons, the proponents of coal and coal stokers should not place too much reliance on the possibility of increasing fuel oil prices as a major sales argument for their product.

Although the surface has just been scratched in stoker merchandising, results so far are most encouraging and prospects for the future are very bright. The coal producers are cooperating with stoker manufacturers to the fullest extent, and practically every leading operator is now making a specially sized and specially prepared coal for domestic stoker use. To indicate the reception by the trade, one operator alone in the southern Illinois field will sell over 100,000 tons of its special stoker size during 1937. Improvement in stoker design and a lowering of initial installation costs, which should normally result from volume production, will add fuel, and by that I mean solid fuel, to the fire.

In the main, the remarks thus far have been directed to the question of the competition of coal with oil burned in a conversion burner. There are two other forms of oil competition in the domestic field that are becoming increasingly important. The first of these is the self contained oil furnace or boiler used as a central heating unit and the second the so-called space heater. The self contained unit is particularly popular in new homes selling in the higher price bracket. There can be no denying that these burners are doing a nice job and through their greater efficiency of operation will reduce heating costs below those that can be obtained with a conversion burner. About 25,000 of these unit burners were sold last year. However, in spite of their superiority over the conversion burner from the standpoint of efficiency, except in those districts remote from a dependable supply of coal, heating costs with such burners are still considerably in excess over those that may be obtained with solid fuel.

The space heater is a small unit sold in most cases in homes, stores, or shops not equipped with central heating plants. These burners sell at retail from about $50 to $100 each, and are equipped to burn No. 1 fuel oil, a higher and more expensive grade than that ordinarily used in a conversion burner. They are being strongly featured by the larger department stores and mail order houses and are selling quite fast in certain areas. In view of the fact that there are nearly 14,000,000 one- and two-family homes in the country that are not now equipped with central heating plants, to say nothing of the millions of stores, small shops, filling stations and similar structures, this new form of competition is of deep concern to both the coal producer and the retailer. They are wide awake to the situation, however, and fully realize that only through intensive and continual public education on the advantages of solid fuel heating, improvement in heater design and maintenance of coal prices on a fair and equitable basis, can coal hope to hold its place in the sun.

CHANGES IN THE CONSTITUTION OF ILLINOIS COALS THROUGH PREPARATION PROCESSES, AND THE IMPORTANCE OF THESE CHANGES ON UTILIZATION*

By

L. C. McCabe

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Many of the problems of combustion of Illinois coals are related to the kind and quantity of bands in the coal beds (fig. 1a-d) and in the prepared coal. Such significant characteristics as the ash content, the fusion point of the ash, the swelling, coking, free burning tendencies, friability, grindability, and B.t.u. content are intimately related to the kind of bands making up the fuel.

The physical behavior of these bands in mining, screening and shipping is important. If a number of blocks of coal are examined, it becomes apparent that on the majority of them the surface parallel to the bedding plane is covered with fusain (fig. 1c). This is rather definite proof that the fusain is structurally the weakest member of the four coal components and is primarily responsible for degradation.

Occasionally blocks will be seen with one or both surfaces parallel to the bedding plane covered with vitrain (fig. 1d). Vitrain is more resistant to breakage than fusain, but is much weaker than clarain. It is the secondary cause of breakage in mining and preparation. Clarain, on the other hand, is closely knit together and stands up well under mechanical handling. When durain is present, it is the toughest and most resistant component. It is of little importance quantitatively, as clarain, vitrain, and fusain probably make up over 99 per cent of the combustible parts of Illinois coals.

These breakage characteristics have a great deal to do with the kind of coal that goes into the prepared sizes. Both vitrain and clarain can be found in the lump, and most of the surfaces will have a thin layer of fusain on them where the lumps have split along fusain layers. Most of the fusain has broken off, however, and will be found in the screenings, or if the coal is dedusted it will be found in the dust.

The egg (3 by 2 inches) may have some of the smaller vitrain bands, but for the most part is clarain. The No. 2 nut (2 by 1¼ inches) is still

* This paper has been published since the Conference in the Mining Congress Journal, vol. 23, no. 12, pp. 18-19, 1937.

richer in clarain. In most coals the No. 3 nut (1¼ by ¾ inches) is 8 to 10 per cent higher in vitrain than the coal bed from which it was mined.

Vitrain continues to concentrate below 48-mesh in most instances until the 100- or 200-mesh size is reached. Below this the fusain is ordinarily highly concentrated.

Washing may play a considerable part in separating the ingredients. In the minus 1¼-inch screenings from one mine, 58.9 per cent of the coal floats at 1.30 sp. gr. The coal floating is 58.2 per cent vitrain, 40.0 per cent clarain, 1.1 per cent fusain, and 0.7 per cent middling refuse. The average vitrain content of the coal bed is only about 20 per cent. This vitrain content is so highly concentrated in the fraction floating at 1.30 sp. gr. that there is, as previously indicated, a diminution of vitrain and an increase of clarain in the nut and larger sizes.

The Coal Division of the State Geological Survey recently made a microscopic analysis of a washed ⅜-inch by 48-mesh coal from an Illinois mine which showed the following composition in comparison to the coal in the seam:

	Washed ⅜-inch to 48-mesh (per cent)	Coal Bed (per cent)
Vitrain	40.8	19.0
Clarain	51.9	60.9
Fusain	2.6	4.5
Refuse	4.7	6.6

The foregoing summary of the effect of sizing and washing and the chemical characteristics and distribution of the banded ingredients give a generalized view of the information collected for the purpose of conducting studies of how these different sizes and, consequently different mixtures of ingredients burn.

To understand and make use of these differences is the problem which now confronts us. Differences of several hundred degrees in the fusion points of the ash from vitrain and clarain have been reported.

There is a wide difference in ease with which the bands grind. Durain is difficult to grind, clarain is less difficult, vitrain grinds easily, and fusain offers little resistance. These are important considerations where the coal is powdered before firing and the cost of grinding must be considered.

Much of the difficulty of uneven burning in the stoker fuel bed may be attributed to the high-swelling nature of the vitrain which our studies have shown to be concentrated in the stoker sizes. Crushing egg and large nut sizes, which are high in relatively free burning clarain, and mixing them with the normal stoker sizes or marketing the product as a special stoker fuel, may be desirable for some mines.

These characteristics are strikingly brought out in several hundred feet of colored moving picture film which the Survey has made of the combustion

of the different coal ingredients from the same mine. In the high vitrain fuel marked coke tree development was obtained accompanied by "blow holes" in the fuel bed. A very even fuel bed developed in the clarain.

Other fuel problems may arise because of the physical behavior of the bands which make up the coal. Sometimes a regional study of the coal beds may suggest changes in screening or washing procedure which will alter the composition of a particular coal.

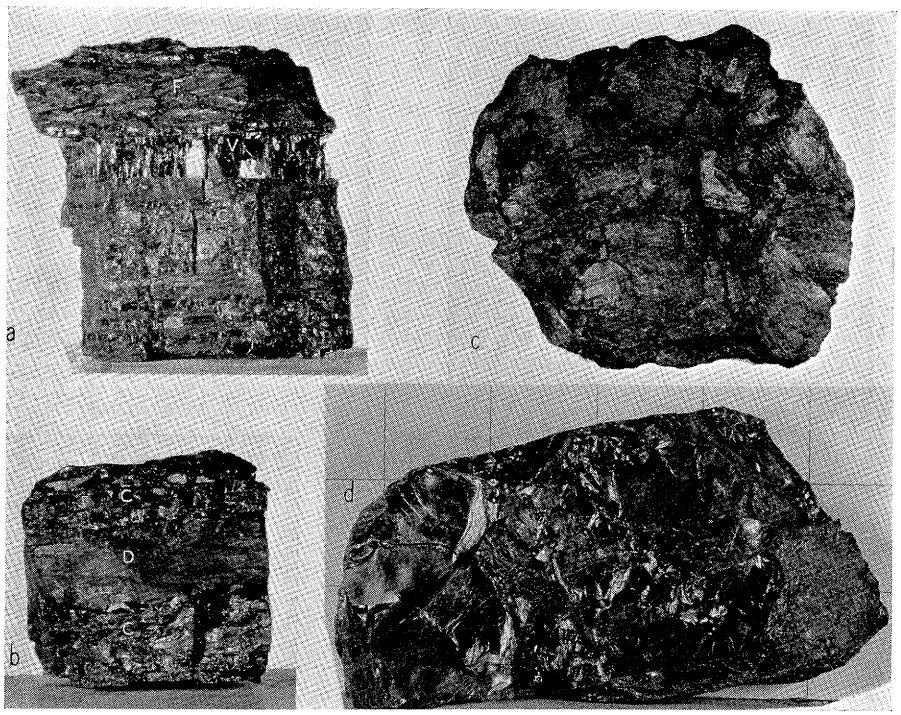

FIGURE 1.—Coals showing fusain, vitrain, clarain, and durain and common causes of breakage.

a. Block of No. 6 coal composed of fusain *(F)*, vitrain *(V)*, and clarain *(C)*; b. Lump of No. 6 coal containing clarain *(C)*, and durain *(D)*; c. Fusain as it appears on the surface of a block. This is a common cause of breakage; d. Block turned on edge to show break in vitrain (2-inch grid).

AIMS OF THE BITUMINOUS COAL ACT OF 1937

By

Hon. Walter H. Maloney

Commissioner, National Bituminous Coal Commission, Washington, D. C.

Mr. President, Ladies and Gentlemen:

It is an honor and is certainly a tribute to the National Bituminous Coal Commission that you requested a member of the Commission to appear here on this occasion. I am pleased to bring to you the sincere good wishes of every member of the Bituminous Coal Commission and to say that the Commission is very happy to accept your gracious invitation.

You are, doubtless, acquainted with most of the problems that have for years beset the bituminous coal industry and, likely, know in a general way the effort projected by the Government in displacing chaos and destruction with a better business arrangement offering security to all concerned in the industry. It is my opinion, however, that too few of the people of this country realize the necessity for what is being done by the Government, and the great import of this step.

I can assure you the National Bituminous Coal Commission, charged with the duty of administering this law, welcomes any opportunity to discuss with you the problems that must be met, understood and overcome. It is our hope that as the Nation becomes acquainted with the involved conditions in the coal industry there will arise a clearer understanding among you, those of the industry, and those concerned with legislation, which will result in continued betterment and ultimate solution of the troubles of this long-time ailment.

Coal is the business of all the people of these United States. That may impress you as rather an extravagant statement, but impartial surveys show that directly or indirectly the production and merchandising of bituminous coal affects the welfare, comfort and happiness of all but a very few of our population. It is definitely a matter of great and grave import to the Government as it serves the people.

Another vital interest of the Government is apparent when we contemplate the vast amount of energy furnished by bituminous coal in turning the wheels of industry and commerce in these United States.

I observe from the program I am asked to discuss the "Aims of the Bituminous Coal Act of 1937." This is a happy privilege. We must remember at the outset that the objective of the Bituminous Coal Act of 1937, and

the task of the National Bituminous Coal Commission, is not merely one of making it possible for the operators and others engaged in the industry to make a profit. That is *one* of our primary objectives. But we have also to consider the economic and physical welfare of more than 600,000 miners who are employed in this industry; we must consider the welfare and protection of the consumer, and all the great industries that "King Coal" serves; and we *must* provide for the conservation of this greatest of all natural resources while conservation is still within the realm of a possibility.

It is necessary that we discuss briefly something of the recent history of the bituminous coal industry—by recent I mean approximately the last 20 or 25 years. I might go back of that period and demonstrate, that for many years prior thereto the conditions which exist today, were in the making. The history of the coal industry is one of bad management, waste and bad merchandising. Not even the example of modern progress in other industries served to eliminate these conditions. The Bituminous Coal Act of 1937 is not the creation of a recent impulse. It is the product of years of impartial and, if you please, nonpartisan study—and, I regret to say, of bitter experience. The facts and studies which led your Government to the adoption of this Act were not gathered within the last two or three years. Since the reconstruction period, following the World War, the Government has been deeply concerned about the situation which has existed within the industry, and throughout that period it has been actively considering a remedy. The libraries in Washington and elsewhere are filled with countless volumes of reports and recommendations and statistics about this problem. Heretofore, efforts toward a solution have been confined primarily to inquiry and academic discussion. Now we are about to translate research and discussion into terms of action, to replace volumes upon volumes of printed words with definite accomplishments.

The matter of conserving the sources of energy is not something that can be left to future generations. Too long have we postponed such action, and as a result millions of tons of coal already have been lost irretrievably. It may seem strange to the layman, as we witness the great competition coal now encounters from oil and gas, to learn that eventually coal must again take the place of these sources of energy. Our reserves of oil and gas are extremely limited, and the power load that is now being carried by these fuels will have to be produced from coal in a comparatively short time, thus increasing future demands upon our reserves. We once had a comforting notion that our reserves of coal were almost unlimited, with a sufficient quantity in the ground to carry us through probably 5,000 years. More accurate analyses show, however, that the best expectancy is about 300 years, but in thinking of such a period of time you must have in mind, and what is more important, that the probable life of our fields of high grade coal is nearer 100 years.

But even these arresting figures do not tell the story of bituminous coal. The picture we must fix in our minds is not one of danger of absolute exhaustion in the future, but rather an early and impending increase in the cost of coal to industry and the domestic consumer, if depletion of the rich and accessible deposits continues at the present rate. This can be prevented.

Despite an original magnificent endowment, depletion is further advanced than even mining men generally realize. It is true, that there are stupendous reserves of low grade bituminous coals, but shocking indeed is the knowledge we now have that in many of the high grade seams depletion is far advanced. Already, the great Moshannon bed is but a memory, only a few acres of virgin coal remain in the famous big vein of Georges Creek, and the life of the Pocahontas and New River coals is good for not more than two or three generations, and that of the Pittsburgh seam in Pennsylvania is of somewhat uncertain duration. Competent authority tells us, that the highest grade gas and metallurgical coals are 11 per cent exhausted in West Virginia and Virginia. Ponder well the fact, that the Pittsburgh bed in Pennsylvania and the southern low and high volatile metallurgical coals are the foundation of our great American steel industry. Thus the cold truth of mathematics shows unnecessary depletion of these great beds will handicap not only the steel industry, but every other industry that depends upon steel.

Why do these conditions exist? What is the great underlying cause for the deplorable waste of our greatest natural resource? I shall not answer these questions with facts obtained by the National Bituminous Coal Commission. I will turn instead, to the reports of investigators and boards, which preceded our Commission by many years; for instance, the report of the National Coal Commission, that was appointed by President Harding in 1923, and which was headed by John Hays Hammond, one of the greatest engineers of our time. I could refer you also to the field investigation which was conducted by the Bureau of Mines at the request of the Hammond Commission, and to government, state and industry publications dating back many years. The unanimous opinion of all has been, that we have literally wasted a treasure house of energy, because we have permitted mismanagement, bad management and no management, where orderly and profitable business methods should have existed. With spendthrift abandon our resources have been wasted to an extent, which now brings us face to face with the truth, that symptoms of advanced age in our coal supply are becoming apparent.

Consider these figures. For the last 10 years the production of bituminous coal in the United States averaged 483 million tons annually, and in each of those same 10 years, approximately 250 million tons were lost, much of it lost beyond hope of recovery. According to accurate field studies in 1923, conducted by the Bureau of Mines and the Hammond Commission, the average waste has been more than 35 per cent, of which 15 per cent was

unavoidable, but 20 per cent was sheer waste. What does this mean in terms of tons? It means that every year 150 million tons of coal have been left in the ground and are lost forever. Mind you, 150 million tons per year. Measured by the yardstick of energy, that is equivalent to double the production of natural gas in the United States. And even more deplorable, conditions have not grown better, they have become worse.

Howard N. Eavenson, past President of the American Institute of Mining and Metallurgical Engineers, testifying in the Appalachian Coal case in 1932, said:

> "The depressed condition in the coal business has had a great deal of effect on the waste in the mining of coal. Since the depressed condition of the last seven or eight years, a good many mines have found that it is very much cheaper for them to lose a very considerable proportion of the coal in the ground than it is to try to mine it. In other words, instead of recovering 85 per cent or more, a number of them have gone to a practice where they will not get ultimately more than from 60 to 65 per cent, because the ultimate result is cheaper than if they tried to mine the greater amount of coal. I think I could make the broad assertion that there is not a single bituminous mine in the country today that is not mining the very best coal that it has, and the cheapest, and is allowing portions of the mine to get into shape where a lot of the coal will never be recovered, because they cannot afford, at present prices to mine it."

Again, according to Newell G. Alford, from 1923 to 1932, no less than 4,802 bituminous coal mines were shut down or abandoned. Exhaustion accounted for but a small percentage of this mortality. The great majority of these old pits are not likely to be reopened. The quantity of coal lost through collapse of roof, crushing of pillars and stumps, or through permanent isolation of odd acreages must certainly run into hundreds of millions of tons. If such a thing happened in a country like Belgium, or any one of several foreign countries, such a loss would be considered a national calamity; but in our own United States we delude ourselves into false beliefs about the extent of our resources, and passively approve what is going on. This is a fallacy that no longer can be ignored.

In the presence of uncontrolled and ruinous competition, coal has for years been sold far below the cost of production and at prices cheaper than the dirt under our feet. In effect, the coal industry has been dying of economic starvation in a poorhouse of its own making. The waste that has grown from year to year is not the fault of the individual operator who has little or no choice under existing competitive conditions. The operator has neither the economic incentive, nor the financial means, to prevent

waste, while the bituminous coal industry continues to exist amid surroundings of constant warfare and stark poverty. Obviously, the first step is to take this industry out of such surroundings and place it on a basis of economic stability and respectability—and that is exactly what your Government proposes to do under the Bituminous Coal Act of 1937. But the National Bituminous Coal Commission has other duties to perform along with that of putting the industry on a business basis. We make it possible for the producer to mine coal profitably without unnecessary waste, we also have the immediate responsibility of protecting the consumer, and in that duty we shall not fail. Briefly, our purposes may be summed up in four points:

1. Stabilization of the industry to preserve capital,

2. The maintenance of reasonable wage standards and stable employment through the establishment of normal economic conditions within the industry,

3. Conservation of the nation's coal resources, and

4. Protection of the consumer against unreasonable prices, not only in the immediate future, but in the more distant future through the conservation of our coal supplies.

Now I want to talk to you for just a moment about this question of labor. As I have said before, approximately 600,000 men earn their living by mining coal, and considering their families, nearly 2,000,000 are dependent thereon. The destructive conditions that have existed in the industry have produced not only an economic calamity for the industry itself, but they have resulted in labor conditions of which America cannot be proud, and they have taken a terrific toll of human life. In the 24-year period from 1910 to 1935, no less than 42,591 men were killed in the bituminous coal mines of the United States, either by accident or through negligence. This is more than the United States lost in battle during the World War. And for every fatal accident, there were 71 accidents which did not result in death. The United States Government cannot afford to close its eyes to these conditions and say: "Oh, they are merely the hazards of a hazardous industry."

No peacetime industry can afford to be so hazardous; nor need it be. Conscious as we are of the fact that the Bituminous Coal Act of 1937 gives no direct control over mine labor, the National Bituminous Coal Commission nevertheless believes that through the establishment of normal and healthy business conditions in the industry, stabilization of employment, maintenance of reasonable wages, and reduction of the mortality rate, will follow as surely as it has followed prosperity and employment in other lines of industry.

Out of the misery, poverty and failure that rode the back of the coal industry, affecting not only the producers, but the miners and consumers too, there developed an organization of mine labor known as the United Mine Workers of America. All of us know the conflict that inevitably developed

between the union and the producers. With the exception of one union here in the State of Illinois, the United Mine Workers constitute the sole labor organization in the entire industry. And it is worthy of note, and only fair to say, that under the effective, useful and dominant leadership of that organization and its leader, the industry has obtained the only relief it has known to this date.

That the mine workers have faith in the ability of the present law to remedy conditions within the industry, is shown by the fact that at the hearings preceding the adoption of the Bituminous Coal Act of 1937, Mr. John L. Lewis, President of the United Mine Workers of America, frankly stated that if it were not for the passage of that law, his organization would have to adopt the only weapon it had at hand for the common defense of its members. Thus the law is serving also to preserve peace between workers and producer, while the Commission carries forward the work of establishing order and prosperity on a basis of permanency.

So now we come to the law enacted by Congress to establish order in the bituminous coal industry. This law is not an attempt to inflict unreasonable or unnecessary regulations upon those who produce coal. On nineteen different occasions Congress has considered the problems of the industry. It has had the benefit of years of experience and help from impartial groups. That the time for the translation of academic discussion into affirmative action has long since passed, is shown by the report of the Hammond Commission, which was submitted in 1923 and said in words that no one can misunderstand:

> "The *Government* must go beyond continuous fact finding and publicity, important and elementary as these functions are. * * * *
>
> "* * * * The Government can act only through administrative agencies and it is clear, that if anything is to be done at all commensurate with the gravity of the problem, an effective agency, with sufficient funds, experience and power at its disposal, must be charged with the direct responsibility for such regulation and supervision as is necessary. Honest and efficient coal operators and dealers have nothing to fear from this. On the contrary, they have reason to welcome it."

And now you have the law, 14 years after it was first recommended by the Hammond Commission. It is not an arbitrary statute that takes away the rights of anyone. It merely preserves the rights of all. Sound in concept, and thoroughly American in administration, it provides every check to protect the rights of the industry. It establishes the means whereby the industry, with the assistance of the National Bituminous Coal Commission, may set its own house in order; it does not centralize administration in one place, but leaves much of it out in the districts where coal is produced; and it specifically reserves to every producer his right to a fair, full and judicial

hearing before the courts of the United States if other means fail. It is not the product of Government desire, rather it is the result of a demand from within the industry itself. It is a gift from the Government to the coal industry.

The Commission is conscious of the fact that some may regard it as a step toward tossing business and industry generally into the power of a governmental bureaucracy; on the other hand, many coal producers regard it as the beginning of a golden age, wherein profit will be guaranteed without due endeavor; and perhaps some consumers have the notion that it means excessive and unjustified prices. All are wrong. The Act preserves and fortifies sound economic principles. It offers the hope of a reasonable prosperity only to those who have the initiative and energy, plus quality of product, to go out and get the business. And above all, it does not permit the producers of bituminous coal to burden the consumer with unreasonable and unwarranted prices.

The Act provides for the establishment of the National Bituminous Coal Commission, consisting of 7 members, all of whom must be divested of every personal interest in the coal industry. It stipulates that two of the members shall have had experience as miners and two as coal producers, and in clear language the Act says that the administrative force must be a thoroughly impartial body. For the protection of the consumers, it has created a Consumers' Counsel to represent the public and protect the public interest in all matters before the Commission. The Consumers' Counsel is responsible not to the Commission, but directly to Congress to which he reports. While the Commission necessarily is vested with powers, which are essential to the proper administration of the law, the Act provides that no order that is subject to judicial review, and no rule or regulation having the forces and effect of law shall be made until we have given proper public notice of a hearing, afforded all interested parties an opportunity to be heard, and made findings of fact based upon such hearings.

Section 4 of the law provides for a code of fair competition which has been promulgated by the Commission and is required to be filed by all producers of bituminous coal who expect to comply with the provisions of this Act. Those who do not sign this code and comply with the provisions of the Act, will pay the penalties provided for in Section 2 of the Act which is 19½ per cent of the value of any coal produced and sold by such producers.

The coal industry is further protected by the creation of 23 district producer boards, elected by coal producers, and vested with the power to propose classifications of coals, minimum prices, and marketing rules and regulations, subject to the review and approval of the Commission. One half of the members of each board are elected by coal producers voting on a tonnage basis, and the other half by a numerical vote of the producers, while *one* member of each board represents labor. To assist both the Commission and the boards in

the proper fulfillment of their duties, provision is made for the establishment of a statistical bureau in each of the 23 districts, into which the entire coal areas of the Nation are divided, to compile information on costs of production, price realizations from the sale of coal, and other vital data. It is worthy of note that this is the first time in the history of the industry such an agency of the Government has been created for the purpose of compiling accurate and complete information on the production and distribution of coal.

The law checkmates any possibility of either the boards or the Commission seizing arbitrary power over the industry, even if such a notion should arise. Every coal producer who becomes a code member under the Act has full power to appeal direct to the Commission for a review of any action taken by one of the district boards, and if the Commission fails to give judicial relief, the appellant may carry his case to the United States Circuit Court of Appeals. Thus every right of the producer, the distributor, and the consumer is protected, strictly according to the fundamental principles of our American system of government.

Probably no section of the law has been more widely discussed than that having to do with the determination of minimum prices. This section of the Act is based upon the sound business principle that coal is a commodity which shall not be sold below the cost of production, and with that policy I believe no one will take issue. Congress reviewed the principle of restricting each individual producer to sales at or above his individual production cost, but obviously, if this had been written into the law, a premium would have been placed upon efforts to reduce production costs regardless of the method employed. That policy had been one of the principal causes of ruinous price-cutting and wage reductions. So Congress divided the producing fields of the entire Nation into 10 minimum price areas, each possessing common production and distribution characteristics and problems. The law provides, therefore, that minimum prices shall be based upon the weighted average of the total production cost, per net ton, in each of the price areas. Thus, we have found a broad and fair highway to the elimination of cutthroat competition, which has wasted our coal reserves, resulted in merciless slashing of wage scales, and created the unparalleled expedient of selling a commodity below the cost of production.

For many years schedules of freight rates have to a large extent determined the availability of coal markets, and very generally transportation costs have exceeded the selling price at the mine. Congress, taking due cognizance of these facts, has authorized the National Bituminous Coal Commission to make complaints to the Interstate Commerce Commission with respect to rates, charges, tariffs and practices relating to the transportation of coal and the prosecution thereof. The district boards and the Commission are also required to apply the principle of forbidding sales, at less than cost of produc-

tion, in a manner to meet the changing conditions of the industry and the competition of other sources of energy.

But in no sense, does the Bituminous Coal Act of 1937 permit governmental control of production. Subject to the maintenance of minimum prices and proper marketing rules and regulations, as established by the Commission, every producer may mine as many tons of coal as he is able to distribute to his own markets. Those producers who show higher degrees of efficiency, whose coal is more readily accepted by consumers, and who enjoy the benefits of natural and geographical advantages, are not to be deprived of those advantages, but are to retain them for themselves by way of increased rates, safeguarded at the same time against unprincipled and unsound business practices of competitors who may measure success only by the yardstick of tonnage, and who seek to hold their positions in the markets by indiscriminate price-cutting.

The erroneous idea that this Commission fixes the price of coal, has too often been conveyed to the public through the conclusions of critics of this law and those who read it solely for the purpose of criticizing.

I have said before that the consumer would be protected against excessive prices, and in this connection Congress has vested authority in the Commission, in times of emergency, to establish maximum prices which may be charged by coal producers.

The Bituminous Coal Act of 1937 was drafted, not merely to provide for immediate needs but to build a foundation for the more distant future. Despite the failure of the industry to regulate itself in the past, Congress has left the door open for such voluntary action. To this end, the Act gives clear recognition to marketing agencies as a lawful method of cooperative action in the coal industry, and Section 12 specifically provides that marketing agencies may, as between members and as between agencies, provide for cooperative marketing of coal upon compliance with certain conditions which are prescribed in the Act. Thus such marketing or cooperative agencies among coal producers may carry on their business without fear of prosecution, and again for the first time, we have a law permitting members of a great industry to join in such efforts under the protecting supervision of the Government.

The law also empowers the Commission to conduct research and studies into the many problems incidental to the production, distribution and consumption of coal, and under this provision there can be created and carried out a broad program which will serve to guide the industry along the road of progress in the future, enabling it better to meet the competition of modern developments.

Obviously, the elimination of unfair trade practices is essential to the stabilization of the coal industry. Congress has provided for this. Specifically

declared to be unfair trade practices are such activities as the misrepresentation of the quality of coals; allowance of secret rebates or price concessions; any attempt to purchase business by gifts or bribes; unauthorized use of trade-marks or trade names already adopted by competing operators; inducing breaches of contracts between coal consumers and competing producers; and shipment from the mine of unordered coal, a trade practice which in the past years has demoralized coal markets. Similarly the law classifies prepayment of freight charges with intent to grant a discriminatory credit allowance; also any attempt to purchase information concerning competitors' business; and, the employment or appointment of any person or sales agent at a compensation obviously disproportionate to the ordinary value of the services rendered, and whose employment or appointment is made with the primary intention of securing preference with a purchaser of coal.

These, gentlemen, are the primary provisions of the coal law. Time does not permit me to go into minute details, and in explaining those I have here presented, I have not attempted to confine myself to legal phraseology or official interpretation. Instead, I have sought only to give you a briefly summarized picture of the Act that has been adopted to raise the bituminous coal industry from the depths of poverty, destructive practices, and low labor standards, to the position of an economically sound and financially prosperous American business and industry.

My friends, politically and economically, we are a favored nation. We enjoy the fruits of peace and progress; we have been spared the burden of heavy armaments; and we look to the future with confidence and security. These things are true because we were endowed at the beginning with vast natural resources, which make us largely a sustaining nation. We shall enjoy these benefits so long as we preserve the gifts of Providence. Ours is not the task of building only for today, for if we do, then our structure will rest upon a foundation of quicksand. Ours is the duty of building both for the present and the future. To the National Bituminous Coal Commission, under the law as it has been adopted, has been entrusted the duty of conserving our greatest natural resource and building up one of our greatest industries. Beyond that we have no aims and no purposes. To that end and that purpose our whole effort is dedicated.

In conclusion, may I ask the coal industry—What degree of confidence have you in your Government? Is there any reason why you should doubt its sincerity in this effort to cure an ailment of long standing? May I remind you, the railroads of the Nation trusted the Government when the Interstate Commerce Act was adopted, and who would now be without it? We believe you should have faith in your Government; it has always served its people well; it cannot fail in this test that will lead the way to a new confidence in government and people, as well as an improved industrial safeguard in times as perilous as those in which we now live.

SMOKE PREVENTION MEASURES AND ILLINOIS COAL*

By

Osborn Monnett

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The coal deposits of Illinois underlie nearly three-fourths of the State covering an area of approximately 37,500 square miles. In connection with smokeless operation they present a diversified problem when considered from the utilization standpoint. The coals of the State (over 30 per cent) are classed as high volatile in rank. Ash and sulfur content vary considerably in the different fields as does the fusion point of ash. For this reason the design of furnaces and boiler settings for any particular location should take into consideration the field from which the major part of the fuel is to come.

Illinois coal is sold in the industrial, railroad and domestic market and it is in this order that discussion of the problem will be attempted. Perhaps it would first be well to take up briefly the standards by which smoke is judged and the degree of smokelessness required by ordinances. Most smoke ordinances are based on the Ringelmann chart, which divides the degree of density into five divisions: (1) 20 per cent dense; (2) 40 per cent; (3) 60 per cent; (4) 80 per cent; and (5) 100 per cent. The degree of density prohibited by most smoke ordinances is No. 3; smoke that is 60 per cent dense or "smoke that cannot be seen through" is allowed for six minutes in any one hour when the fires are being cleaned. On this basis a plant making this much smoke per hour, would be running 6 per cent density. In areas where smoke abatement work has been going on for years there is a tendency, by special rulings, to cut down the amount of No. 3 smoke and even to object strenuously to No. 1 and 2 smoke, if persisted in for long periods. For instance, if a plant made No. 1 smoke continuously, it will have a smoke density of 20 per cent, which is three times the density allowed by the six-minute clause.

With the above considerations in mind, it can be seen that to burn Illinois coal in a satisfactory manner, the smoke density should be kept well under 20 per cent or No. 1 smoke. As a matter of fact, hand-fired H.R.T.

* This paper has been published since the Conference in Coal-Heat, vol. 32, no. 4, p. 52, 1937.

settings with plain grates have been and are being operated with Illinois coal inside of 2 per cent smoke density. It has been the practice in most smoke abatement campaigns to attack the industrial smoke first, largely because more rapid and spectacular progress can be made and because of the theory that the little fellow should not be bothered, while the big fellow was permitted to operate unrestrained. So it has come about that industrial boiler settings have been the object of careful study for many years. In fact, many communities limit their activities to industrial smoke and let the little fellow go.

Perhaps in no other state has there been made so intensive a study of the various industrial power plant boiler settings, as in Illinois. The notable work of Prof. Breckinridge and his associates at the University and the work done here in later years, as well as the standards developed by the Department of Smoke Inspection, City of Chicago should be mentioned. In the main the coals of this State together with those of other states, east and west, can be classed as free burning, medium- to high-ash, according to the fields from which they come. This type of coal has always been eminently suited to the chain grate type of furnace which has wide use in industrial work in Illinois. It still holds its own and is used in all parts of the State with coals from any of the fields, whatever the quality. Natural draft, front feed, side feed and gravity feed stokers, semi-stokers and furnaces are satisfactorily using Illinois coal of varying ash content from widely separated fields. These furnaces are generally found in units of 75 to 350 h. p. and fit into an important field in which industrial usage requires units with moderate rates of combustion.

The underfeed stoker is also in use in the Illinois industrial field. With the high boiler ratings now obtained, the forced draft of the underfeed with its correspondingly higher rates of combustion, naturally follow. The underfeed type handles the better grades of Illinois coal very well up to the limit of the fusibility of the ash. The low grade high ash coals of the State are not so well adapted to the underfeed. In underfeed installations careful consideration should be given to the required rating of the unit, the combustion rate, the ash content and the fusion temperature of the ash of the coal to be used.

Hand-fired units above 50 h. p. with plain grates may be considered as obsolete. While it is possible to operate such units with a very satisfactory smoke density, it requires great skill and careful supervision, and units of this size are not now permitted in congested communities where smoke ordinances are enforced.

Development in the last few years of the overfeed type of stoker has provided another means for utilizing the very lowest quality of coals produced in the State. With this type the zone of high temperature is above the

grate, consequently the ash content and the fusibility of the ash are not such serious factors. This type of stoker utilizes the small sizes which have been largely a waste product. This should prove to be a benefit to not only industrial users, but to the producers of Illinois coal. From the smoke inspector's standpoint there is one consideration, however, which must be noted in connection with overfeed stokers. Burning coal partly in suspension, with forced draft involves the production of fly ash. In old boiler installations with inadequate settling chambers, this is still a problem. Better results can be expected from newly designed settings which provide dust-settling facilities in the gas passages of the boiler.

Smoke from railroad sources, if unrestricted, may form a large percentage of the total smoke of any community. It is possible, with the cooperation of the railroads, to reduce this to a very small figure in comparision to that produced by other classes of smokers. Standardized devices on locomotives, together with constant training of firemen and close supervision by road foremen have made it possible to operate in most classes of railroad service with less than No. 1 smoke. The principal problem at the present time is with intermittent switching service and in round house operation.

In Scotch marine and other special types of boilers, the overfeed principal gives promise of furnishing a satisfactory solution of the problem. Attention is becoming more and more centered on smoke from heating plants. As the industrial boiler settings are modernized it is becoming apparent that heating smoke is a problem that has not yet had the attention it deserves. This class of smoke constitutes as much as 70 per cent of all the smoke of some cities. In Illinois there has been a tremendous increase in the number of small stoker installations on heating plants in the last few years. The small underfeed stoker at the present time dominates this field. The rate of combustion is low and Illinois operators are producing stoker sizes of coal specially for this service. This permits Illinois coal to be used in heating plants from residence size up and comply with all regulations regarding smoke. The small residence stoker is gaining favor daily and is making a good record in economy and smokelessness as compared to other fuels. It is reasonable to expect a large application of these stokers among householders.

Inevitably there remains in every community the miscellaneous collection of stoves or small furnaces which for one reason or another will never be equipped mechanically to burn soft coal without smoke. It is this last class of smoker which is giving the most trouble. For years the U. S. Bureau of Mines and others have recommended methods for firing stoves and furnaces with high volatile coal of which the alternate method of firing has been the most successful. It is possible for a careful person, firing by this method, to operate easily within the limits of No. 1 smoke. With the longer

firing period, less soot and greater economy result. These methods have been taught to householders in educational campaigns from time to time in the hope that some progress could be made. In spite of all efforts the results have been only partially successful. Owing to the large number of persons involved and the inherent carelessness of the individual, the tendency, even after instruction, is to lapse back to the old methods.

The only 100 per cent solution to the smoke problems is an absolutely smokeless, fool-proof fuel, supplied at a figure which will make it possible for every one, even the poorest of families, to use. This, however, is not beyond the realm of possibility. A smokeless fuel from small sizes of Illinois coal is being produced with the Curran-Knowles process. Several hundred thousand tons per year of this fuel are now being supplied to the heating and domestic trade. Research is active in this field and other processes are being investigated. At Urbana the Piersol briquetting process has reached a gratifying stage of development.

On the whole there need be no fear but that Illinois coal can and will in the future be burned smokelessly in all classes of equipment. As technical progress advances the Coal Measures of Illinois, which are such an important source of revenue for the State, will continue to hold their own.

DEVELOPMENT OF A HAND-FIRED DEVICE FOR BURNING BITUMINOUS COAL SMOKELESSLY IN THE DOMESTIC FIELD

By

Julian R. Fellows

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In connection with Mr. Monnett's subject "Smoke Prevention," I thought perhaps you might be interested in the Down Draft Conversion Burner on which I have been spending what time I could spare from my regular duties as Associate in Mechanical Engineering at the University of Illinois.

High volatile bituminous coal can be burned as efficiently and as smokelessly with the down draft principle, properly applied, as with the underfeed principle; in effect, the two principles are the same. In either case, the coal gases are heated to a temperature higher than the ignition temperature by the incandescent carbon or coke through which they pass. If, following this heating process, the gases are mixed with the correct amount of oxygen or air, they will burn without the production of any smoke.

The advantage in the down draft principle is that the natural draft of the chimney is sufficient to pull the gases through the incandescent coals and deliver the air to the proper places for admixture with the gases. This principle can, therefore, be used without any mechanical equipment whatever.

About two years ago I conceived the idea of a down draft conversion burner which could be applied to any conventional updraft domestic boiler, furnace, or stove. The burner which is installed through the firing door without making any changes whatever in the original plant, is illustrated in principle by figure 2. Two vertical sections of a conventional warm air furnace are shown. Both sections are taken through the center of the furnace and show the down draft conversion burner in a freshly charged condition.

The burner consists simply of an inverted double-walled box which is suspended from the firing neck of the furnace with the open side down. The box or charging housing may be used with or without the coals spreader shown in the illustration. The coals spreader, which is also suspended from

the firing neck of the furnace, is helpful in maintaining the coals from the previous charge at the necessary level for smokeless operation. Practically the same effect can be attained with a very deep ash layer or by lowering the parts of the walls of the box which extend into the combustion chamber of the furnace.

The operation of the burner consists simply in poking the coals down to a level about one inch above the lower edge of the walls and filling the box with coal. When a charge of green coal has been placed it immediately begins to coke at the points where it is in contact with the hot coals from the previous charge. The gas produced by the coking process is drawn through the incandescent coals directly below the coking region and heated to a very high temperature. The air spaces between the two walls of the box are designed to deliver the correct amount of air in such a way that it positively mixes with the highly preheated gases; thus fulfilling all of the requirements for their complete and smokless combustion.

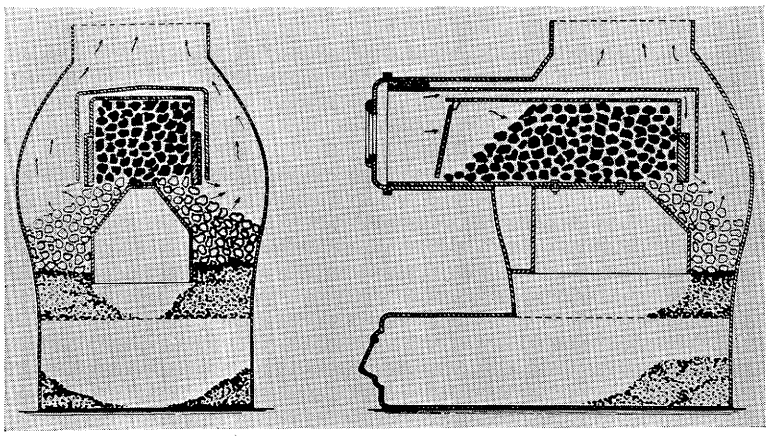

FIGURE 2.—Sections of a warm-air furnace showing downdraft burner in place.

Since the charge of green coal is not heated by the flames as in the conventional way of burning coal, the coking process and the amount of heat delivered can be controlled at will regardless of the amount of green coal in the furnace.

The furnace controls are used exactly as before. The chain running to the ash pit draft door is changed to a small draft door on the main door of the burner. When the fire is turned "on," air is admitted through this small door into the inner compartment of the charging housing. This air passes through the green coal and the oxygen unites with the glowing coals just below, producing heat at this point which accelerates the coking process and the evolution of gas. When the fire is turned "off" this small draft

door is closed, cutting off nearly all of the air passing through the fuel bed so that the evolution of gas is decreased to correspond with the decreased amount of secondary air that is pulled through the passages when the check door in the smoke pipe is open.

The size of the burner, and as a result, the fuel capacity of the burner, is limited by the size of the door opening through which the burner must be placed. Nearly all warm air furnaces will admit a burner of such capacity that the time between firings will not be less than with ordinary hand firing.

Very special heat resisting materials and a very special design to overcome warping are required, but I have worked very diligently on this phase of the problem during the past summer with the financial support of the Binkley Coal Company and the cooperation of their engineer, Mr. Frederick H. Bird, and with the assistance of Professor D. R. Mitchell. I believe that the burner can now be made so that it will stand up for a long period.

If experience with a number of burners in actual service during the coming winter proves the practicability of the design that has been worked out, they will be put on the market. It is hoped that they will make it possible for people with limited incomes to handfire the most economical bituminous coals without producing noticeable smoke.

RECLAMATION OF REFUSE AT ILLINOIS COAL MINES

By

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And

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Refuse produced by coal-mining operations may be roughly classed as follows:

1. "Pickings" or the waste product from the hand-picking of coal on picking tables, conveyors or railroad cars. It is characterized by containing a high percentage of good coal and ranges in size from approximately 1 inch to large lumps.
2. Cleaning plant refuse. This is the reject obtained during the operation of a mechical type of cleaning plant. Very little coal is present and in size may be from 6 inches to the finest dust.
3. Waste produced in conjunction with mining operations as underground gob. May be characterized by a high coal content and at some mines by a high sulphur content. Gob will in general range in size from nut to large lumps.

In addition to these three, dust is produced at some mines, incidental to preparing the coal, that is not marketable or brings such a low price that it should be classed as a waste product.

Methods that have been used or proposed for salvaging or using refuse may be enumerated:

1. Refuse that has a fairly high coal content can be used as a fuel under certain conditions for power production at the mine.
2. Marketable coal can be recovered in some instances by crushing and washing pickings and middlings.
3. Sulphur in the form of pyrite may be recovered by hand-picking or washing from some wastes.
4. Waste, free from coal and pyrite, may in some instances make a suitable raw material for rock wool manufacture, brick or other ceramic products.
5. Distillation at the mine of refuse high in coal for recovery of gas and oil by-products.

In 1935 we reported to this conference the first results of an investigation of the utilization of coal mine wastes, which is being conducted by the Engineering Experiment Station of the University of Illinois. Since then the Station has issued Bulletin 285 which deals with the possible economic recovery of coal from such wastes.

The conclusions set forth in that bulletin are that probably two million tons of coal-bearing material are being wasted annually at Illinois mines, and that roughly one third of such material could be profitably recovered as salable coal, adding fully $1,000,000 annually to the gross revenue of the Illinois coal industry.

To date, only picking-table refuse has been sampled and studied, although there are possibilities of recovering usable coal from finer refuse, such as cleaning-plant dusts and sludge. However, we shall focus our attention today on pyrite, a possible by-product of any process designed to recover coal from the coarser wastes, such as pickings.

Just as the coal would come from the lightest end of such waste, the pyrite would come from the heaviest end, its specific gravity being about five. After the coal had been removed from the crushed waste, pyrite could be concentrated by jigging, tabling and possibly by flotation. Such pyrite, if sufficiently pure would be salable to manufacturers of sulphuric acid. In fact, such recoveries and sales are being made in at least four plants in the Midwest, two of which are in Illinois. The usual practice is for coarse pyrite to be picked from the refuse by hand and then cleaned further in a rotary breaker. Small size concentrates may be made by use of a special jig, concentrating table, launder, or froth flotation. There is no universal method of concentrating pyrite from refuse. Each mine presents a problem all its own, the successful solution of which depends on a thorough study of the physical properties of the refuse under consideration.

Specification for pyrite for acid manufacture limit the carbon to 5 per cent maximum, and sulphur to 45 per cent minimum. Size is not important at most acid plants. At others where flash roasting is used the pyrite must be minus 100 mesh. One company has specified 20-mesh or finer. Quotations for pyrite of 45 per cent sulphur have ranged from $3.00 to $4.00 per ton at the point of delivery. Other properties of pyrite such as the presence of arsenic, probably as arseno-pyrite associated with the pyrite, may limit its use even though a concentrate can be made complying with specifications otherwise.

Some notion of the pyrite potentially available from table pickings or from cleaning-plant rejects from Illinois coal may be had from tests which were run on the 1.60-sink fractions of the samples discussed in Bulletin 285.

A portion of the 1.60 sink material from each sample was crushed to minus 60 mesh and float-and-sink tested at a specific gravity of nearly three,

acetylene tetrabromide being used as the test liquid. As pyrite and marcasite are the principal minerals having specific gravities more than ordinarily associated with coal, the 2.97 sink fractions should give a product high in pyrite. This was found to be true. Other heavy minerals such as heavy silicates, and iron oxide prevented a concentration of 100 per cent pyrite at this specific gravity.

Twenty samples were tested at 2.97 specific gravity, the average sulphur content of the sink material being about 40 per cent sulphur. Subsequent microscopic examination of this sink fraction showed the pyrite particles to be free from the included heavy minerals most of which are probably lower in specific gravity than the pyrite. It is believed that a 45 per cent or higher sulphur content could be made from the refuse represented by these samples. Whether or not it would pay to build a plant to make such a separation is an economic problem that must be solved at each mine.

Sulphuric acid is our leading industrial acid, 1933 production being estimated at 5,168,000 tons of 50° Bé acid. (1)* This was an increase of about 25 per cent over 1932.

The acid is made from dilute concentrations of gaseous SO_2 by two processes, the older lead-chamber process and the newer contact process. At present each process accounts for about one-half the output, but all recent installations have been contact plants.

Acid plants get their SO_2 from the combustion of sulphur in one or more of three forms: (a) brimstone, (b) pyrite, (c) sulfide ores, principally of zinc, copper or lead. It is estimated that nearly 60 per cent of the 1933 production was from brimstone and 20 per cent from pyrite. Five hundred and fifty thousand tons of pyrite were used, 60 per cent having been imported, principally from Spain.

Several small plants were built in Illinois during the World War years to make a pyrite concentrate. The largest of these was at a stripping mine in the Mission field, near Danville. (2:9-11) It had an annual capacity of 12,000 tons of cleaned pyrite which was marketed to a sulphuric acid manufacturer at about $3.50 per ton. As a by-product, it produced about 7,500 tons of coal annually, valued at $0.80 per ton. Although indications are that it should have been profitable, the plant was reported to be just making expenses. There is no report on where the cleaned pyrite was shipped, nor as to the amount of or who paid the freight. For the year 1915, the U. S. Geological Survey reported that Illinois pyrite producers received about $1.70 per ton for their product. While Professor Young ascribes the discrepancy between this and his reported figure of $3.50 to error, it may represent the freight on the pyrite concentrate from the mine to the acid plant.

The operation of this plant, coupled with increased demand and price for pyrite during the War led the then local station of the U. S. Bureau of

* Numbers in parentheses refer to citations at end of report.

Mines to inquire into the feasibility of making further use of the pyrite refuse from coal mines. Yancey (3:105-9) examined many specimens which were sent in from Illinois and adjoining states, and reported that 93 per cent of the Illinois samples contained more than 40 per cent sulphur. He stated that it would be feasible to prepare from them a pyrite concentrate containing less than 4 per cent carbon. He estimated that 1,500,000 tons of such concentrates were recoverable annually in the Eastern and Central coal fields.

Following this, Holbrook (4) tested several one-ton lots of hand-picked refuse, which were sent to the Mining Laboratory from the Danville district. These samples contained about 29 per cent sulphur and 40 per cent coal, so they were essentially free of substances other than pyrite and coal.

ECONOMICS OF PYRITE RECOVERY

Holbrook developed a process for treating pyritic refuse which called for a concentration of 1.76 : 1. It provided for the treatment of 50 tons of refuse per day in a jig-and-table plant costing $18,000. His indicated cost of treatment, excluding the cost of the feed material was $1.06 per ton. While his capital cost, $360 per ton-day capacity, seems high, it is so because the plant was to run only eight hours per day. To put it on a 24-hour basis would reduce the cost to $120 per ton-day which is more nearly in line with later estimates (5) for jig-table mills.

Holbrook charges interest and depreciation at 20 per cent per annum which seems high, but this is offset by a $3.00 daily wage, so an estimated concentrating cost of $1.00 per ton of feed seems reasonable. This is exclusive of any cost for the raw refuse to the mill.

As to the returns to be expected from the operation of such a mill, the mean annual value of the pyrite produced in the United States (6:680) declined from 10.4 cents per long-ton unit in 1929 to 7.62 cents per long-ton unit in 1932. The price that has been mentioned recently is $3.00 per ton for 40 per cent sulphur content, or 7.5 cents per unit, delivered at the purchaser's plant. This is to be compared with the quoted price of 18 cents per unit, plus freight from the Gulf Coast for brimstone which is now being used.

Freight charges on pyrite from Illinois mines to acid plants can hardly be expected to average less than $1.00 per ton, which leaves an estimated return of $2.00 per ton of pyrite concentrates, applicable to concentrating costs and profits.

If a concentration ratio as low as 2 : 1 could be achieved this figure would become $1.00 per ton of pyrite refuse, which is the estimated capital and operating cost of the plant. Thus, as a producer of pyrite alone, the plant could break even if its raw materials were supplied to it without charge, but it would have an additional source of income in coal recovered from the pyritic refuse.

Letting the figures stand as they are, it appears that an $18,000 plant treating 50 tons per day, 300 days per year would yield a profit of $0.35 per ton of feed, or an annual profit of $5,250. This is 29 per cent of the investment. While this might be regarded as a satisfactory rate of return it does not allow for any acquisition cost of the feed material. Such a cost must be met, unless the refuse washery is built immediately adjacent to a mine tipple so that the refuse drops automatically into the feed bin of the washery. Were a central concentrating plant built to serve a group of mines, the cost of collecting the refuse and bringing it to the plant would have to be deducted from the estimated profit of 35 cents per ton of feed. It might well amount to one half this figure, thereby reducing the estimated return on the investment to 15 per cent, and making it unattractive.

The foregoing analysis is based on a year of 300 working days, which is not warranted. Illinois coal mines have averaged less than 150 days per year lately, and 200 days may be taken as the maximum permissible estimate. This would increase the capital cost per ton of feed 50 per cent. This cost was 20 per cent of $18,000 on 15,000 tons, or 24 cents per ton. A 50 per cent increase in this item is 12 cents per ton of feed, which, deducted from the estimated maximum profit of 35 cents per ton, leaves 23 cents per ton on the 200-day basis.

In reviewing the estimates on which this postulate is made, the capital costs might be reduced some by building a smaller plant and operating it two or three shifts daily, and the operating cost would probably be less in a larger central plant than in a small plant for an individual mine, like the one predicted. However, the larger plant immediately runs into acquisition costs so capital and operating costs of nearly $1.00 per ton of feed seems to be a fair estimate.

The assumed concentrating ratio of 2 : 1 is dangerously low. As has been stated data at hand indicate that concentrating ratios of 3 : 1 or even 4 : 1 are more probable. This view is strengthened by an examination of the sulphur content of the 1.60 sink fraction in channel or sized samples reported by Mitchell (7:28, 32, 36, 40). Thirteen of these had a sulphur content greater than 20 per cent while 29 had a sulphur content between 20 and 10 per cent. The remaining 25 carried less than 10 per cent sulphur. The last group need not be considered, of course. Of the samples represented in the other two groups, roughly two thirds would require concentration ratios appreciably greater than 2 : 1. Only one-third, those whose sulphur content is greater than 20 per cent, would be amenable to a 2 : 1 concentration. The significance of the concentration ratio becomes evident when it is considered that, under the conditions previously assumed, a 2 : 1 ratio yields one-half ton of pyritic concentrate per ton of feed, netting $1.00 in income to the plant; whereas, a 3 : 1 ratio would yield but one-third ton of concentrate, netting but $0.67. The difference of $0.33 is more than the estimated profit for the

entire operation under the foregoing assumptions, operations would be, therefore, limited to pyrite refuse which runs 20 per cent or more in sulphur.

Samples listed in Bulletin 258 with two additional ones from Bulletin 217 whose theoretical yields in 6 x 3-inch refuse met the requirements, are listed below:

SAMPLES MEETING REQUIREMENTS OF THEORETICAL YIELDS

Bulletin No.[a]	Table No.	Kind	Mine	County	Bed	Sulphur refuse (Per cent)	Nearest Acid Plant (Miles[b])
217.....	25	5 x 3.....	E	.....	.....	20.9	.....
217.....	37	6 x 3.....	G	.....	.....	22.2	.....
258.....	2 G11-2	Channel.....	.....	Henry.....	2	22.0	60
258.....	2 I14	Channel.....	.....	LaSalle.....	2	26.1	20
258.....	2 AC37	Channel.....	.....	Saline.....	2	34.6	120
258.....	4 J15	Run of mine.	.....	Livingston...	5	20.2	40
258.....	4 AN40	Channel.....	.....	Gallatin.....	5	31.4	150
258.....	4 AE42	Channel.....	.....	Saline.....	5	20.6	120
258.....	4 AE43	Channel.....	.....	Saline.....	5	33.1	120
258.....	6 X31	Channel.....	.....	Sangamon...	6	22.4	90
258.....	6 AA34	Channel.....	.....	Christian....	6	21.5	80
258.....	6 AD39	Channel.....	.....	Gallatin.....	6	26.2	150
258.....	8 J2-16	Channel.....	.....	Livingston...	7	25.4	40
258.....	8 AK53	Channel.....	.....	Vermilion...	7	24.0	20

a University of Illinois Engineering Experiment Station.
b Estimated.

It would seem that the place to look for good sources of pyrite refuse is in the neighborhood of any of these samples. Most of these are thought to be within 100 miles of a sulphuric acid plant, which is probably the limit for a $1.00 freight rate.

Differential picking has been suggested as a possible means of selecting the salable pyrite. Since the working time of Illinois mines is so limited it is imperative to keep capital costs at a minimum, and differential picking, being a matter of labor rather than machinery would be a step in that direction. However, since Yancey (3) found many of the handpicked pyritic specimens which were sent to him to contain less than 40 per cent sulphur, and more than 3 or 4 per cent carbon it is unlikely that differential picking alone could develop an adequate volume of salable material to make the venture pay. Nevertheless, Holbrook (4) found that the over-size from a 1½-inch disintegrating trommel was salable, so it might be possible to pick differentially and clean the pickings in such a device, the undersize to go to refuse. This might work out roughly as follows:

One repicker selects 10 tons of pyritic material from 50 tons of refuse per day. On passing through the disintegrating trommel this becomes 7 tons of salable pyrite, bringing in $2 per ton at the plant. The return is thus $14

per day, or $2,800 annually. The annual labor cost would be $1,000. The purchase cost of a 48-inch x 8-foot trommel with drive motor would be about $1,500, which with an additional $1,500 installation and housing cost would make a capital cost of $3,000 on which the annual charges would be $600. With a 10 h.p. motor, the power consumption would cost roughly $40 per year. Thus the total operating cost would be $1,640, giving an estimated net return of $1,160, or not quite 40 per cent on the investment.

While this looks attractive, the underlying assumptions as to daily output of salable material need verification before confidence can be placed in the project.

On the whole, the outlook for marketing pyrite from coal is not promising, but Nicholson* has suggested the possibility of converting the sulphur in the pyrite into sulphuric acid at the mine, thereby eliminating freight charges on the pyrite and securing the profits of acid manufacture to the entrepreneur. He suggests locating the plant near a group of mines in central Illinois which produce 10,000 tons of coal daily, which should yield 400 tons of pyritic refuse. From this could be concentrated 200 tons of pyrite averaging 40 per cent sulphur, at an estimated cost of $200 per day. This is 80 tons of sulphur, which at 60 per cent extraction would yield about 50 tons of sulphur in the form of SO_2 gas. From this in turn could be produced 150 tons of 66° Bé sulphuric acid, which at current quotations of $15 per ton would yield $2,250 daily, or $675,000 annually.

All recent installations of sulphuric acid plants have been of the contact type, the capital cost of which may be estimated (9:190) at $6,000 per ton-day capacity. For the postulated plant this would be $900,000, on which the annual charges at 15 per cent would amount to $135,000. The annual operating cost (9:192) at $4 per ton of acid would be $180,000 which, plus $60,000 concentration cost would bring the total cost to $375,000. This leaves a net annual profit of $300,000, which is 33 per cent of the investment on the basis of a 300-day year. For a 200-day year the income would be 200 x $2,250, or $450,000. The capital costs would be as before, $135,000, and the operating costs would be $160,000, giving a total annual cost of $295,000, leaving an estimated profit of $155,000, which is only 17 per cent on the investment. However, it amounts to $1.94 per ton of feed which sounds like an attractive figure. It is several times the profit per ton indicated from the concentrating plant alone. To this might be added the value of coal recovered in the concentrating plant, or about $0.35 per ton of feed refuse.

Inasmuch as the working time of the plant would be only about one-half of full time, it might be somewhat better to install a lead-chamber plant at from one third to one half the construction costs, but with about twice the operating costs per ton of acid.

* Nicholson, H. P., personal communication to Professor Callen, March 20, 1934.

However, any acid plant so situated would face many grave risks. Perhaps the foremost would be the limited market for sulphuric acid. The price of $15 per ton is apparently an artificial one, since it has been reported at that level, or nearly so, for years. A strong indication that there is a limited market for the acid is that by-product acid plants are operating only at from 10 to 40 per cent capacity (10:35-38), wasting most of their SO_2 to the air. Were there a profitable market for the sulphuric acid represented by this SO_2, they would hardly waste it. Furthermore, there is a definite threat to new acid plant construction in that future legislation will probably increasingly force by-product SO_2 into acid to avoid atmospheric pollution.

Other shadows hang over new acid capacity. The fertilizing industry has been the best user in the past, but the sulphate radical of the acid serves only as an inert carrier in fertilizers, whereas nitrate and phosphate carriers have fertilizing merit in themselves. Recently the trend has been away from sulphuric acid toward these more effective agents. The petroleum refining industry has been the next large user of H_2SO_4, but a similar trend away from the acid is noticeable there. Higher antiknock gasolines require less sulphuric acid treatment, as do the colored gasolines which need not be made water-clear before they are dyed. The result of these and like tendencies is that this industry used less acid in 1933 than in 1932, while producing more gasoline. Furthermore, hydrogenation may lead the petroleum industry to become a producer of H_2SO_4.

In conclusion, we could not advocate new acid plant construction or the construction of a concentrator to ship cleaned pyrite to an existing plant unless one or more of the estimates used in postulating the concentrator were substantially more favorable than those stipulated. These stipulations were:

a. Cost of the plant—$120 per ton per 24 hours, equals $18,000 for a 50-ton plant operating 8 hours per day.
b. Interest, depreciation, taxes, etc.—20 per cent per annum.
c. Feed—free of charge to plant.
d. Concentrating ratio, 2 : 1.
e. Operating cost, $1.00 per ton of feed.
f. Value of pyrite concentrate delivered, $3.00 per ton of concentrate.
g. Freight on pyrite concentrate, $1.00 per ton of concentrate.
h. Value of coal recovered, $0.35 per ton of feed.

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TRENDS IN COAL SELECTION FOR SMALL STOKERS*

By

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"Dustless treatment," "ease of operation," and "recommendation of the stoker dealer or salesman" stand out in order as major preferences in the selection of coal by household stoker users.

To find out more about the selection of stoker coal, we asked several hundred stoker dealers, retail fuel merchants, stoker manufacturers, stoker engineers, fuel engineers and others what factors govern the selection and purchase of both household and commercial and semi-industrial stoker coal.

Here is what we asked:

> From the stoker user's viewpoint, what factors now govern the selection and purchase of stoker coal for (1) household, (2) commercial or semi-industrial use?
>
> Check these factors numerically—1, 2, etc.—in order of descending importance:
>
> Household
> Commercial
> Semi-industrial
>
> A. Dustless treatment.
> B. High B.t.u. content.
> C. Ease of operation.
> D. Freedom from fines.
> E. Low freight rate.
> F. Minimum non-combustible or low ash content.
> G. Price per ton (low). (Medium cost per season.)
> H. Recommendation of the stoker dealer or salesman.
> I. Recommendation of the coal merchant.
> J. Recommendation of other stoker users.
> K. Special sizing.

Thanks to the enthusiastic cooperation of the major stoker manufacturers, key coal producers, retail coal associations, stoker dealers and others, we secured a consensus of opinion from the men who are selling 80 per cent or more of the stokers and stoker coal in the United States.

The result of their experiences, observation and judgment is shown in the accompanying tabulation, a summary of summaries, each group being accounted for separately. The final order of relative preference is given on the bottom line (see table No. 1).

As will be noticed, this tabulation gives the viewpoint of each group as a group. In other words, it shows the consolidated viewpoint of a number of combustion or fuel engineers as a group, chief engineers of major stoker companies, sales managers of leading stoker manufacturers, members of various retail coal associations and other groups.

* This paper has been published since the Conference in Coal-Heat, vol. 32, no. 4, p. 54, 1937.

PREFERENCES

In order of preferences, dustless treatment stands out first, closely followed by ease of operation. The phrase "ease of operation," of course, takes in considerable territory. Low ash content, clinkering characteristics, coking tendencies, amount of fuel required, frequency and amount of clinkers to be removed, the way the coal burns or holds fire in mild weather—in the early fall or late spring—all come under this heading.

Recommendation of the stoker dealer is a big factor. Several groups marked it first on the list. A few coal operators put this far down the list—which indicates that they are not quite as close to the stoker industry, dealers, salesmen, engineers, manufacturers, as they might well be in view of the rapid growth of the industry and increasing demand for stoker coal.

Low ash content came fourth, recommendation of the coal merchant, fifth, high heat content, sixth. Only one group—the Canton stoker dealers—put high heat content in first place, several groups placed it near the bottom of the list.

SPECIAL SIZING

Despite all the conversation and propaganda about special sizing of stoker coals, it was rated seventh. Technically, this may be erroneous. Practically, special sizing is a concomitant of "ease of operation."

In studying the summary you will notice that only one group put special sizing at the head of the list—the salesmen and representatives of a leading Illinois coal operator. Outstanding fuel engineers put it in third place. A group of fuel engineers in New York put it in second place. Pittsburgh dealers put it in third place. However, the final summary shows special sizing in seventh place in order of preferences.

Price per ton is not much of a factor within certain limitations, of course. By various groups it was ranked 4th, 11th, 10th, 7th, 11th, 5th, etc., "Recommendation of other stoker users" came ninth and "Freedom from fines" tenth. Only a few groups listed "Freedom from fines" near the head of the list, chiefly a group of Cincinnati coal operators and a number of coal merchants in Wisconsin.

FREIGHT RATES

At the bottom of the list came low freight rates. This indicates that the household stoker user is not particularly concerned about the cost of freight—it is the cost of the coal in the bin, the cost of heating per season, freedom from complaints, it is the satisfaction in use and ease of operation that count.

One of Chicago's oldest and best posted fuel engineers, the representative of a company with a large stoker tonnage in the city, told me recently that well over 60 per cent of their stoker users didn't care particularly what the

TABLE 1—RELATIVE ORDER OF PREFERENCES GOVERNING THE SELECTION OF STOKER COAL

GROUPS QUESTIONNAIRED[1]	Household stoker user's viewpoint											Viewpoint of commercial stoker users										
	Dustless treatment	High B. t. u. content	Ease of operation	Freedom from fines	Low freight rate	Minimum noncombustible or low ash content	Price, per ton (low)	Recommendation of the stoker dealer or salesman	Recommendation of the coal merchant	Recommendation of other stoker users	Special sizing	Dustless treatment	High B. t. u. content	Ease of operation	Freedom from fines	Low freight rate	Minimum noncombustible or low ash content	Price, per ton (low)	Recommendation of the stoker dealer or salesman	Recommendation of the coal merchant	Recommendation of other stoker users	Special sizing
Outstanding fuel engineers	2	8	1	9	11	10	4	5	7	6	3	7	2	3	11	4	6	1	8	9	5	10
Chief stoker engineers	3	6	2	9	10	4	11	1	8	7	5	8	10	6	11	2	7	1	4	5	3	9
Engineers, stoker dealers	2	5	1	8	11	4	10	3	7	6	9	7	6	5	11	2	10	1	3	9	4	8
Mail order personnel	1	2	5	4	11	3	10	6	7	9	8	6	5	4	9	8	7	1	2	6	3	10
Sales managers, stoker manfacturers	1	8	3	7	11	2	9	4	5	6	10	4	7	6	11	9	8	1	2	3	5	10
General managers, stoker manufacturers	4	9	3	7	11	6	10	1	2	5	8	6	8	5	10	10	7	1	2	4	3	9
Members, St. Louis Coal Exchange	2	10	3	6	11	8	9	1	4	7	5	10	5	6	9	11	8	1	2	4	3	7
Cincinnati producers	2	6	5	3	11	4	7	1	9	10	8	10	4	5	11	3	2	1	6	7	8	9
Wisconsin coal dealers	1	9	5	2	10	6	11	3	4	7	8	5	1	9	10	2	4	3	6	8	7	11
Chicago stoker salesmen	2	6	1	9	11	3	10	4	5	7	8	6	2	5	9	11	10	1	3	4	7	8
Illinois coal operator's men	3	2	6	7	11	4	5	8	9	10	1	8	2	7	6	3	5	1	10	9	11	4
Members, Branch office, St. Louis	3	6	4	7	11	10	5	1	2	8	9	6	4	3	10	10	8	5	1	2	7	6
Aurora, Ill., coal dealers	2	6	1	9	10	9	3	4	5	7	8	4	3	6	7	10	11	2	1	5	9	8
Kansas City, Mo., producer	5	9	1	4	8	11	10	2	3	6	7	5	9	1	10	11	4	3	2	7	8	6
Canton, Ohio, stoker dealers	5	1	2	10	11	4	3	6	7	8	9	5	2	4	11	10	3	1	6	8	7	9
Central Michigan stoker dealers	4	7	3	6	10	8	2	1	9	5	9	3	2	7	11	4	10	1	6	9	8	5
Knoxville, Tenn., dealers	1	6	2	7	11	8	10	3	4	9	5	8	3	7	11	4	10	1	5	2	6	9
C. V. Beck	2	5	1	11	10	9	7	3	8	6	4	5	3	4	11	10	9	1	2	7	8	6
Kansas City coal producer	1	10	2	11	9	3	4	8	7	5	6	3	1	2	11	6	4	5	7	10	9	8
Heating engineers, Chicago	5	10	2	6	11	7	1	4	9	3	7	7	1	10	6	4	3	2	5	8	9	11
Fuel engineers, New York City	1	8	5	11	6	3	4	7	9	10	2	6	4	3	10	2	11	1	7	9	8	5
Stoker dealers, Pittsburg, Pa.	4	6	7	9	11	5	10	1	8	2	3	10	9	4	3	8	7	6	1	10	2	11
Stoker salesmen, Chicago	2	5	1	11	10	7	6	3	8	9	4	9	7	1	11	3	4	1	6	8	5	10
Stoker district representatives, Ohio	3	6	4	8	7	11	5	1	2	10	9	8	3	5	10	1	11	2	6	7	4	9
Chicago coal merchants	2	5	1	7	11	4	6	3	9	10	8	8	6	9	10	2	11	1	5	4	3	7
Total score	63	161	71	188	255	153	172	84	157	178	163	164	109	128	242	150	180	45	108	164	152	205
Rank, in order of preferences	1	6	2	10	11	4	8	3	5	9	7	7	3	4	10	5	8	1	2	7	6	9

[1] These groups have been questionnaired so as to get a cross-section of opinion as to the factors governing the selection of stoker coal. The consensus of opinion of each group represents the judgment from anywhere from three or four to several hundred men.

delivered price of stoker coal was—they want the best coal they can get. In some of the foreign sections where there are quite a number of stokers in use, they want the cheapest coal they can get, irrespective of the quantity of ash or the amount of clinkers to be removed.

EASE OF OPERATION

What stands out in this study of household stoker coal is the marked agreement, the demand for proper dustless treatment, for the coal that gives the maximum ease of operation.

Among the commercial or industrial users, on the other hand, the situation is different. Here, the price per ton is the number one factor: Recommendation of the stoker dealer is second; high heat content, third; ease of operation, fourth; low freight rate, fifth; recommendation of other stoker users, sixth; recommendation of the coal merchant and dustless treatment, seventh; low ash content, eighth; special sizing, ninth, and freedom from fines, tenth.

Such are the conclusions of a number of groups selling well over 80 per cent of the stokers and a major percentage of the stoker coal tonnage, based on their experience and observation.

COAL DEALERS

What the coal merchant wants in stoker coal, what factors lead him to handle a particular coal, are shown in table 2. It gives a summary of the impressions, opinions, and preferences of coal merchants in Chicago, St. Louis, Cincinnati, and various key cities throughout the country. In our investigation we had the cooperation of such groups as the Illinois Fuel Merchants' Association, which circularized its membership, the St. Louis Coal Institute, the Extension Service of the University of Wisconsin, members of the Chicago Coal Merchants' Association, the Norfolk & Western, Chesapeake & Ohio railroads, and others.

The final order of preference is given in the right-hand column. As will be noted, the major factors governing the dealer's selection of stoker coal are:

1. Dependability and freedom from complaints.
2. Acceptance of a particular coal in a local community by stoker dealers and manufacturers.
3. Special preparation or sizing.
4. Margin of profits.
5. Prestige or standing of coals from a particular community.
6. Reputation of the coal producer.
7. Present tie-up with a producer or producers.
8. Competitive price and freight rate structure.
9. Special sales helps.
10. Geographic complexes — such as the use of Iowa coals in Iowa, or Ohio coal in Ohio.

Practical business experiences transcend state lines. Economically, there may be certain advantages in trying to use local coal in stokers, but practically, can the stoker dealer or coal merchant jeopardize his relations with

customers by recommending a coal the chief virtue of which is that it is produced in the same state, particularly when other coal (in certain geographic areas) can be purchased at approximately the same prices and which actually deliver greater value per fuel dollar?

This is not to be construed in any way as a direct slap at any coal, or any market. All coals can be used. Human nature being what it is, however, just as long as we have any freedom or choice of action, just as long as no dictator forces us to burn this or that coal, just as long as economic barriers are not set which tend to freeze markets, the ultimate consumer will normally burn that fuel in his particular community which works the best.

PRICE FACTOR

Economics is a factor. Price counts. But there is a lot more to this question of household stoker coal than price per ton. The quantity of clinkers to be removed has a lot more to do with whether one's coal is used or not than the price when there isn't a big difference in the delivered price—which happens to be the case in certain communities.

In general, stoker manufacturers and dealers are cost conscious. They want to take advantage of every opportunity to give the home owner the maximum in heating comfort at the lowest possible cost, but not at the price of satisfactory operation.

Just because a coal works well in a stoker in East St. Louis, or because the customer there is well satisfied, doesn't justify the notion that the same coal will appeal equally to the stoker user in Chicago or Milwaukee. Just because certain coals can be used in Indianapolis or Des Moines, doesn't necessarily mean that the household stoker user will find them preferable to a high-grade, low ash eastern coal.

The ultimate consumer is the boss. He wants the best he can get. And the best stoker coal is not necessarily the coal with the finest analyses. Many of us question the chastity of the average coal analysis. Inherent quality alone will not give a particular coal the stoker business.

If one's coal through lack of sizing or insufficient preparation, results in noise from crushing or segregation of sizes, the home owner won't continue to buy it if he can find anything else. Whether or not the new coreless feed screw will revolutionize feed screw design or not, no one knows. Theoretically, the coreless stoker feed screw makes possible the use of considerably larger sizes (even up to three inches), but can such coals be handled without segregation of sizes?

TABLE 2—FACTORS GOVERNING THE SELECTION OF STOKER COAL, BY THE DEALERS

Factor	Order of preference																				Total points	Order of preference
A. Acceptance of a particular coal in the local community by stoker users, stoker dealers or manufacturers	1	2	10	3	3	1	2	1	1	1	5	1	3	1	5	2	8	8	1	1	60	2
B. Dependability and freedom from complaints	3	1	1	2	4	3	1	4	7	...	...	2	2	2	2	1	1	2	2	2	42	1
C. Margin of profits	5	3	5	9	1	2	4	3	6	3	4	3	1	4	6	3	2	3	...	5	72	4
D. Special preparation or sizing	4	7	2	1	5	4	3	4	5	...	...	4	4	7	3	...	3	4	4	4	68	3
E. Geographic "complexes"	10	...	4	10	7	10	9	2	10	...	...	10	9	8	9	...	9	10	...	10	127	10
F. Present tie-up with a producer or producers	9	4	8	8	8	5	7	...	2	...	2	6	...	5	7	...	10	9	...	8	98	7
G. Prestige or standing of coals from a particular district	2	5	7	5	9	9	8	2	4	2	3	5	6	3	1	...	7	5	...	3	86	5
H. Reputation of the coal producer	8	...	3	4	6	8	6	...	8	...	...	7	7	9	4	4	4	6	...	6	90	6
I. Competitive price and freight rate structures	6	6	6	7	2	7	5	6	3	4	1	9	...	6	8	7	5	1	3	9	101	8
J. Special sales helps	7	8	9	6	7	6	10	5	9	...	...	8	8	10	...	8	6	7	...	7	121	9

SEGREGATION OF SIZES

Segregation with screenings is as inevitable as the immutable laws of physics. Segregation occurs even with deliveries of small quantities of stoker coal (under four tons) if there is any marked difference in top and bottom sizes.

The closer the limits are brought together, the less the segregation. D. R. Mitchell and Henry Hebley may well be congratulated for the work they have done in study of segregation. Use of Mitchell's non-segregating chute helps correct the problem in the larger plants. Since building a four-ton bunker in my own basement four years ago, I have had considerable experience with segregation. I know what happens.

TECHNICAL ASPECTS

With many of the technical factors affecting the use, sale and production of stoker coal the ultimate consumer is not concerned. He does not reason why one coal works well, or why another does not. All he wants is heat, hot water or steam with the least effort, at a reasonable price.

Hence, the human equation takes precedence over geology, chemistry, furnace, boiler and stoker design. To ignore John Q. Public, his likes, dislikes, whims, fancies, social concepts, etc., is to play the ostrich. What John Q. gets out of our product is what counts.

Technically, of course, several basic factors affect the use, sale and production of stoker coal. In all their ramifications, these total several thousand. Suffice it to say that heating comfort depends on a lot of things besides coal or a stoker, to-wit:

1. The human equation.
2. Type of housing or building construction.
3. Age, character, condition and operation of the heating system—facilities for heat distribution and control as well as heat generation.
4. Choice or adaptability of the fuel or equipment used.

Putting a bituminous stoker into an old furnace or boiler that was originally designed for anthracite doesn't assure the ultimate in heating satisfaction. The average home is thirty years of age, you will remember. Ninety per cent of the heating equipment in use today is obsolete, when compared with present day standards.

Without an up-to-date heating system, proper building construction, insulation, storm windows, weather stripping, etc., how is the home owner to secure the maximum in heating comfort? If they recognize the innumerable factors affecting satisfactory heating, few men will expect their coal or stoker to perform miracles in any home.

A stoker is but a part of a complete heating system. Fuel is worthless until consumed. What one gets out of a stoker or a coal depends, therefore, on what Bently calls "the equipment and utilization factors."

SIZING

In discussing stoker coal at the Institute on Coal Utilization, at the University of Michigan, recently, Professor R. S. Hawley said:

> From the results of tests it appears that sizes from ⅝-inch down will be more successful in household stokers than will the larger sizes. The best results we have had to date were obtained from coals of ⅝-inch to ¼-inch size.
>
> We have had no difficulty in burning coals with as much as 50 per cent slack. We have observed, however, that when burning slack coal there is a greater tendency for particles of ash to carry up with the gas flow and lodge around the heating surfaces of the boiler or furnace.

Arthur O. Dady, now chief engineer, Stokol, and one of the outstanding engineers in the stoker industry, has commented on the trend toward the use of ¾ by ¼-inch household stoker coal. Dady, in discussing this at a "Short Course on Coal Utilization," at the University of Illinois, said:

> One of the greatest sources of satisfaction is uniformity both in quality and preparation. On stokers of from 100 to 500 lbs. capacity, ¼ by 1¼-inches will satisfy most makes. The percentage of fines below ¼-inch should not, in general, be over 30 per cent.

DIRT AND FINES

Clarence V. Beck declares in his book, "Modern Combustion, Coal Economics and Fuel Fallacies":

> Screenings are not a satisfactory fuel for the householder. They are far too dirty.
>
> The householder who puts in a stoker wants economical heat, freedom from trouble, freedom from dirt. The householder will not stand for the dirt of small screenings. It is almost impossible to wet small screenings so that they will not be dusty. Were it possible to wet small screenings sufficiently to kill the dirt the coal would stick in the hopper and would not feed. This lets out screenings as a domestic fuel for the householder. The fuel for the householder, therefore, must be free of dust and approximately of three-fourths inch maximum top size.

E. D. Benton has pointed out:

> Much has been written regarding the desirability of "fines" in stoker coal. No one questions that evenly mixed fines are desirable in helping reduce smoke and in preventing some coals in being too flashy and burning too fast, but in the great majority of cases, coal is handled several times before it gets into the customers' stoker hoppers. Each time coal is handled segregation occurs. Consequently the stoker feeds all coarse coal at one time and all fines at another.
>
> The air adjustment for one size coal is improper for another. Feeding rates will vary as much as 25 per cent when going from all nut coal to all fines, requiring a further change in air adjustment if any degree of efficiency is to be expected.
>
> The average small user pays little attention to size content or air adjustments, with the result that numerous complaints are received that the coal either will not give sufficient heat or burns too fast. Properly sized quality stoker coal will do more in reducing complaints than any other single item.

A top size that is too large not only interferes with feeding, but is noisy and tends to aggravate segregation difficulties. Too large bottom size causes stokers to smoke back.

It is poor salesmanship to let price interfere with the difference in satisfaction to be received between properly prepared coal for small stokers and coal the sizing of which precludes satisfaction in the majority of cases.

STOKER COAL TROUBLES

J. McClintock, manager, Freeman Stoker Division, Illinois Iron & Bolt Company, Chicago, at a "Short Course in Coal Utilization" at Urbana, says:

At the present time there are more service calls due to delivery of improper fuel than to all other reasons combined. This is the greatest weakness we have in the industry at the present time even with the enormous progress that has been made during the past few years by the operators and retailers in the delivery of better stoker coal.

A thorough analysis by our service department shows that at least 50 per cent of the men's time is spent in what we might call the servicing of coal, a good part of which could be eliminated by a better understanding of the stoker coal business by operators and their representatives as well as the retail coal yard owners and their representatives.

The period is past when the coal industry can get by by having representatives that say "we have the best coal mined." If the representatives, both of the producers and retailers, would make a thorough study of the stoker coal business a large part of the service calls could be eliminated.

COMBUSTION CHARACTERISTICS

Robert M. Pilcher, mechanical inspector, Norfolk & Western Railway Company, Roanoke, Va., in a paper at the University of Michigan, a few months ago, after considerable study and tests of the burning characteristics of Pocahontas coals in stokers, reports:

The size of the coal has some influence upon the feeding characteristics from the hopper to the retort, but within reasonable limits the size has little influence upon the combustion characteristics.

In the majority of household stokers the worm size is such that coal having dimensions in excess of 1½ inches is slow entering the flights and may become so arranged around the entrance to the conveyor tube as to cause the worm to run nearly empty at times.

When such lumps enter the flights a crushing load is placed on the stoker, but because of its friability, the crushing of Pocahontas coal in most cases causes no trouble. In some instances, when coupled with loads already on the worm, it is sufficient to operate the protective devices of the machine.

A coal, none of which exceeds 1¼ inches in size, is best adapted to the average stoker. There are instances when the 1¼-inch size may prove excessive because of the size of the conveyor screw. In such cases the maximum size must be further restricted to obtain satisfactory results.

As to the actual burning of the coal, the size had little effect. Coal containing as high as 80 per cent passing a 16-mesh per square inch screen with a majority of this proportion passing a 64-mesh per square inch screen, gave satisfactory results.

FINES REQUIRE MORE AIR

As the percentage of very fine coal increases, the resistance to air flow becomes greater and it is necessary to increase the air damper opening when burning the fine coals. Also, as the per cent of fine coal in a mixture increases, particularly that portion that will pass a 16-mesh per square inch screen, the coal becomes dustier to handle.

Where slack mixtures are intended for household use, a dustless treatment is desirable, as this will remove any inclination for wetting on the part of the person firing, and thus eliminate opportunity for getting the coal wet enough to arch in the hopper and cause feeding difficulties.

Because of its friability some crushing of Pocahontas coal, regardless of size, takes place in its passage from the hopper to the retort. The larger sizes of coal show a greater degree of crushing than the smaller sizes, so that by the time the coal reaches the burning zone the resultant is about the same whether a nut around 1¼ inches is placed in the hopper or whether a nut and slack mixture is placed in the hopper.

Just as good or slightly better over all efficiencies were obtained when firing mixtures containing high percentages of fines as when firing the sized coals, but where the coal contains large portions of fines, there is some increase in the opportunity for interruption because of improper feeding. This increase, however, is slight and in no way an obstacle in the use of slack coal in any well designed stoker where the designer has considered the use of his machine with a reasonable variety of coals.

FEED WORM CONTROLS COAL SIZE

Frank Hoke, vice president, Holcomb & Hoke Mfg. Company, Indianapolis, at a recent meeting of the Chicago Wholesale Shippers Association, said:

Coal was once a bugbear in the stoker industry. There is one thing that determines the top size of coal which a stoker will feed, the size of the feed worm housing and the size of the screw.

Is 1¼-inch the best size? No, it is not. Throw the coal in the bin and the nut coal rolls to the outside. For a day or two, we throw nothing but nut coal in the hopper. Our air will have to be changed because it takes less air to burn the nut than the fines, which are in the middle of the pile. That is one reason why we should like to have the top and bottom sizes closer together.

Noise is another factor. When we have a 1¼-inch top size, naturally some pieces get caught and make a noise. The more differential between the top and bottom sizes, the greater the segregation when a car of coal is shipped and unloaded.

W. J. O'Neil, sales manager, Chicago branch, Iron Fireman Manufacturing Co., in a letter to members of the Chicago coal trade, says:

Once in a while some one of our service men, called out on a trouble call, discovers that the user is not satisfied with the performance of his Iron Fireman because he is burning a cheap coal or a coal that is not properly sized and prepared.

We understand the coal man's problem. We know that often a buyer will insist on a cheap coal or thinks he knows best what size or kind of coal he should use.

But you know and we know how important it is that the stoker user get a good quality coal—important to the user, to you and to us.

High quality, suitably sized and prepared stoker coals are available from several fields, thanks to the foresight of responsible purchasers. Let's push those coals.

> We urge buyers of Iron Fireman to ask their coal dealers for high quality coals. And we tell them why they should insist on it—for their own benefit.
>
> For your own protection and to make sure that your customers are entirely satisfied with the performance of their stokers, recommend and sell quality stoker coals.

D. H. McMaster of the Bell & Zeller Coal Company, Chicago, says:

> It has been our experience in merchandising stoker coal, that the public demands in addition to low ash and high heat stoker coal, a coal that will be dustless not only when it is placed in the customer's bin, but one that will remain dustless throughout the heating season.

From their studies on the use of stoker coals, M. P. Cleghorn and R. J. Helfinstine of Iowa State College, report that the smaller sizes (¾ inch by 5/16 inch) gave the most evaporation per pound of coal. No great amount of difference was found between this size and the larger size nut coal tested, however, they explain in Bulletin No. 134.

BULK DENSITIES

Ralph A. Sherman of Battelle Memorial Institute, in Part II, of Technical Report No. 1, for Bituminous Coal Research, Inc., emphasizes the advantages of uniformity. In the conclusion of this report, he points out that:

> The greatest effect of the size of coal on the operation of the stokers was the change in the rate of feed due to the difference in the bulk densities of the different sizes. To maintain uniform combustion efficiency, the rate of air supply must be changed as the rate of coal feed is changed. As a consequence, although one size of coal may perform as well as another when the stoker is properly adjusted, it is important that after the adjustments are made, the size be kept as uniform as possible.
>
> The size of the coal supplied by the dealer in successive deliveries and charged to the stoker by the user from day to day can be kept more uniform the closer the limits of the size range of the coal.
>
> Although the clearance between the feed tube and the core of the worm in present-day residential stokers, and, therefore, the maximum size of the coal fed are about 1¼-inch, stokers with larger clearances could be built. The difficulties with segregation would, however, increase with the increase in the size range.

SIZE RANGE

> For this reason, the recent tendency toward narrowing the size range of stoker coal has merit. The production of a coal with a narrow size range practically always causes the producer difficulty in mechanical arrangements for the preparation and in profitable disposal of the resultant odd sizes. Care must be taken, therefore, that the narrowing of the size range is not carried to absurd limits or beyond the limit where the cost of preparation becomes greater than the gain in the performance.
>
> Whether the top size chosen by a producer for his stoker coal is 1¼ inches, 1 or ¾ inch, or any other size, it is important that it be real and not nominal. That is, the screening should be so well done that the oversize is negligible. Occasional pieces of a 2- or 3-inch coal can cause serious difficulty from noise in crushing and from obstruction of the feed.

CAKING AND COKING

Sherman and E. R. Kaiser said, in a paper before the American Institute of Mining and Metallurgical Engineers:

> The two principal characteristics of a coal that determine its performance on small stokers are its caking and coking tendencies and its size range, and that these are, for many and probably for most bituminous coals, closely related.
>
> Conditions are favorable to coke formation, as is shown by the fact that coals normally considered free-burning, form coke in the stoker fuel bed. Practically all coals, therefore, form coke trees, but even rather strong coke formations cause little or no real difficulty in properly designed combustion chambers. The objections to coke trees are frequently entirely unsound.
>
> No sharp line of demarcation exists in the caking and coking characteristics, which divide suitable from non-suitable coals for stokers. The caking and coking tendencies may generally be reduced by the adjustment of the size range, which may include either reduction of the top size or removal of the fines from the coal, or both, but with many coals this is entirely unnecessary. When it is desirable, the size for removal cannot be categorically defined; it remains as yet a problem for determination on each individual coal, although with increased knowledge a more general answer is to be expected.
>
> Originally it was thought that only the truly free-burning coals could be used, but now a wide range of caking and coking coals is burned successfully. With a better understanding of the phenomena of caking and coking, it is probable that the design of retorts and tuyeres will be so modified as to make possible the successful use of even the most strongly caked coals.

Such is the comment of a representative group of men who have had considerable experience with stoker coal.

MANUFACTURERS' SUGGESTIONS

Some sort of instruction card or folder is shipped with every small stoker. These cards cover lubrication, regulation of the stoker, adjustment of controls, fuels, etc.

Anchor, for instance, includes a notice also about coal on the hopper lid. It reads:

> This Fire Chief Model Anchor Kolstoker is designed for burning the smaller sizes of coal. Coal should be used which will pass through a one-inch screen for best results.
>
> If larger coal is used noise from the crushing of the large pieces of coal passing through the worm will be noticeable.
>
> Properly sized prepared stoker coal with low ash content gives better results and requires less attention from the operator.
>
> High grade coal with low ash content is usually more economical to use than low-grade cheap coal.
>
> Use the better grades of prepared stoker coal for best results.

Kelvinator says: "Use a good grade of stoker coal. Bear in mind in selecting coal for use with the burner that the better grades of coal contain more heat units and over a period of time will prove more economical than cheap coal."

QUALITY—IMPORTANT FACTOR

Fairbanks-Morse tells its household stoker users that "The coal for use in a Fairbanks-Morse stoker may be buckwheat size, 3/8 by 1/2 inch, or one-inch prepared stoker screenings of a heating value of at least 11,500 B.t.u. per pound, and a low ash content of high fusion temperature. The quality of coal used is an important factor in securing complete satisfaction with a stoker."

Freeman says, among other things: "Make sure that coal does not contain too large a percentage of fines. Don't put anything in the stoker hopper except clean, small sized coal. Coal for this stoker should not exceed 1 1/4 inches in size."

"Use good fuel. Don't be tempted by cheap coal," says the Eddy Stoker Corporation, Chicago, in the first paragraph of their illustrated instruction card. "The Eddy Stoker will burn any stoker coal. But clean, dustless stoker coal burns hotter, uniformly, economically. It requires less attention. It gives more heat for less money. It costs less to use. Buy a good graded coal. Order a 5/16 by 10-mesh stoker coal. If not available, use 1-inch screenings with at least 35 per cent fines," they suggest.

GOOD COAL MOST ECONOMICAL

Auburn tells its household stoker users that "there are many prepared coals for domestic use which have the slack and dirt washed out or are treated to eliminate dirt in handling. The most desirable grade of coal is a high volatile, free-burning coal, preferably 1/4 inch to 3/4 inch in size, over a round screen. One and one-fourth inches may be used, but results in noise due to crunching. The washed coals are much more satisfactory than the chemically treated coals. (Good coal is the most economical.)" Such is the advice of another manufacturer as regards coal and its use in small stokers.

SELECTING STOKER FUEL

The Will-Burt Company of Orrville, Ohio, in its operating instructions goes into considerable detail as to selecting stoker fuel. In their instructions they say:

> The importance of selecting proper fuel for our Will-Burt stoker cannot be over-emphasized, because the coal you use will determine, to a great extent, the satisfaction you will obtain from your stoker.
>
> Heating plants vary widely in their characteristics and your coal should be selected, as nearly as possible, to fulfill the requirements of your particular heating system. For that reason it is often advisable to try several different coals, in small quantities at first, until you find the coal which best meets your requirements, considering burning qualities, price, etc. Many coal producers now furnish sized and dust-treated coal which is particularly suited to domestic use and is sometimes used on commercial installations.

The following figures will give you some idea of how the analyses of different coals may vary:

Heat value—10,000 to 15,000 B.t.u.

Ash content—3 to 15 per cent per lb.

Sulphur content—½ to 5 per cent.

Fusion temperature of ash—2,000 to 3,000 deg. F.

A properly sized, free-burning coal, high in heat units, low in ash and sulphur, and cleaned of all foreign materials which might obstruct the coal screw, provides the most trouble-free and satisfactory stoker operation and usually proves to be more economical, even at a greater cost per ton. Coke is very abrasive and is not recommended as a stoker fuel.

Coals best suited for domestic use should be 1 inch and under in size, high in heat units, low in ash and sulphur, with a fusion temperature of around 2,200 to 2,400 degrees, and cleaned of all tramp iron, pieces of wood, stones, etc.

If the coal is larger than 1 inch it will have to be crushed in passing through the coal tube. This creates an objectionable noise, causes undue wear on the stokers and increases the current consumption. If the lumps are too large to fall into the flights of the screw, they will ride on top and prevent the rest of the coal from feeding.

Normally a coal with a medium ash fusion temperature of from 2,200 to 2,400 degrees is to be recommended. If, however, the boiler or furnace is small or the radiation inadequate for the building, or both, so that the heating system must be crowded to carry the load, the fire box temperature will necessarily be higher and the fusion temperature should be proportionately higher.

With too low a fusion temperature ash melts, runs down into the burner pot and closes part or all of the air ports. The clinkers stick tightly to the tuyere or brickwork, often causing a pin to shear or the overload relay to "throw out." Clinkers under these conditions are difficult to remove. The remedy is to use coal with a higher fusion temperature. If the fusion temperature is too high the ash will not fuse into clinkers and obviously coal with a lower fusion temperature should be used.

When using a coal of high ash content it can be expected that more attention will be required in filling the hopper and removing the clinkers.

Link-Belt, in its operating instructions for smaller stokers, says:

The efficiency of the heating plant and the operation of the stoker is affected by the quality of coal used.

Best results are obtained with the use of a free-burning, non-coking, good quality of stoker coal. The largest lumps should not exceed 1¼ inches. The coal should contain about 40 per cent fines or small particles. The coal made up of yard sweepings or entirely fines is too dense to allow good air penetration.

When stoker coal is loaded into your bin, the fine and coarse parts separate, the coarse running to the sides and bottom of the pile. Therefore, when filling the stoker hopper take a shovelful alternately of the fine and the coarse coal.

The Morse Chain Company, manufacturers of the "Templux" stoker, says, in speaking of the "Kind of Coal to Use":

The Templux will burn any of the regular bituminous stoker coals. The best size is that which will pass through a 1-inch or ¾-inch mesh screen and be retained upon a ¼-inch mesh screen.

If lumpy coal is used without any fines or slack, it is difficult to control the forced air, with the result that the back pressure from the combustion chamber is apt to make the smoke back up through the loose coal into the hopper. On the other hand, a coal that is all slack will so retard the air supply that a spotty fire is apt to result,

with the fire bed caked over to the point of smothering the fire, and causing the fire to burn back into the retort with possible damage to tuyeres.

Herman Winkler, U. S. Machine Corp., Lebanon, Indiana, in his instructions on coal selection, says:

> For domestic installations, a bituminous coal, low in ash (5 per cent or less) with an ash fusion temperature of 2,300 to 2,600 degrees F., and from 1¼ inches maximum to ⅜ inch minimum is ideal. However, nut and slack preparations may be used, although the percentage of fines should not exceed 25 per cent.
>
> In any case, oil treatment is recommended for dust elimination.
>
> A high quality coal will be most satisfactory and usually most economical. On small stokers the annual coal tonnage is relatively small and convenience is the primary object of the stoker.

Iron Fireman Mfg. Company, in its instructions for household stoker users, says:

> A good grade of prepared stoker coal gives best results with these units. The largest lumps should not be over 1 inch dimension and the fines ¼ inch dimensions, (or less) should not represent a high percentage of the total. Do not use coal that is extremely wet as it will not feed out of the hopper properly.
>
> Some dust treatments contain salts which cause the metal parts of the stoker to rust out in an abnormally short time. Coals that have been treated with these materials should be avoided.
>
> No paper, rags, sticks of wood, or rubbish should be put in the hopper. No glass, cans or metals should be thrown into the fire, as they will melt and close up the air slots in the firepot.

Combustioneer, in its operating instructions for its small stokers, discusses fuel in the second paragraph:

> The coal used in Combustioneer should be either prepared stoker coal (which most coal dealers can furnish) or screenings with a top size of 1¼ inches and containing 30 to not over 50 per cent fines below ⅛ inch. Consult your coal dealer or other stoker users as to the types of coal sold in your city that have given good satisfaction in stokers.
>
> Coal purchased at the lowest price per ton may not be the most economical. Low grades of coal are low in heat content and usually contain a high percentage of ash and other impurities which cause low efficiency and excessive clinker formation. It is recommended that the Combustioneer owner start with the best stoker coal available. After using such coal he will be in a position to make a comparison with lower grades if he desires to experiment with them.

Sears-Roebuck includes a large instruction chart with every household stoker shipped. The first paragraph in their large instruction sheet reads:

> Good stoker coal is more economical than ordinary grades, even though it may cost more per ton. We recommend prepared bituminous stoker coal, sizes ⅜ inch by 1¼ inches, or 1 inch by No. 10 mesh with fines (slack) washed out. If screenings are used, specify not over 1¼-inch size with not more than 30 per cent slack. Any coal of over 12,500 B.t.u. with ash fusing temperature of 2,200 degrees F. will be found satisfactory. Consult your local coal dealer. He is familiar with various kinds of coal available in your locality and can assist you in selecting the proper coal to use. Get him to show you mine analysis of coal.

Schwitzer-Cummins Company, in its Stokol bituminous stoker instruction card, says:

> For home installations, a bituminous coal, low in ash (5 per cent or less) with a fusing temperature approximately 2,500 degrees, size from 1¼ inches maximum to ⅜ inch is recommended.
>
> A washed, oil treated coal is recommended for dust elimination. Nut and slack preparations may be used. Lower quality fuels may be used on commercial installations. The percentage of fines (⅛ inch and lower) should not exceed 50 per cent of the total, with 20 per cent larger than 1 inch.
>
> The lowest priced coal per ton is not as a rule the cheapest, as the higher B.t.u. contents of the better fuels more than offsets the price difference. The lower the quality of fuel the more attention required to care for the fire.
>
> The Stokol dealer should advise the coal that has been used with satisfaction in other Stokols. Use good stoker coal for best results.
>
> Inspect coal as it is placed in the hopper for spikes, large nails, rocks, etc., which would lock the feed screw.

Norge Heating-Conditioning Division, Bog-Warner Corporation, Detroit, Michigan, gives this advice:

> Use prepared bituminous stoker coal size ⅜ by 1¼ inches with fine (slack) washed out.
>
> Where screenings are used, ask for not over 1¼-inch size with not over 30 per cent fines. A coal of 12,500 B.t.u. with ash fusing temperature of 2,200 to 2,500 degrees gives best results.
>
> Be sure coal is free from iron, spikes, stones, or similar hard matter, as they will jam the stoker. Do not put garbage, wood chunks or floor sweepings into hopper.

Sinker-Davis Company, manufacturers of the Fire-King Stoker, in their stoker instruction bulletin says:

> The question of fuel is a more or less difficult problem in some territories. An underfeed stoker is at its best with a free-burning bituminous coal, having some 25 to 35 per cent volatile with not over 10 per cent or less than 4 per cent of ash and a sulphur content down to .05 per cent, with an ash fusing at not less than 2,400 degrees F., and with non-caking combustion characteristics.
>
> It is impossible to tell from a coal analysis what a coal will do under fire. Coals with practically the same analysis have entirely different burning characteristics. Where the most accessible coal in any area is of a coking nature, certain changes in the method of burning have proven helpful. In general, restricting the grate surface will tend to reduce heavy coking. In all cases the depth of fuel bed should be increased from 8 to 10 inches, depending on the stoker size.
>
> It must be borne in mind that the smaller the stoker size, the more exacting it becomes in its fuel requirements. The frequency of attention is a factor in the selection of a suitable fuel that should not be overlooked.

CONCLUSIONS

Such is the evidence. It speaks for itself. Right or wrong, these printed instructions reflect the experiences of a representative group of stoker manufacturers. Much of what they say is incontrovertible—as anyone knows who has had experience in using several kinds or sizes of coal in a household stoker in his own basement.

With some of the assertions on a few of the instruction cards I do not agree. Nine years' experience and experimentation, in my own basement, with forty kinds and sizes of coal, five stokers and in as many furnaces and boilers, assure me that one can (but won't) burn literally any kind of coal. Except for the experimenters among us, however, the average individual soon orders that coal which works best, requires the least attention, offers the most in consumer satisfaction.

Price is secondary. Dustless treatment, ease of handling, are paramount. Cleanliness, not a coal analysis, is the number one factor.

Few manufacturers now predicate the operation of their stokers only on the use of a free-burning coal. Caking or coking, one can use them all. Whether we do or not depends, sometimes, on what else is available, and on what kind of a stoker we have. Geographic location is sometimes a factor, not always. To say that one "can't burn" a coking or caking coal is to put himself among that group of whom Barnum said "one is born every minute."

The experiences of other users, the recommendation of the stoker dealer or salesman—these are the factors, too, that count in the selection and purchase of household stoker coal.

Trick sizing is not necessary. Simplification and standardization of coal sizing, however, is most desirable, imperative. The needless multiplication of stoker coal sizes came about not through the demand of stoker manufacturers or stoker users. Competitive rivalries, one coal operator or district with another, or the desire to offer something the other fellow did not have, explain the innumerable sizes now offered.

Actually, as we have seen, stoker manufacturers aren't demanding split sixteenths in coal sizes. Economics of stoker manufacturing, however, set certain limits on feed worm sizes and consequently on maximum coal sizes. Bringing the limits of coal sizes closer together is desirable. Greater uniformity will reduce segregation and simplify the problem of air control. It will further consumer satisfaction. Oversized stoker coal is out. It's too noisy.

With the tremendous increase in preparation facilities at the mines, the customer can get what he wants at a reasonable price. The rapid increase in stoker sales is being more than paralleled by the increase in preparation facilities at the mines. There is no question about the market. It's what you make it. Give John Q. Public what he wants and the business is yours.

CURRENT DEVELOPMENTS IN OIL AND GAS

DEVELOPMENTS IN ILLINOIS SINCE JANUARY 1, 1937*

By

Alfred H. Bell

Geologist and Head of the Oil and Gas Division, Illinois State Geological Survey

In the past one article in the course of a year on oil and gas developments in Illinois has usually been sufficient. This year, however, developments during the first nine months are without parallel in importance to the State, since the discovery of the Southeastern Illinois field in 1904. Therefore, a review of developments seems fitting at this time. Certainly five and possibly seven or eight new oil fields have been discovered this year. The doubt concerning the number arises from the fact that certain wells which found oil in commercial quantity may represent either separate productive areas or extensions of known fields. The number of fields, however, is less significant than is their location far from previous fields and the consequent large territory which is outlined for early testing.

Events leading up to this year's discoveries began several years ago. Most important, perhaps, was the discovery in 1928 of the Mt. Pleasant field in the central part of the Michigan basin, a large geosyncline similar in many respects to the Illinois basin. Previously, such basins had been considered unfavorable to the occurrence of oil because it was thought that any oil formerly present had migrated to the margins. The presence of structural irregularities in the central part of the Michigan basin was demonstrated prior to the discovery of oil by subsurface data obtained from brine wells. At that time subsurface data in the Illinois basin was insufficient to reveal the details of the subsurface structure. The probability that unknown local structures, some of them favorable to the occurrence of oil and gas, were present in the Illinois basin was recognized by the Illinois State Geological Survey and an article was prepared and presented before the annual meeting of the Illinois Academy of Science, May, 1930.[1] This report recommended that the central basin area be explored for oil.

* This paper has been published since the Conference in The Oil and Gas Journal, vol. 36, no. 23, pp. 28-29, 1937, from which the illustrations are used.

[1] Bell, A. H., The relation of geology to the development of the petroleum industry in Illinois: Trans. Ill. Acad. Sci., Vol. 23, No. 3, March, 1931, pp. 367-370.

A map, based on geologic data accumulated by the State Geological Survey for many years was prepared by the writer in 1930, divided the State into areas according to relative probability of finding new oil fields. Although this map was not printed at the time, it was exhibited in Chicago by the Western Society of Engineers in September, 1930, along with other material illustrating the work of the State Geological Survey. It will be noted that all recent discoveries have been within area number 1 of this map, which is designated as having "best possibilities," in the earlier edition.

Actual demonstration of the presence of structural irregularities in the Illinois basin has been made by both geological and geophysical methods. Studies of Pennsylvanian stratigraphy initiated in 1927 under the supervision of Dr. J. M. Weller of the Survey staff made possible correlations over wide areas of the State with a precision hitherto believed impossible. These studies were carried into the basin area and demonstrated the presence of structures favorable to the occurrence of oil. The results of these studies in one area were published March 1, 1936.[2] The reflection seismograph method of exploration was started in Illinois by the Pure Oil Company in the fall of 1935. Geophysical investigations by this company resulted in the discovery of an important structure in the central part of the basin. The seismograph method has since been adopted on a large scale by oil companies in the area and at present about 16 parties are operating. It is noteworthy that the first three wells located by the seismograph in Illinois all discovered oil.

The discovery wells of the first three fields of 1937 were already being drilled in late 1936. Two of these were drilled by cable tools and one by rotary. This was the first rotary test for oil to be drilled in Illinois. The following table shows the discovery wells of new fields in chronological order.

GEOLOGICAL CONDITIONS IN THE NEW BASIN FIELDS

Well data from the basin area are beginning to reveal something of the subsurface geological conditions governing accumulation of the oil. It is already evident that anticlinal structure is not the only factor of importance and in some cases it may not even be essential. The principal producing horizon in these fields is the McClosky "sand," defined as any oolitic beds occurring in the Fredonia limestone member of the Ste. Genevieve formation. The typical McClosky in all of the best producing wells so far obtained is a light gray pure limestone made up of exceedingly well sorted oolites. There has been very little deposition of interstitial material, so that porosity may, in some cases, approach the theoretical maximum for closely packed uniform spheres. The thickness of the pay is variable within short distrances,

[2] Weller, J. Marvin, and Bell, A. H., Geology and oil and gas possibilities of parts of Marion and Clay counties, with discussion of the central portion of the Illinois basin: Illinois State Geological Survey Report of Investigations No. 40, 1936.

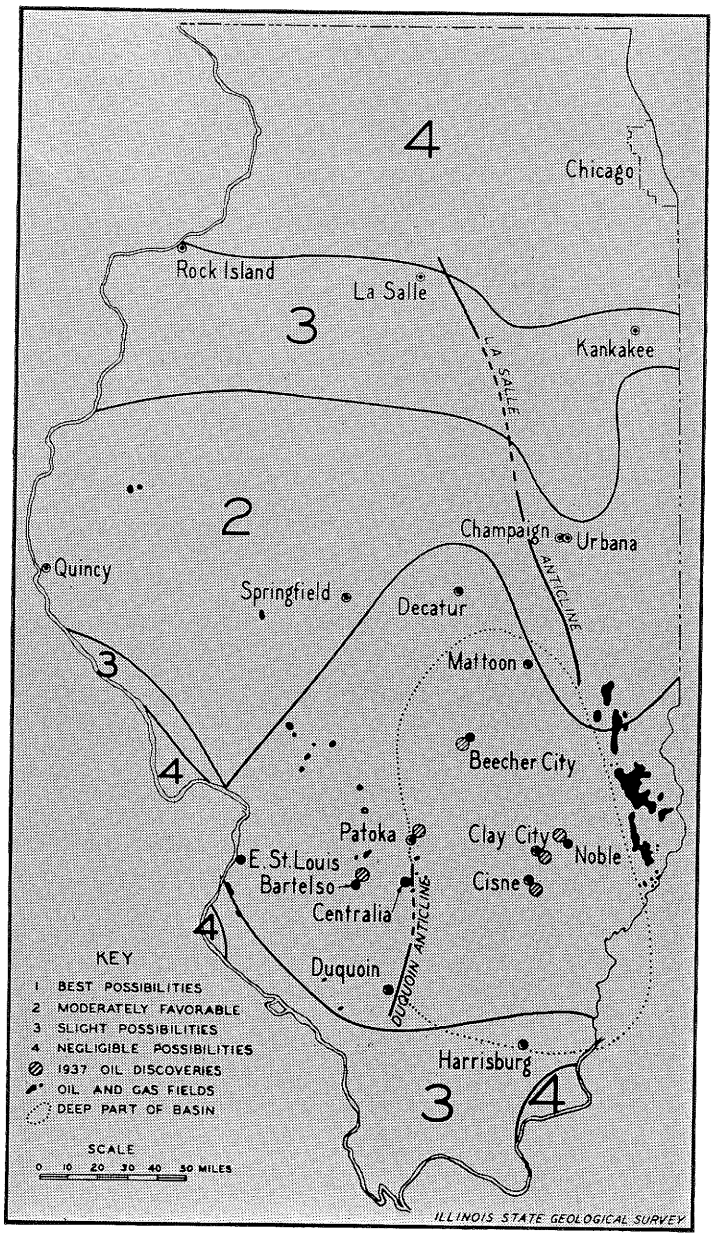

FIGURE 3.—Map of Illinois showing areas classified according to the probability of finding oil.

as well as its position in the stratigraphic section. Because of the lenticular character of the reservoirs, production may be looked for well down on the flanks of structures, as well as dry holes on the high parts, in some cases offsetting good producers. It is planned that further discussion of these conditions with cross-sections showing specific locations, will be included in an early publication of the Survey.

STRUCTURE OF THE BASIN

A sufficient number of datum points on the contact between the overlying Chester series and the top of the Lower Mississippian series are now available to permit making a generalized regional contour map of the basin on this horizon. Maps of the basin contoured on the base of the Pennsylvanian have been published previously. The last one of these maps published on a contour interval used is 100 feet, is dated May, 1937. It is subject to revision in accordance with new well data received since that time. It may be noted in general that the Chester series thickens southward across the basin, when this map is compared with one contoured on the top of the Lower Mississippian series, using a contour interval of 200 feet. The difference between the elevations shown on these two maps for any given point is the thickness of the Chester series at that point.

The La Salle anticline upon which the Southeastern Illinois field is located in Clark, Cumberland, Crawford and Lawrence counties is seen to be a discontinuous feature and is much broken up with saddles, flats, and cross-folds. These cross-folds were emphasized by Mylius in Bulletin 54 of the Survey. One of these cross-folds runs NNE-SW through the Westfield and Siggins pools. The map on the top of the Lower Mississippian shows this fold to continue southward across Jasper County into Richland, Clay and Wayne counties. It appears to be a structure of comparable importance in the accumulation of oil with the La Salle anticline itself.

PROBABLE RECOVERY IN THE NEW FIELDS

Data are as yet insufficient to make a reliable estimate of ultimate per acre yield in the new fields. The best indication now available is a comparison of the thickness and character of the reservoir rock with that of the same strata in the old producing field. Thus, the McClosky oolites in the new basin fields are more uniform, and well sorted, than are those in the Lawrence County field, judging from the few samples available from the old field. The average thickness of "pay" is probably greater in the new fields. Therefore, an ultimate yield per acre at least is as great as in the old field may be expected.

TABLE 1—DISCOVERY WELLS IN NEW SOUTHERN ILLINOIS OIL FIELDS

Field	County	Company	Date completed	Farm	Well No.	Location			Total depth (feet)	Producing formation	
						Sec.	Twp.	R.		Depth (feet)	Name
Bartelso....	Clinton...	Bartelso Oil & Gas Co....	Apr. 20, 1936	Trame.....	1	8	1N	3W	1,037	1,027	Carlyle
Patoka.....	Marion....	Adams Oil & Gas Co.....	Jan. 27, 1937	Merryman...	1	21	4N	1E	1,418	1,391	Benoist
Clay City...	Clay.....	Pure Oil Co.....	Feb. 26, 1937	Weiler.....	1	33	3N	8E	2,613	2,608	Cypress
Clay City...	Clay.....	Pure Oil Co.....	May 15, 1937	B. Travis....	1	33	3N	8E	2,960	2,950	McClosky
Cisne.....	Wayne....	Pure Oil Co.....	Mar. 4, 1937	Bradley.....	1	26	1N	7E	2,987	2,982	Ste. Genevieve
Noble.....	Richland..	Ohio Oil Co.....	Aug. 2, 1937	Arbuthnot...	1	8	3N	9E	2,990	2,898	McCloskey
Noble.....	Richland..	Mammoth Oil Refining Co.	Sept. 2, 1937	Heitz.....	1	34	4N	9E	3,009	2,972	McClosky
Beecher City	Fayette...	Carter Oil Co.....	Sept. 1937	Miller.....	1	12	8N	3E	1,607	1,601	Benoist

In the largest area of continuous McClosky production, in Dennison township, Lawrence County, 23,270,168 barrels of oil were produced in 23 years (1908-1931) from an area of 1,455 acres, or a yield of 16,000 barrels per acre. The wells were open in the Kirkwood and Tracey sands as well as the McClosky and separate figures on the recovery from each sand are not available. In this area, however, it is known that the McClosky was by far the

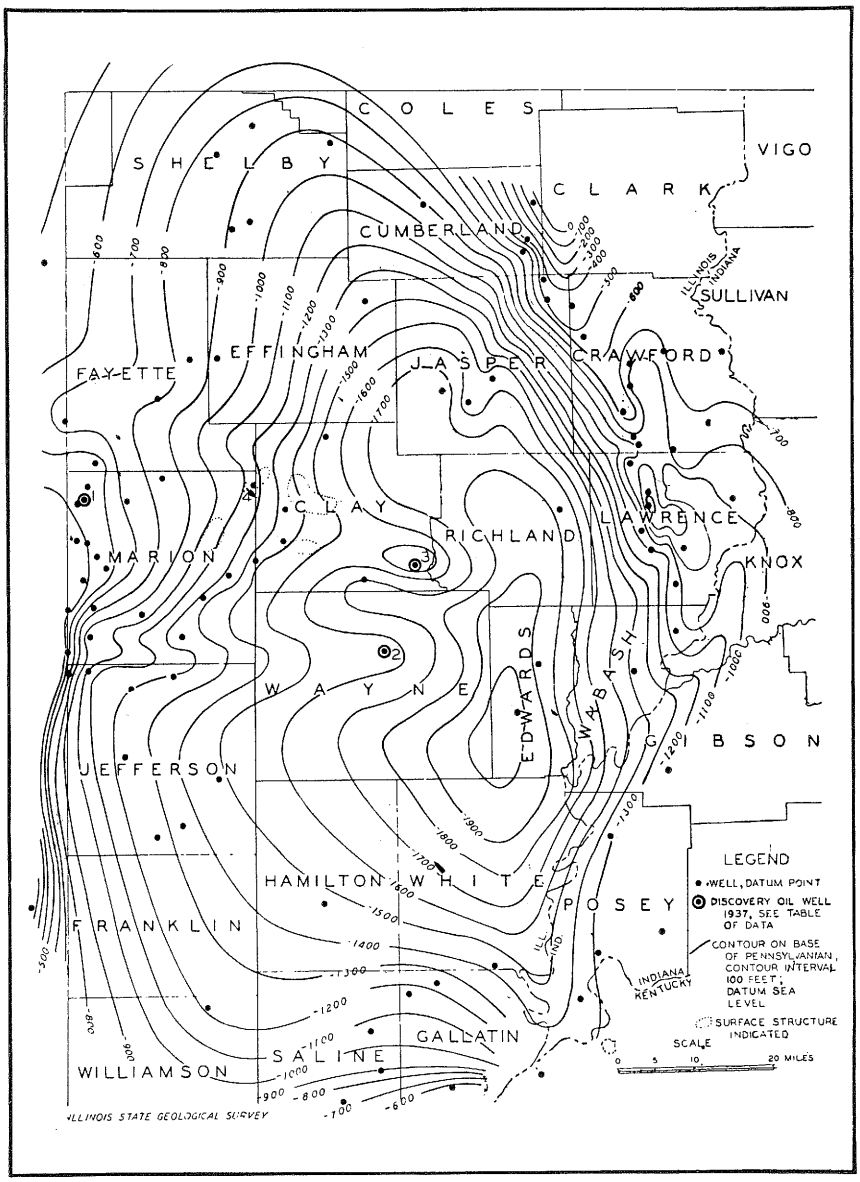

FIGURE 4.—Subsurface countour map of the Illinois basin on the base of the Pennsylvanian.

most productive horizon, and probably has yielded an average of 12,000 barrels per acre out of the 16,000 barrels per acre total. Some individual leases in the old fields yield as much as 25,000 barrels per acre mostly from the McClosky. In view of this record ultimate yields of 8,000 to 10,000 barrels per acre from the new basin fields from the McClosky are not improbable.

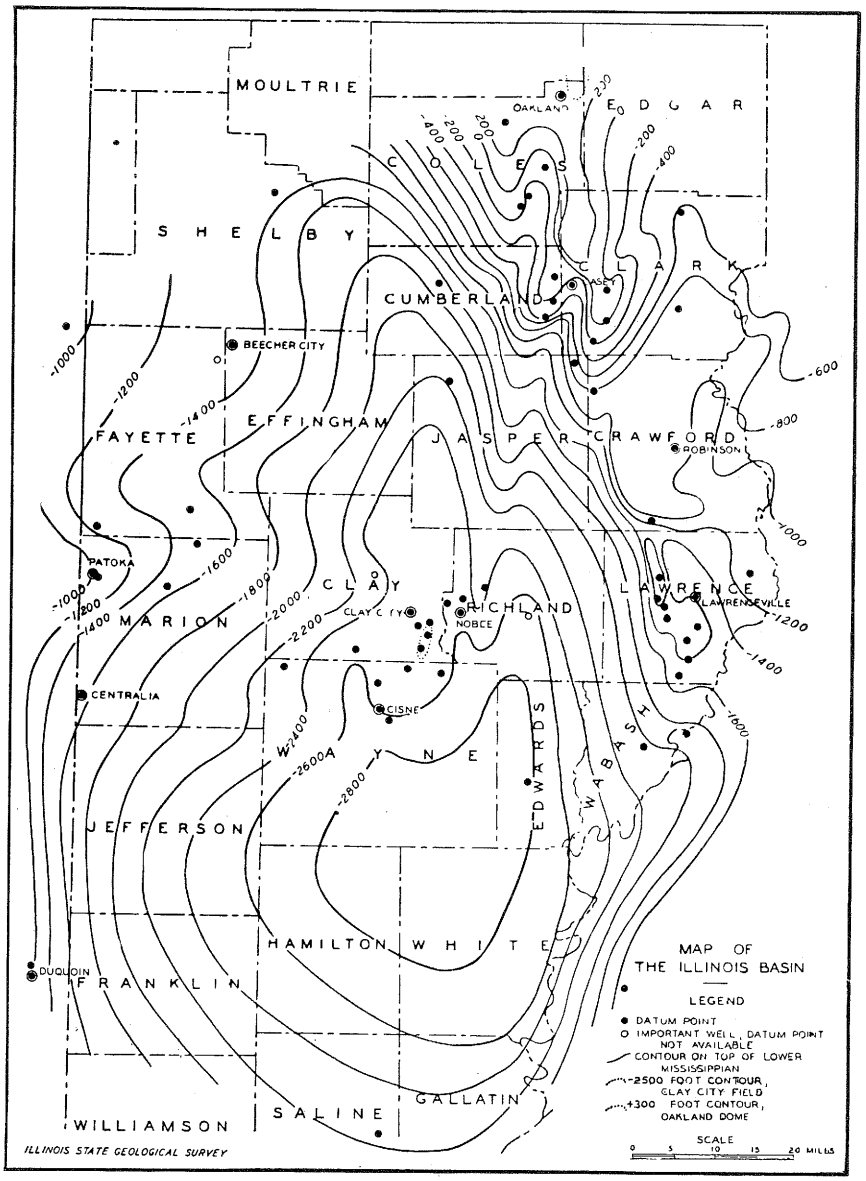

FIGURE 5.—Subsurface countour map of the Illinois basin on top of the Lower Mississippian.

DRILLING ACTIVITY AND NEW PRODUCTION

At the end of September, 1937, there were approximately 111 oil and gas drilling operations in Illinois, almost a threefold increase since the beginning of the year. From January to September 30, approximately 215 wells were completed in the State, of which 169 were oil producers.

The number of wells in the new fields are shown in the following table:

TABLE 2—WELLS IN THE NEW FIELDS, SEPTEMBER 28, 1937

Field	Producers	Dry holes	Drilling[1]	Rig
Noble field	7	2	8	1
Clay City	35	3	11	4
Cisne	3	1	.....	.....
Total central basin fields	45	6	19	5
Patoka	56	13	5	20
Bartelso	16	3	1	1
Total	117	22	25	26

[1] Within ¼ mile of production.

Production in the new fields alone is considerably greater than the previous total production of the State. This is illustrated in the following table of production by months:

TABLE 3—PRODUCTION OF CRUDE OIL IN ILLINOIS FOR 1937[a]
(Barrels)

Month	Production	Month	Production
January	368,000	June	463,000
February	343,000	July	530,000
March	410,000	August	674,000
April	386,000	September	849,000
May	416,000		
		Total	4,484,000

[a] Figures obtained from U. S. Bureau of Mines.

It will be noted that the production for September is estimated to be well over twice that for January. Further increases in production in the known fields are to be expected during the remainder of the year, and it seems probable that additional fields will be discovered.

The Survey does not as yet have anything like complete data on the wells so far drilled. Because of the importance to the industry of assembling, correlating, and thoroughly studying these data, so that conclusions of both scientific and practical value may be reached, the cooperation of all is earnestly requested in filing the drillers' logs, and in making available the well cuttings and cores to the Survey for study and preservation.

OIL EXPLORATION IN THE EASTERN PORTION OF THE ILLINOIS BASIN*

By

Theron Wasson

Chief Geologist, Pure Oil Company, Chicago

INTRODUCTION

Appearing before the State Geological Survey and the University of Illinois to discuss the southeastern portion of their State seems like carrying oil to Tulsa, or coals to Newcastle. We are indebted to the State Geological Survey for its work in publishing the results of drilling in the old area and forecasting prospective territory in advance of the drill. All operators in the southeastern fields know the work of Blatchley, published in Bulletin 22, 1913; and Mylius, Bulletin 54, published in 1927. We also know that since the first development in this old area over four hundred million barrels of oil have been produced. The eastern portion of the Illinois basin has had oil fields and continuous oil development for thirty years. The general geological conditions affecting this area have been known for over 100 years. In 1930, the State Geological Survey exhibited maps and cross-sections at the meeting of the Western Society of Engineers in Chicago (fig. 6). Members of the State Survey staff at that time called attention to the large unexplored basin area of southern Illinois.

Near the old fields in the eastern part of the basin, a new area is under development. At this time, 50 wells are producing in a belt over 20 miles long, many wells are drilling, and a pipe line is under construction. While the new area appears large and boom conditions now prevail, we should not lose sight of the fact that this is another Illinois field. It should not be measured by mid-Continent standards. The old fields of Illinois have made their production from small, long lived, pumping wells. The same will be true in the new fields, thirty miles away.

Production is coming from the McClosky, an oolitic limestone member of the Ste. Genevieve formation which is well known in the fields of Lawrence County. The new development has gone far enough to demonstrate that while some flashy initial production may be expected, dry holes will be found offsetting big wells. From experience in the old fields we know the flowing life will be short. Decline will be rapid in the first months of production and the area as a whole will make its oil from wells that are on the beam, or pumping from a central power.

* This paper has been published since the Conference in The Oil and Gas Journal, vol. 36, no. 24, pp. 20-21, 1937, from which the illustrations are used; and the Bull. Am. Assoc. Pet. Geol., vol. 22, pp. 71-78, 1938.

While there have been great improvements in drilling and production technique since the old fields were discovered, we can not escape the fact that we are dealing with limestone production from thin pay zones of varying porosity. A great many wells will have to be drilled in order to maintain a reasonable settled production over a period of years.

AREA OF NEW PRODUCTION

The area under discussion, which includes Wayne, Clay, Richland, Jasper and adjacent counties, is 60 miles long and 30 miles wide. It is a flat farming region, rather thickly settled by people whose pioneer ancestors came into the region from Kentucky and Virginia. These hard working, friendly people live on 40 and 80 acre farms which are outside the rich corn belt of Illinois. Power machines such as tractors and combines are not common. This territory has an elevation of about 500 feet above the sea. Drainage is into the Wabash Valley by streams flowing southeastward. From south to north across the area, the Little Wabash and the Embarrass are the principal streams. The B. & O. Railroad runs east and west, and the Illinois Central north and south through the area under discussion. The main towns from south to north are Fairfield, Olney and Newton.

GENERAL GEOLOGY

Geologists familiar with this territory know that the relatively flat plain has a surface cover of glacial drift and till about 50 feet thick, consisting of unconsolidated sands and clays left upon the retreat of the ice sheets which once covered the greater part of Illinois. This mantle of glacial material has covered the bed rock to such an extent that it is impossible to do any detailed surface mapping. The old Southeastern Illinois fields are on the LaSalle anticline, which has been outlined by drilling and by studies of rocks exposed on the surface near LaSalle. Early oil explorers venturing west from the fields of Crawford and Lawrence counties soon lost interest after drilling into salt water at depths comparable to those at which they found oil in the old fields. Very few tests went deeper than 2,000 feet. In mapping the subsurface conditions in the old fields both Blatchley and Mylius showed a rapid dip to the west. Other publications of the State Geological Survey have outlined the LaSalle anticline in considerable detail, calling attention to the steep dip on the west side and the rather flat east side.

GEOLOGICAL EXPLORATION

Following the discovery of oil in Michigan in 1927, the Geological Department of The Pure Oil Company became interested in the Illinois basin and for the first time became acquainted with the staff of the Illinois Geological

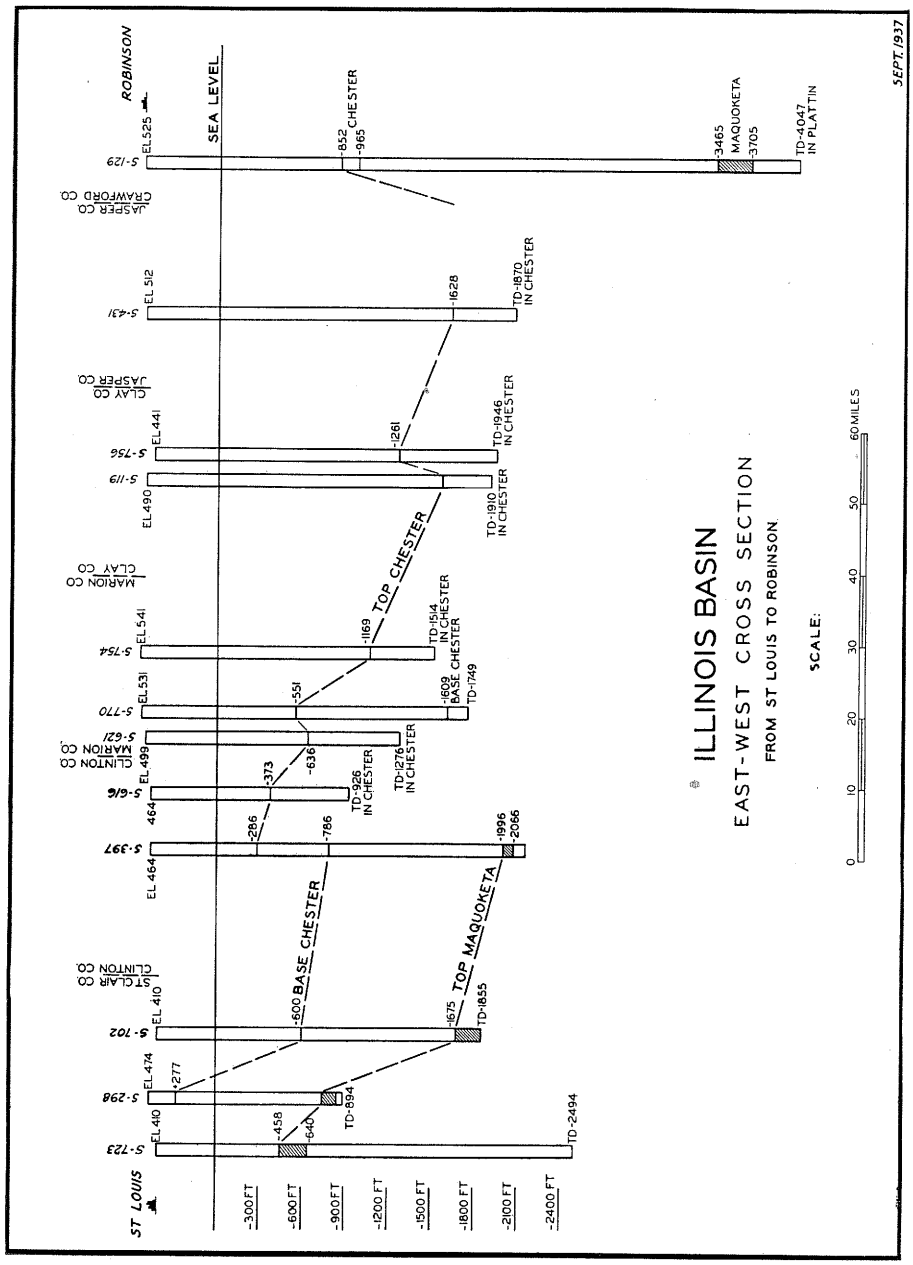
ILLINOIS BASIN
EAST-WEST CROSS SECTION
FROM ST LOUIS TO ROBINSON
SCALE:
0 10 20 30 40 50 60 MILES
SEPT. 1937
ST LOUIS
ROBINSON
SEA LEVEL
-300 FT
-600 FT
-900 FT
-1200 FT
-1500 FT
-1800 FT
-2100 FT
-2400 FT
S-723
EL 410
-458
-640
TD-2494
S-298
EL 474
-277
TD-894
S-702
EL 410
-600 BASE CHESTER
-1675
TD-1855
TOP MAQUOKETA
ST CLAIR CO
CLINTON CO
S-397
EL 464
-286
-786
-1996
-2066
S-616
464
-373
-636
TD-1226 IN CHESTER
TD-1276 IN CHESTER
S-621
EL 499
CLINTON CO
MARION CO
S-770
EL 531
-551
-1609 BASE CHESTER
TD-1749
S-754
EL 541
-1169
TOP CHESTER
TD-1514 IN CHESTER
S-119
EL 490
TD-1910 IN CHESTER
S-756
EL 441
-1261
TD-1946 IN CHESTER
MARION CO
CLAY CO
S-431
EL 512
-1628
TD-1870 IN CHESTER
CLAY CO
JASPER CO
S-129
EL 525
-852 CHESTER
-965
-3465 MAQUOKETA
-3705
TD-4047 IN PLATTIN
JASPER CO
CRAWFORD CO

FIGURE 6.

Survey. As a preliminary study, a cross-section was prepared from Lawrenceville to St. Louis (fig. 6). The published logs of old wells were used for this section. It showed a disturbance in the area between Flora and Olney. This suggested structural feature was not given great weight because there was a chance of error in the logs. It, however, was a clue which led to the reconnaissance torsion balance survey made in 1930. This work, which started at the Indiana line and crossed a portion of the old fields, indicated a gravitational disturbance similar to that found on the south end of the LaSalle anticline. The work was discontinued before the north end was completed. The success of the reflection seismograph in Oklahoma and Texas led to a survey by that method in Illinois during 1935 and 1936. The seismograph work checked the existence of a structural disturbance running across Wayne, Richland and Jasper counties. Drilling has so far confirmed the geophysical work. The structural feature along which the new pools are located appears to be an extension southwestward from the Oakland anticline. It has an axial trend parallel to the cross folds outlined by Mylius in Bulletin 54.

The Duquoin anticline and some other structures of southern Illinois have similar northeast-southwest trends.

DEVELOPMENT

A block of 250,000 acres, taken during the month of April 1936, led to the drilling of a first test near Cisne, Wayne County, and the second test near Clay City, Clay County, twelve miles north. These tests discovered oil in sands of the lower Chester group. Deeper drilling at Clay City on the Bunyan Travis farm discovered the first production in the McClosky "sand" a member of the Ste. Genevieve. This well's initial production was 2,640 barrels per day from a depth of 2,964 feet. More recently, drilling has been extended northeastward 6 to 8 miles to the Noble area, Richland County.

The principal production so far has been from the McClosky pay horizon found in the top of the Ste. Genevieve of Mississippian age. It is one of the pay horizons in the south end of the old fields of Lawrence County where it was first discovered on the McClosky farm in section 25, Dennison Township. The McClosky is an oolitic limestone of varying porosity depending on the condition of the oolites. Wells which make big initial production are from oolitic layers which are soft and porous. These porous spots change quickly into areas of dense, tightly cemented oolites. The thickness of the oil saturated section varies from a few feet to 10 or 15 feet in the best wells. In the Clay City and Noble areas the McClosky is found at a depth of 2,950; at Cisne it is at 3,070. The greatest development to date has been in the Clay City area of Clay County where over 50 wells have been drilled to the

McClosky or are now close to it. The field at Noble including the northeast extension has 15 or 20 wells in or close to the McClosky. The Bradley area near Cisne, where so far the McClosky has shown little porosity, has 3 wells. These are producing from the Bradley sand and the McClosky. So far, the objective of all wells since the discovery of oil in the Bunyan Travis No. 1 has been the McClosky. Many wells in the Clay City area have been drilled through the McClosky pay without finding water. Some tests on the west flank have reported salt water, but little information has been developed in regard to possible water levels. Due to the lensing character of the porous streaks, water levels will probably be poorly defined.

Acid treatment is common practice and results in general are favorable, as the oolitic McClosky is easily dissolved by acid. Acid, however, can not make a producer out of a dry hole.

The first wells in the Cisne and Clay City areas were drilled with standard tools. The Bradley test at Cisne was spudded November 3, 1936 and it was completed in the Bradley sand of the lower Chester on April 3, 1937.

Information obtained by the first test wells drilled with cable tools made it possible to use mid-Continent rotary equipment with resultant increased speed and a great reduction in drilling cost. Wells are now drilled into the McClosky in less than three weeks. Good cores are obtained of the pay horizons.

Schlumberger electrical logs have been run in a number of key wells throughout the area and this method of logging will probably be of assistance in correlating beds drilled by the rotary but not cored.

COMPARISON WITH OLD FIELDS

Except for greater depth and increased thickness, the section drilled in the new area is similar to that in the south end of the old field.

The McClosky "sand" of the St. Genevieve formation is found at a depth of 1,600 to 1,800 feet in Lawrence County. Published records show that the thickness of pay and type of porosity varied from one well to another. These wells had high initial productions in some cases, but they declined rapidly. Their production has been made from a great many pumping wells. The McClosky in the Clay City and Noble areas is found at a depth of 2,950 feet, which is approximately 50 feet below the top of the Ste. Genevieve limestone. The pay ranges up to 15 feet in thickness. One well in the Clay City area has drilled through the Ste. Genevieve, showing it has a thickness of 230 feet.

Above the Ste. Genevieve formation lies the Chester group, with a thickness of 300 to 500 feet in Lawrence County. Several sands are productive in this section. In the Cisne and Clay City areas the Chester is 1,000 feet thick, and sands in the basal portion are productive while sands of the upper

Chester carry salt water. The productive sands appear to be lenses and, although production may be spotted, they will add considerably to the total production of the area. These sands have not yet been tested sufficiently to make estimates of their possibilities. The Bradley sand in the Cisne area is at the base of the Chester, and the Weiler sand of the Clay City area is about 150 feet above the Bradley. These have not been correlated with sands in the old field but are referred to by operators as the Bradley and Weiler sands.

Study of the Chester section in wells so far drilled from Cisne to Noble shows very strikingly the marked unconformity at the base of the Pennsylvanian. In the Cisne area a nearly complete section of Chester is found while at Noble, some 18 miles north upper Chester beds are missing, having been eroded in pre-Pennsylvanian time. This same condition exists along the LaSalle anticline from Lawrence County northward.

The unconformity at the base of the Chester is not so apparent. There is a constant interval from any well defined limestone in the Chester to the top of the Ste. Genevieve indicating that no angular unconformity is evident. Above the Ste. Genevieve, however, there appears to be a weathered zone about 80 feet thick which suggests a widespread interval of erosion. Further drilling along the new structure will develop the details necessary to show the relations of the Ste. Genevieve to the overlying beds.

In sub-surface work done so far, the Chester has been divided into zones based on the content of micro-fossils (Pl. I). These zones conform fairly well with the subdivisions of the Chester established by Stuart Weller and published in his Hardin County report, Bulletin 41 of the Illinois Geological Survey.

The old fields produce from several shallow sands in the Pennsylvanian. So far the 2,000 feet of this formation drilled in the new area has shown only salt water in thick sand bodies. It is possible that productive sands similar to the old fields may be found on the north end of the structure in Richland and Jasper counties where the Pennsylvanian is not so thick.

DEEPER DRILLING

In Illinois and Indiana, production is found in rocks older than the St. Genevieve so that it is natural to speculate about the deeper possibilities in the new area. In western Indiana, oil is found in Devonian limestones and dolomites. In the old Illinois fields there is proruction in the Trenton. The St. Peter offers little possibility as it has not produced east of the Mississippi River. In a new area where a thick sedimentary section exists, there is always the possibility of unknown and unexpected producing horizons. It will require drilling to a depth of 7,000 feet to answer these questions.

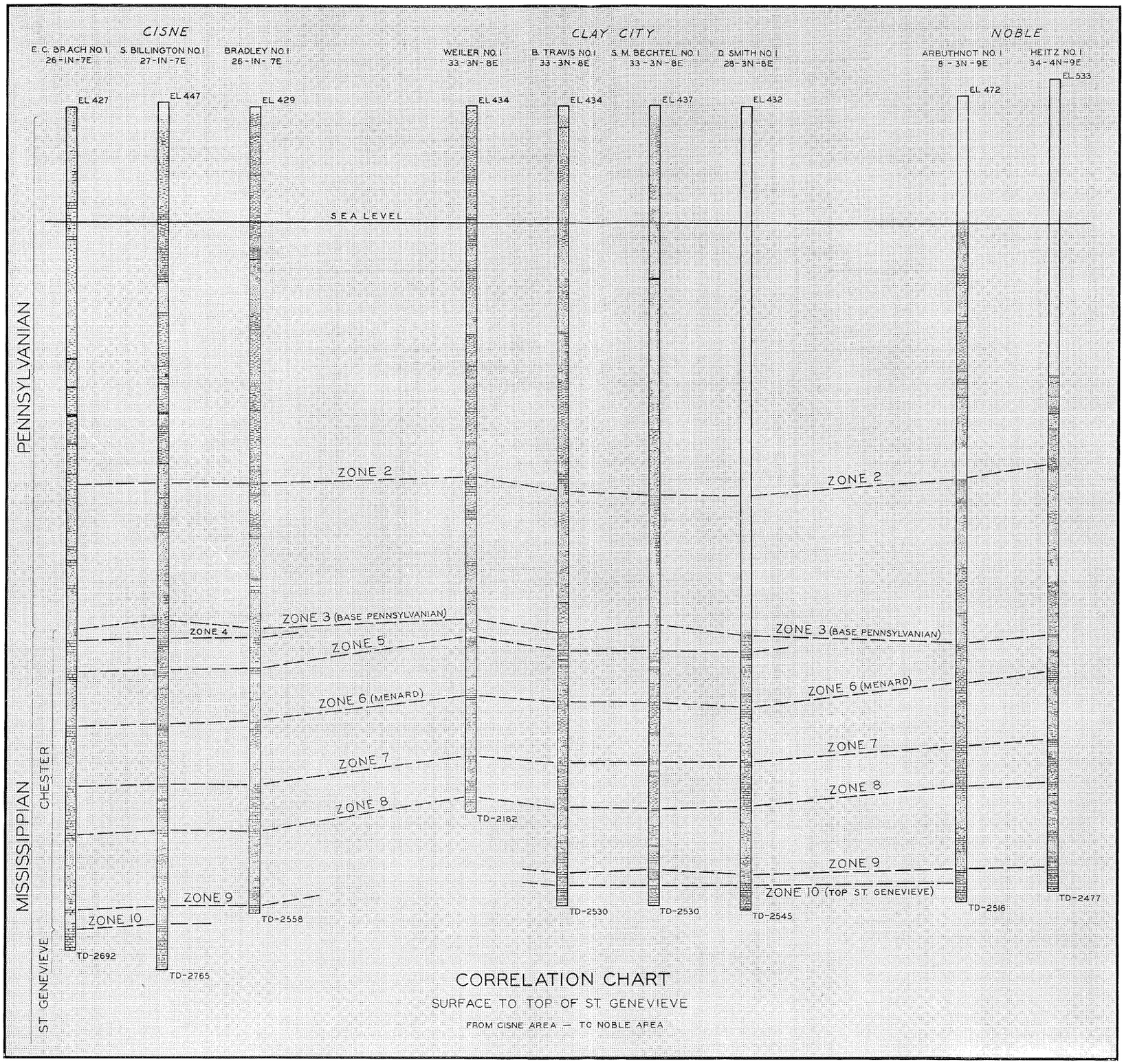

PLATE I.—Zones of the Chester formations (Upper Mississippian), based on their micro-fossil content.

THE WATER-FLOODING OF OIL SANDS*

By

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INTRODUCTION

The results that can be expected from the intentional flooding of partially depleted oil sands, and the methods that may be most advantageously employed to obtain the results desired have been brought to the attention of the oil industry in Illinois for several years. In 1932 Bell and Piersol published an excellent account of the water floods that were in operation in the State at that time.[1] The information in this paper was later supplemented by Dr. Bell in 1934.[2] Much data have been published on the extensive water-flooding operations in the Bradford and Allegany fields of northwestern Pennsylvania and southwestern New York, and more recently considerable attention has been devoted to and interest shown in the application of water-flooding for the purpose of increasing oil recovery in the shallow fields of southeastern Kansas and northeastern Oklahoma.

Notwithstanding the fact that only a very small percentage of our national oil production is derived from water-flooding operations, there is every reason for carefully considering the possibility of its more widespread application in the future. Under certain conditions, which will hereafter be thoroughly discussed, water-flooding is unquestionably the most efficient method for increasing oil recovery that has ever been devised. In fact it can be shown in quite a few instances that effective water-flooding operations will result in a larger oil production than has ever been obtained by natural methods of production. In addition, water-flooding holds forth many advantages over natural production, owing to the methods which have been developed to control the yield of oil as it may be desired by the operator, and to the rapidity with which increased oil production can be obtained. It is therefore most appropriate to emphasize at this point that due consideration to the possibility of water-flooding should be given to every new field. Cores of the producing formation should be taken and studied to ascertain whether the pay possesses characteristics which would be adaptable to successful water-flooding operations, and if it is found that favorable conditions do

* This paper has been published since the Conference in The Oil Weekly, vol. 87, nos. 12, 13; vol. 88, nos. 1, 2, 1937, from which the illustrations are used.

[1] Bell, Alfred H., and Piersol, R. J., Effects of water-flooding on oil production from the McClosky sand, Dennison Township, Lawrence County, Illinois: Illinois Geol. Survey, Press Bull. No. 22, June 18, 1937.

[2] Bell, Alfred H., Further data on natural water-flooding in Illinois oil fields: Illinois Geol. Survey, 1934.

exist, the drilling and operation of the field should be so planned and conducted that additional recovery can be obtained with little extra expense after natural oil production has declined to an uneconomic level.

In preparing this paper, the writer has had in mind the desirability of eliminating as much as possible an involved discussion of the more technical aspects of water-flooding. It is his purpose to set forth the results that have been obtained and the reasons why they have been obtained, and to point out conditions under which water-flooding may in the future find a much wider application.

In the beginning a definite differentiation should be made between a natural water flood, or as it is more frequently called "water encroachment," in an oil field, and intentional water-floods where the water is introduced into the oil sands by artificial means.

The problems of controlling natural water encroachment in oil fields have confronted the industry almost from its beginning. Premature invasions of water into the producing formations, either through faulty equipment or through a wasteful dissipation of the reservoir energy, have frequently been responsible for disastrous results, the water advancing rapidly through the more permeable parts of the pay and drowning out the wells, leaving much of the original oil content of the pay unaffected, and in most instances in a condition making it very difficult to recover at a later date. There are, however, many instances where the effects of normal water encroachment have been most beneficial to the ultimate recovery of oil. The great East Texas oil field is an outstanding example of this fact. Rapid water encroachment has been prevented by reduced oil production allowables, and the advance of the water, being controlled in proportion to the withdrawals of the oil from the reservoir, will undoubtedly add most materially to the total recovery that can be expected from the field.

The control of water encroachment in the East Texas oil field is relatively simple in comparison to the conditions found in many other oil fields. Where the structural relief of the field is not of sufficient magnitude to permit a complete original separation between oil-bearing and water-bearing pay along the flanks of the structure, many complications may arise in an attempt to utilize the flushing effect of the water moving through the reservoir as the oil is removed. Under such conditions, the upper part of the sand will generally be found to be oil-bearing whereas the lower part will carry water, and great care must be exercised in drilling the wells so that the lower water-bearing parts are not penetrated. Regardless of all of the precautions that may be taken, if the sand is to any extent a homogeneous body, the water will have a tendency to come upward into the well, necessitating the plugging back of the hole. This coning effect may be temporarily helpful, in that oil is floated upward into the hole, but its eventual

results are generally of no permanent value; for when the water-oil ratio becomes too high to permit profitable operation, the hole must be plugged back thereby trapping oil between well locations.

The benefits that may be attributed to or the damage that may be done by natural water encroachment will therefore depend entirely upon individual conditions in each field. Where the effects of water encroachment can be controlled, great benefits may be expected both from the conservation of reservoir energy, thereby prolonging the flowing life of the wells, and from the flushing action of the water as it moves through the sand. Where the encroachment of water cannot be controlled, every precaution should be taken to hold the water back from the oil-producing area by the plugging back of wells, by the artificial cementation of the more permeable lenses of the pay, or by building up the bottom-hole pressure of the reservoir by the artificial introduction of gas.

Strictly speaking, fields which produce entirely under hydraulic control may not be expected to react favorably to artificial water-flooding. Fields which begin to produce under volumetric control and then change to production under hydraulic control can generally be placed in the same category. But those fields which begin to produce under volumetric control and then change, due to the exhaustion of most of the original gas content of the reservoir, to capillary control may in great part be regarded as favorable prospects for artificial water-flooding.

HISTORY OF WATER-FLOODING

The intentional water-flooding of oil sands for increasing the recovery of petroleum is believed to have been first applied in the Bradford oil field, and in this field and in the nearby Allegany fields the technology of flooding has largely been developed to its present status. There is little specific information as to how intentional water-flooding originated. In fact its early history in the Bradford field is almost legendary. It is supposed that the first floods were accidental due to improperly abandoned holes allowing water to enter the sand. Regardless of the original means whereby flooding was started, it is known that it has been practiced for over forty years. For many years flooding was regarded by some of the operators as an iniquitous practice, and floods were therefore secretly developed. However, economic conditions in the fields required the adoption of some method for increasing oil production, since very few of the wells could be profitably produced under natural conditions, and water-floods were therefore openly commenced, notwithstanding legal restrictions then in effect. The advantages of water-flooding were finally brought to the attention of the Pennsylvania legislature after floods had been in operation for quite a few years, and in 1921 a special act was passed authorizing flooding in certain of the State's fields.[3]

[3] An Act of the Senate and House of Representatives of the Commonwealth of Pennsylvania entitled "An Act to Regulate the Drilling, Operating, and Abandoning of Oil and Gas Wells and Providing a Penalty for Violations of the Provisions of this Act", No. 322, Approved May 17, 1921.

The original effects of flooding were rather haphazard. Such wells as remained in the vicinity of the input well were affected, but no serious attempt could be made to control the rate and direction of water movement, since in many cases the source of the water was unknown. It was, however, soon discovered that in order to obtain full advantage of the initial water input well, it must be fairly well surrounded by producing wells. Old wells were utilized as far as possible, but ordinarily the original spacing used for natural production was too wide for efficient flooding operations so that it was necessary to drill at least a few new wells. The circle flood was thus developed, consisting of one water intake well surrounded by a group of producing oil wells in a more or less circular pattern. Although this method requires a minimum initial capital investment, its disadvantages soon became evident. The fact that one well could not supply a volume of water adequate to deplete the surrounding area within a reasonable period of time was apparent. Furthermore, since the flood circle is expanded by each successive ring of wells, the cost of development constantly increases. A quicker and more effective method was made necessary by the heavy investment required in drilling new circles of closely spaced wells, the high price of the land, and the necessity of protecting property lines. The line flood, consisting of producing wells staggered on both sides of an equally spaced line of water wells, met this need. This method, with various modifications, was rather generally adopted, and is still used in the Bradford field on some of the properties where development was inaugurated during the earlier periods of waterflood application.

Various methods of applying the line flood have been employed, the most general one being that of drilling a row of water intake wells across the property with a row of producing oil wells, drilled on a triangular pattern to the water intake wells, on each side. This method allows for approximately twice as many oil wells as water wells during the initial period of flood development, assuring a large oil production within a fairly short time, and a correspondingly rapid depletion. As the flood advances, additional rows of oil wells are drilled so that, in certain instances, as many as three rows of oil wells on each side of the water line are pumped at the same time. Where cooperative agreements can be made between adjoining property owners, it is customary to drill the first row of water intake wells along the boundary line, and thus reduce the initial investment to each operator. Under circumstances where such agreements cannot be made, and where the owner is desirous of completely encircling his property with an advancing flood, water intake wells are alternated with oil wells along the boundary line; when the latter are depleted they are converted into water intake wells, and the develop-

ment of the property then proceeds in the usual manner. The various forms of floods in common use in the Bradford field are illustrated in figure 7.

The successful application of the line flood was soon reflected in an increase in acreage values so that the intensive development of properties, consisting of drilling up the entire area of the lease according to some fixed geometric pattern, naturally resulted. Intensive development was first attempted in 1924, but the well spacing used was so wide that it did not give appreciable results. In 1927 an intensive flood was drilled in the northern part of the Bradford field, in which the wells were better spaced to conform to existing sand conditions. The satisfactory results obtained from this flood clearly indicated the possibilities of the method. Since then some form of intensive development has been almost universally adopted for all new operations.

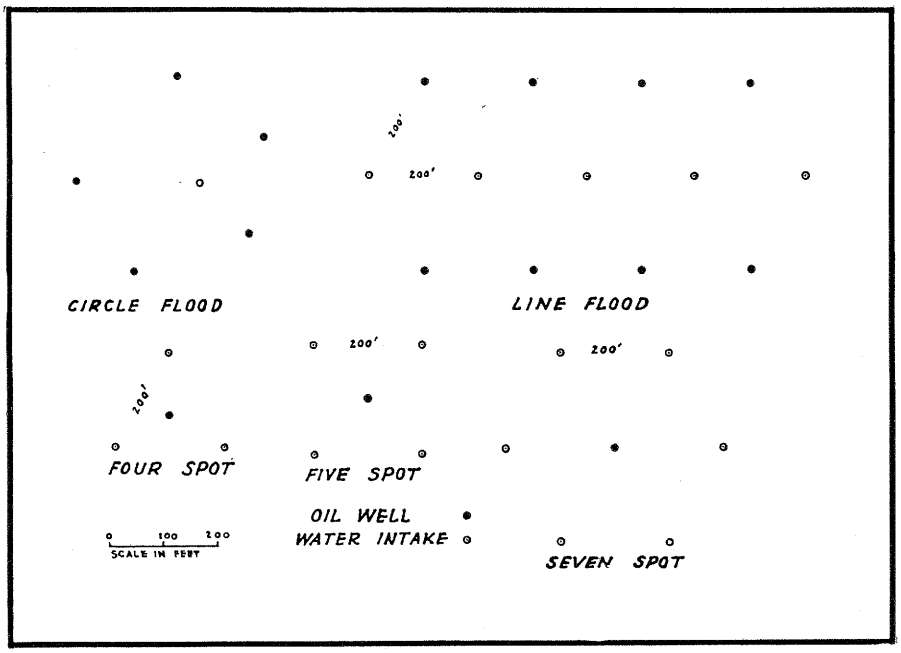

FIGURE 7.—Flooding patterns commonly employed in the Bradford field.

The advantages of an intensive development, the most common type used being the five-spot, over the line flood or other less systematic methods of flooding are: (1) concentration of development and operations in one area which results in a material reduction in operating expense; (2) rapid depletion, which further reduces operating costs and interest charges, and also provides a rapid return of invested capital; and (3) a more efficient flooding of the sand with a consequent increase in oil recovery.

Land values in the Bradford and Allegany fields naturally increased as the technology of water-flooding was improved, and this increase in valuation has led to rather extensive exploration throughout the Pennsylvania grade area for other fields which might respond to the same methods for increasing oil recovery. To date there are several experimental floods in operation outside of the Bradford field in western Pennsylvania. None of these floods has reached a sufficiently advanced stage to indicate how successful they will be, but it is believed that the application of water-flooding in Pennsylvania will not be limited to the Bradford area alone.

According to the information presented by Dr. Bell (previous citation), the floods in operation in the oil fields of Illinois have largely resulted from the utilization of natural water encroachment. These floods have yielded sufficient oil to indicate that intentional water-flooding might be satisfactorily applied in several areas of the State. Dr. Bell's contention that systematic coring of the sands to determine their lithology and oil content is very well taken, and in fact this procedure is absolutely essential to appraise fairly the flooding possibilities of any field regardless of its location.

After the results that could be obtained from water-flooding in the Bradford field became rather generally known, sporadic efforts to flood the Bartlesville sand in northeastern Oklahoma were attempted. These earlier floods were commenced with little regard to geologic conditions, and considering the poor planning and even poorer operation, it is amazing how much oil has been recovered from them. They showed conclusively that the Bartlesville sand was floodable, and by so doing they served a useful purpose in pointing the way to more systematic development along the lines that have been established in the Bradford field. At the present time, there are several active floods in operation in northeastern Oklahoma and southeastern Kansas, and it is very reasonable to believe that in the future the application of water-flooding in this region will be greatly expanded.

Little attention has been paid to intentional water-flooding in Texas due, of course, to the large natural production of that State. There are, however, a few fields in north-central Texas which should respond to water-flooding operations. During 1936 the Texas Railroad Commission granted a few permits for experimental floods, but insofar as the writer knows, nothing of a constructive nature has been established.

GEOLOGIC FACTORS AFFECTING SUCCESSFUL WATER-FLOODING

STRUCTURE OF FIELD

A knowledge of the geologic structure of an oil field in which intentional water-flooding is contemplated may be regarded as being most essential. In the Bradford field, the accumulation of oil has been controlled by a large

anticlinal fold,[4] but the major structural dip is so low, insofar as individual properties are concerned, that it has had very little effect upon flood water movement. However, in a few areas where the dip of the strata is over one degree, is has been found most advantageous to flood up the dip. Flooding down the dip is contrary to the natural association of oil and water, and it has been definitely established, both in the Bradford field and in northeastern Oklahoma, that flooding down dip results in very rapid water migration, and therefore is responsible for the by-passing of considerable quantities of oil.

From the information so far established on the effects of structure on flood movement, it would seem most desirable to commence new water floods along the lower flanks of the structures controlling oil accumulation. This would be of particular importance in fields where some natural water encroachment is already active. In the writer's mind, the ideal situation for flooding a field located on a fairly well-defined fold, and in which sand conditions are favorable, would be a cooperative development among all of the operators,—providing the field is owned by diverse interests,—in which the water would be simultaneously introduced into the sand through a line of intake wells which would correspond and be parallel to the lowest contour that limits the oil production of the field. Further to insure a fair return to all of the operators involved, it would be most desirable to unitize the entire field, and the writer believes that this type of development will be more closely followed in the future than it has in the past. So much has been written regarding the benefits of unit operation in new fields that it is certainly not necessary to repeat them, but it can be stated most definitely that all of the advantages that can be expected from unit operation in a new field could be anticipated in any form of reworking operation, and particularly in connection with water-flooding.

In fields where the producing formation is relatively level, and accumulation of oil has been limited by changes in the lithology of the pay, waterfloods may be established to suit the convenience of each operator. Where accumulations of oil occur along monoclinal slopes, and the dip of the pay is more than one degree, it is believed that the most satisfactory results can be obtained by commencing flooding operations in the lowest structural part of the field and flooding up dip. Flooding up dip in certain of the smaller fields of Allegany County, New York, has been eminently satisfactory, and has amply repaid the operators for the care that they have exercised in selecting the location for their initial developments.

CONTINUITY OF SAND AND SAND LENSES

The most successful results that can be realized from water-flooding operations will naturally be obtained where the producing formation is a

[4] Newby, Jerry B., Torrey, Paul D., Fettke, Charles R., and Panyity, L. S., Bradford Oil Field, McKean County, Pennsylvania, and Cattaraugus County, New York: Am. Assoc. Petroleum Geologists, Structure of Typical American Oil Fields, Vol. 2, pp. 407-442, 1929.

continuous and uniform body. An ideal condition would, of course, be a massive, sheet sand formation with homogeneous porosity and permeability both vertically and horizontally, and with uniform pay thickness. Variations in physical characteristics of the producing formation from well location to location must be generally expected, owing to the lack of uniformity of sedimentary conditions, and since most sands were not deposited upon a level basement, irregularities in thickness frequently occur at the bottom of the sand and to a lesser extent at the top. Furthermore, oil sands generally do not thin out as a smooth wall, but rather they break up into lenses and tongues which sometimes do not extend to adjacent wells even under the close well spacing conditions required in ordinary practice. If the porosity and saturation of the sand is fairly uniform, there is obviously more oil present in thicker parts of the sand than in the thinner parts, and such being the case, and if it is at all feasible, it is most desirable to flood from thin sand sections to thick sand sections. The reason for this is that it is most illogical to push oil away from a thick sand section where it may be easily recovered, to a thinner or lenticular section where the oil may be trapped by shale breaks or by lensing out of certain members of the sand body.

It is, of course, impossible to plan or change flooding operations to conform to sand variations under every condition, but if a study of the records of the old wells from a field reveal irregularities in the sand body, it would be most advisable to attempt to plan the well location pattern to conform as closely as possible to conditions as they are found to exist.

PRESENCE OF WATER IN THE PRODUCING FORMATION

The presence of appreciable quantities of water in the producing formation may be regarded as being most unfavorable for successful waterflooding, since the water present cannot help but reduce the amount of oil available in the sand. However, the fact that wells in a field are making water along with the oil should not prevent a careful investigation of the flooding possibilities of a field since it may be found that the water is coming from a source that may be eliminated. If the water occurs in the bottom of the sand, the water-bearing part may be separated from the oil-bearing part by a definite break, and such being the case, the plugging back of the wells to the bottom of the oil pay will prevent the water from coming into the holes. Furthermore, it will frequently be found that only parts of the field, and this is usually the lower structural areas, have been affected by natural water encroachment. Under such conditions the introduction of water into the sand under proper control may accelerate flooding action in the areas already affected by water, and at the same time provide a much more effective depletion of the unaffected areas.

It should, however, be pointed out that attempts to flood artificially fields in which the producing formation carries any appreciable quantity of water have not proved to be very satisfactory, and unless rather unusual conditions exist in the field, water-flooding could not be recommended.

GAS PAYS AND GAS CONTENT OF THE SAND

In many fields where accumulation is controlled by anticlinal structure, the sands on the higher parts of the structure are completely or partially filled with gas. The Bradford field is an excellent example of accumulation of this type. In the highest parts of the structure, the sand was originally largely gas-bearing with a relatively thin oil pay in the lower part. Going down dip, the amount of gas pay in the sand decreases and the amount of oil pay increases.

Flooding experience in the Bradford field soon indicated that it was very necessary to pack off the gas pay in the water intake wells, since this pay had been largely depleted of its original gas content over the many years of productive life of the field, leaving an open medium which offered very little resistance to water movement. In intake wells where the gas pay was not packed off, the water would migrate very rapidly through the gas pay, leaving the oil pay practically unaffected. Similar results have been obtained in certain of the floods in the Bartlesville sand of northeastern Oklahoma. It therefore, can be stated definitely that no flood can be successfully operated where such conditions exist without packing off or cementing any gas pays that may be present.

Even in very old fields, it is generally possible to obtain some idea of the original gas-oil ratio. If the gas-oil ratio was unusually high, it would be natural to regard the field, insofar as its flooding possibilities are concerned, with some suspicion. However, much of the gas produced may have come out of solution from the oil, and in that event the deciding factor in determining whether the field is a desirable prospect for water-flooding can only be definitely ascertained by saturation tests of cores taken from the sand. It may, of course, be concluded that any free gas present in the sand will reduce the volume of oil originally present and will have a decided effect on the volume of oil left after a long period of natural production. Gas that may have been produced out of solution from the oil would not have such a harmful effect, and as it will later be shown, the compression of gas in the sand in advance of the migrating water from the intake wells is of material assistance in moving the oil into the producing wells.

QUALITY OF OIL

Had it not been for the excellent qualities of Bradford crude, the field probably would have been abandoned in the period prior to the general inauguration of water-flooding. The oil ordinarily commands a premium over

other grades of Pennsylvania grade crude. An operator considering the water-flooding of a previously untested field would naturally be certain of the refining desirability of the crude that he anticipates producing. If the oil does not have a ready market, it obviously would be an unsound investment to drill the additional wells and install the other necessary equipment required for efficient water-flooding operations. Even if the crude produced fulfills all of the requirements of a most particular refiner, a careful investigation of certain of its physical properties should be made to determine whether it will respond favorably to flooding action. The two main factors in this connection are the viscosity of the crude and its tendency to emulsify.

It just so happens that the viscosity of Bradford crude is not too high to affect materially efficient flooding action. In consequence little attention was paid to this property of the oil in connection with the earlier flooding operations. In more recent years, however, when attempts have been made to flood other fields, it has been found that crudes that possess a much higher viscosity than Bradford crude do not respond to flooding action in the manner expected, notwithstanding the fact that other conditions in the sand body might be regarded as being quite favorable for flooding operations. Oils of high viscosity naturally are more resistant to displacement by water drive, and particularly in fields where the sand possesses high permeability, the water may break through the pore spaces leaving the crude adhering to the individual sand grains. From both practical operating experience and laboratory investigations, it has been established that oils possessing a Saybolt Universal viscosity of 35 to 40 seconds at 100 degrees are best adapted to water-flooding purposes. It is very unlikely that an oil possessing a Saybolt Universal viscosity of more than 40 seconds at 100 degrees would flood as efficiently as a less viscous crude.

The tendency of the crude to emulsify should be thoroughly established in the investigations of the water-flooding possibilities of any field. The crude produced in the Bradford field is very stable and does not even form a temporary emulsion when water is introduced into the sand, but it has been found in other fields of western Pennsylvania that water-flooding will be responsible for permanent emulsions which require chemical or electrolytic treatment to break down. The formation of temporary emulsions is not a very serious problem, since the oil can usually be freed from the water by moderate heating, which is universally required by the pipe lines in cold weather to provide a free flow of fluid into their gathering lines. The formation of permanent emulsions is an entirely different problem. These will require special treatment, and if it is found that such treatments will be required, a careful investigation of the costs should be made before starting a flood, since the margin of profit which might otherwise be expected may be required to condition the oil so that it will be acceptable to the pipe line company and the refiner.

PHYSICAL AND LITHOLOGIC CHARACTERISTICS OF THE OIL PRODUCING FORMATION

POROSITY AND OIL CONTENT

The porosity of an oil sand is a most important factor in the ultimate success of a water-flooding operation, for the porosity of the sand determines its capacity to hold oil. The percentage of the pore spaces filled with oil is of equal importance, for it is obvious that under similar lithologic conditions a sand containing a large oil content will yield much better results than one containing a low oil content. Water-flooding under pressures greater than the normal hydrostatic pressure has been fairly successful in sands possessing an average porosity of as low as 7 per cent, but the best results have been obtained from somewhat higher porosities. The average porosity of the Bradford sand is approximately 11.5 per cent, although some samples have possessed a porosity of from 25 to 28 per cent.

The average oil saturation of the Bradford sand, based upon many laboratory analyses using the retort method of determination is about 40 per cent. The oil saturation normally increases going down the dip from the highly gas-saturated parts of the structure, and it is also considerably higher on properties which were developed under natural conditions of production on a wide well spacing pattern. From a multitude of correlations between oil content of the sand and actual oil recovery, it has been established that about 40 per cent of the total oil content of the sand is recoverable by water-flooding. The most efficient floods in uniform sands will probably recover around 50 per cent of the oil content of the sand. Assuming conditions in other fields analagous to Bradford, an oil content of 15,000 barrels per acre should result in an average recovery of 6,000 barrels per acre by water-flooding, and under unusual circumstances of exceptionally uniform sand conditions and efficient operations, a recovery of as high as 7,500 barrels per acre may be realized.

The porosity and saturation of oil sands can be determined only by core analyses, and as Dr. Bell has properly pointed out, the only logical way to ascertain these necessary facts is by systematic coring. Dr. Bell's recommendation is heartily approved and emphasized by the writer. In many instances with which the writer is intimately familiar, the results from water-flooding operations could have been greatly improved, by an accurate knowledge of sand conditions, and many times floods which have resulted in failure could have been made into profitable enterprises if the operator had been aware of the conditions confronting him.

PERMEABILITY

The permeability of an oil sand may be defined as its capacity for penetration by gases or liquids. Permeability depends upon the porosity and

degree of interconnection of the pore spaces in the sand, the size and shape of the pore spaces, and to a lesser extent upon the type of cementing material and the oil saturation. A determination of the permeability of the sand is most essential for successful water-flooding operations, since upon it must be based the most desirable well spacing and the most advantageous water pressure that may be used for development.

The size and shape of the pore spaces in the sand are dependent upon the size of the individual sand grains and the amount of cementing material between them. It has been found in the Bradford field that an average grain-size of less than 0.2 mm in diameter generally yields the best results in water-flooding. The Bradford sand is made up of quartz grains with small amounts of feldspar, mica, and considerable chert-like material. The grains are angular and interlocking. The interstitial material is brown micaceous clay.

The average grain size of the Bartlesville sand on certain properties in northeastern Oklahoma that are being successfully flooded is somewhat larger than that of the Bradford sand, ranging to as high as 0.5 mm in diameter. This larger grain size usually results in a higher permeability of the sand, which must be taken into account in selecting the proper well spacing and water pressure for a new flooding operation.

The most satisfactory results from water-flooding in the Bradford field have been obtained where the sand has a uniform permeability of from 5 to 10 millidarcys. It should be noted, however, that there are great variations in average permeability throughout the field, as well as wide variations in individual sand sections. Profitable flooding operations have been carried on in localities where the average permeability is little more than one millidarcy, but under such conditions a relatively close well spacing and high water pressure are required. It should also be brought out that sands having a permeability of as high as 200 millidarcys are also being flooded, and it is impossible to state at this time what the upper limits of permeability will be that will preclude satisfactory flooding action. If the sand body is fairly uniform and possesses a good oil saturation, there seems to be no good reason why sands of high permeability may not be effectively flooded by proper well spacing and careful control of water input into the intake wells. Here again, the only way an operator can be sure of the best procedure is to core his property systematically, and upon the basis of the results of core analyses determine the best methods to employ. Naturally wide variations in permeability in the sand section will require special operating methods to force a uniform movement of the water through the sand. Fortunately, methods have been developed to take care of situations of this type; these will be described in a following part of this paper.

CEMENTING MATERIAL

From laboratory experiments Uren and Fahmy[5] have discovered that the kind of cementing material or sand grain coating has a marked effect upon the recovery of oil by flooding. The results of their experiments have indicated that sand grains coated with silica are much better adapted for water-flooding purposes than those coated with lime or iron oxide. These experiments should be thoroughly considered before attempting to water-flood a new field, since they give very useful criteria for the determination of the adaptability of oil sands to water-flooding.

THEORETICAL CONSIDERATIONS

The actual mechanics of water-flooding have been thoroughly discussed by Wycoff, Botset, and Muskat,[6] and by Wilde.[7] Little can be added to the facts they have presented, and the writer has only in mind setting forth in this paper a few data relating to the action of the water as it moves through the sand which are derived from actual field experience.

It has been previously mentioned that water-flooding has been most successful in fine-grained sands which possess pore-spaces of capillary size, and such being the case, it may be assumed that capillary action is an important factor in the displacement of the oil held in the interstices of the sand and adhering as a film to the sand grains. Water-flooding may therefore be regarded as a combination of capillary and hydraulic action, the capillary effect acting as the displacing agent, and the hydraulic effect providing the motivating agent which accumulates the oil and pushes it toward the producing well.

After a field has experienced a long period of natural production, the pore-spaces of the sand are not entirely filled with oil. The sand grains are coated with a film of oil of varying thickness, and the main part of the pore occupied by a bubble of gas. The minute interconnections between the main pore-spaces may be compared to conical tubes. In a conical tube a drop of oil will be concave outward at both ends, but since the smaller surface has the smaller radius of curvature, it will exert the greater pressure against the gas and the drop will move to the smaller end of the tube (fig. 8). In figure 9 the position of a drop of oil moving through the pore-spaces of a sand by water-flooding action is indicated. As the water under pressure enters the pore-space of the sand, the drop of oil which has moved by capillary action to position 1 moves to position 2. Upon reaching position 2, the

[5] Uren, L. C., and Fahmy, E. H., Factors influencing the recovery of petroleum from unconsolidated sands by water-flooding; Am. Inst. Min. Met. Eng., Trans., vol. 77, pp. 318- , 1929.

[6] Wycoff, R. D., Botset, H. G., and Muskat, M., The mechanics of porous flow applied to water-flooding problems: Am. Inst. Min. Met. Eng., Trans., vol. 103, pp. 236-237, 1933.

[7] Wilde, H. D., jr., The value of gas conservation and efficient use of a natural-drive as demonstrated by laboratory models: Am. Petroleum Inst., Production Bull. 210, pp. 4-10, 1932.

conical tube effect previously mentioned pulls the drop to position 3. This process is repeated time and time again, each drop of oil as it moves through the sand being separated from other drops by bubbles of gas. As more oil is picked up and pushed ahead by the advancing water, the pressure naturally increases, resulting in the solution of the gas bubbles in the oil. As the oil drops converge due to the solution of the gas, the pore-spaces become more entirely saturated with fluid, and the flood then moves forward to the producing wells under direct hydraulic control.

FIGURE 8.—Drop of oil in a conical tube of variable diameter.

It can be readily appreciated that in a coarse-grained sand a capillary movement of the oil bubbles is impossible. Even if a drop of oil advanced to position 2 in the sand as illustrated in figure 9, it would be so elongated that any application of pressure would break it back to a film adhering to the sand grains rather than moving it ahead to the next inter-connection. Such being the case, the water would tend to drive on through the open pore spaces leaving much of the oil unaffected. Such action is undoubtedly responsible for the lack of success that has been experienced in attempts to water-flood conglomeratic sands.

DEVELOPMENT OF WATER-FLOOD PROPERTIES

PATTERNS FOR WELL LOCATIONS

Various geometric patterns have been used in the intensive development of water-flood properties. (See fig. 7). The most common pattern is rectangular (the five-spot), with an oil well located in the center of a square formed by four water intake wells. This pattern is, in reality, nothing more than a continuous series of line floods, and it was therefore the natural change from the system of flooding most widely in use prior to the more general introduction of intensive development of properties. Its use, in the Bradford and Allegany fields, has been almost universal, owing to the ease with which it is fitted into property boundaries and the manner in which the distance between the wells can be varied to conform to changing conditions in the sand body.

A triangular pattern (the four-spot) has been used on a few properties. In this system an oil well is located at the center of an equilateral triangle formed by three water intake wells at the corners. It is claimed by the operators using this pattern that it will add materially to the effectiveness

of the flood, but comparative data based upon actual operating results, are not available to the writer. From a theoretical standpoint, it is somewhat questionable whether the possible increase in anticipated recovery will be sufficient to warrant the additional expense required in the development of a property on the "four-spot" plan. The triangular pattern alone is very difficult to fit into property lines, but on properties possessing irregular dimensions, it may sometimes be used to advantage in connection with a main development using a rectangular pattern.

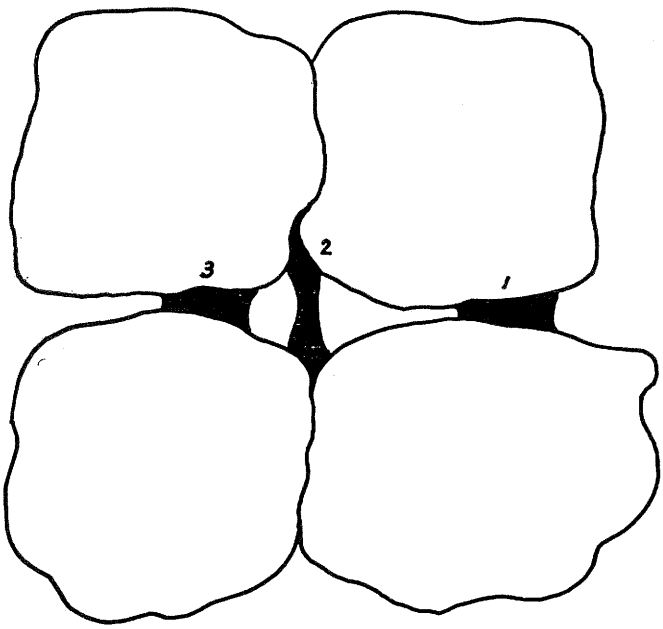

FIGURE 9.—Drops of oil moving through the pore-spaces of a sand by water-flooding action.

Some intensive floods in the Bradford field have been drilled according to a hexagonal pattern (the seven-spot), with an oil well drilled in the center of a hexagon formed by six water intake wells at the corners. The hexagon possesses some very distinct merits, for it is the polygon with the largest number of sides that will fit into a continuous pattern. A hexagonal arrangement of water intake wells will undoubtedly increase the efficiency of a flood, in that the oil well will be more effectively surrounded by advancing banks of water, and the danger of trapping oil between the intake wells will be diminished. The reduction in development cost by the use of a hexagonal pattern will be considerable except where a large number of offset wells must be drilled along the property lines.

In comparing these three patterns, it will be evident that in the four-spot each water well affects six oil wells; in the five-spot each water well affects four oil wells; and, in the seven-spot each water well affects three oil wells. Assuming a constant distance of 200 feet between water intake wells for each pattern, at the time the water has advanced 100 feet away from each intake well and has at this point met the water coming from the opposite intake well, in the four-spot it will be approximately 15 feet away from the oil well; in the five-spot it will be approximately 41 feet from the oil well; and, in the seven-spot it will be approximately 100 feet from the oil well. The danger of by-passing will therefore be greatly reduced in the hexagonal flood, for when the water in any one bed of the sand meets half-way between the intake wells it still has a considerable distance to go before it comes to the oil well, whereas in the triangular pattern when the water meets between the intake wells it has at the same time almost reached the oil well which will then shortly thereafter have to be abandoned on account of the rapid encroachment of water.

Assuming again the same distance of 200 feet between water intake wells, each water intake must flood out 103,800 square feet in the four-spot, 40,000 square feet in the five-spot, and 51,900 square feet in the seven-spot. From this standpoint the relative efficiencies of the five-spot and seven-spot are fairly close, but the four-spot is apparently far less desirable, for if the input of water into each intake well for the three different patterns is constant, it will take a much longer time to deplete the flood-area drilled according to the four-spot pattern.

WELL SPACING

Probably the most important factor determining the ultimate profits that may be expected from a water-flooding operation is the selection of a well spacing pattern designed to conform best with the characteristics of the sand body underlying the property. There are many factors that determine the ideal spacing pattern for a property or an area, but in general it can be stated that the spacing of wells should be so planned that the ultimate recovery can be obtained with a low development cost within a reasonable period of time. Some of these factors have been previously mentioned and discussed such as: geometric patterns, sand porosity and permeability, per cent saturation, and total oil content of the sand. In addition to these factors, the water pressure applied to the sand and the cost of development must be included.

The oil content of the sand should be the object of primary interest in the investigation of the water-flooding possibilities of an untested field. Consideration must, of course, be given to the price paid for the oil and the certainty of markets for an increased production. Owing to the higher posted

price paid for Pennsylvania grade crude over that paid for mid-Continent grades, a property in the Pennsylvania grade area may be profitably operated on a much lower oil content and oil recovery than properties in Oklahoma or Kansas, if development costs are approximately equal. In addition, the valuation of the land must be taken into account. High priced acreage will not only have to produce enough oil to pay for the development cost and operating expense, but it will also have to return the purchase price, and a reasonable profit on the entire investment. Eliminating the factor of acreage valuation, it can be stated that in the Bradford field the lowest minimum recovery that could be expected to yield a profit would be from 3,000 to 3,500 barrels per acre, the variation in required recovery being based upon differences in drilling depth throughout the field. To this recovery figure must always be added the amount of oil necessary to carry the cost of the property.

Following this line of thought, and assuming approximately equal development costs, water-flooding in areas of the mid-Continent region where the sand will not produce a recovery of from 6,000 to 7,000 barrels per acre would be regarded as being a rather hazardous enterprise. In this connection it should be noted that development costs in certain of the shallow fields of northeastern Oklahoma are actually less than one-third of the average cost in the Bradford field, which will therefore permit a profitable development of properties where the sand will yield a recovery of much less than 6,000 barrels per acre. It should, however, be kept in mind that the well spacing, which is responsible for the greatest part of the development cost, may be adjusted to correspond to the oil content and estimated recovery from the sand, taking into account, of course, that the permeability of the sand is sufficiently high to justify a wide well spacing pattern. In thick sand areas carrying a high oil content, the wells may be spaced closer than in thin sand areas carrying a low oil content. The quicker return from more closely spaced wells in thick sand areas may fully justify the additional expenditures required for development.

The selection of a geometric pattern for the well locations will depend largely upon the size and shape of the property. On large properties the hexagonal pattern is favored over the triangle or rectangle for reasons previously presented.

Of all of the factors which must be considered in the selection of the proper well spacing for a property, the average permeability of the sand is probably of the greatest importance. In tight sand areas, a closer spacing must be used than in looser sand areas to recover the same amount of oil within equal time periods. It is possible that the experience obtained from flooding operations in the Bradford field may not be exactly applicable to other areas, but the curve given in figure 10 does represent the relation between well spacing and average sand permeability which has given satisfactory

results at Bradford. There are, of course, reasonable limits beyond which this curve cannot be applied. It is presented in order to show the great importance of taking into consideration the permeability of the sand in planning the well-spacing to be used in a flooding operation, and not as a fixed formula that might be applied in any other area. It is believed, however, that some such relationship will be found in every field that is otherwise adapted to water-flooding operations.

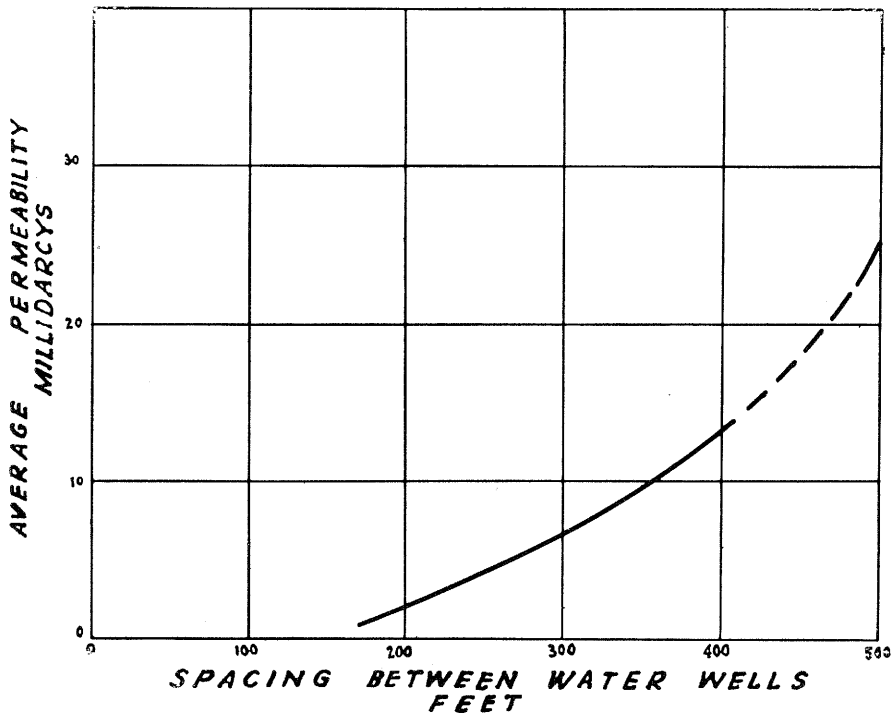

FIGURE 10.—Relationship between average sand permeability and spacing between water wells which has given satisfactory results from water-flooding in the Bradford field.

The modern system of water-flooding involves the use of water under a predetermined presure which will most effectively deplete the sand within the desired time limit. Increased water pressures may be used in areas where the sand possesses low permeability and thereby enable the use of a wider well-spacing pattern than could be used if only the normal hydrostatic pressure was employed. Increasing the pressure does not increase the water input proportionately as will be seen from figure 11, but it does expedite flooding action during its earlier life by further compressing the gas that remains in the sand, and during the later life of the flood by providing somewhat faster fluid movement.

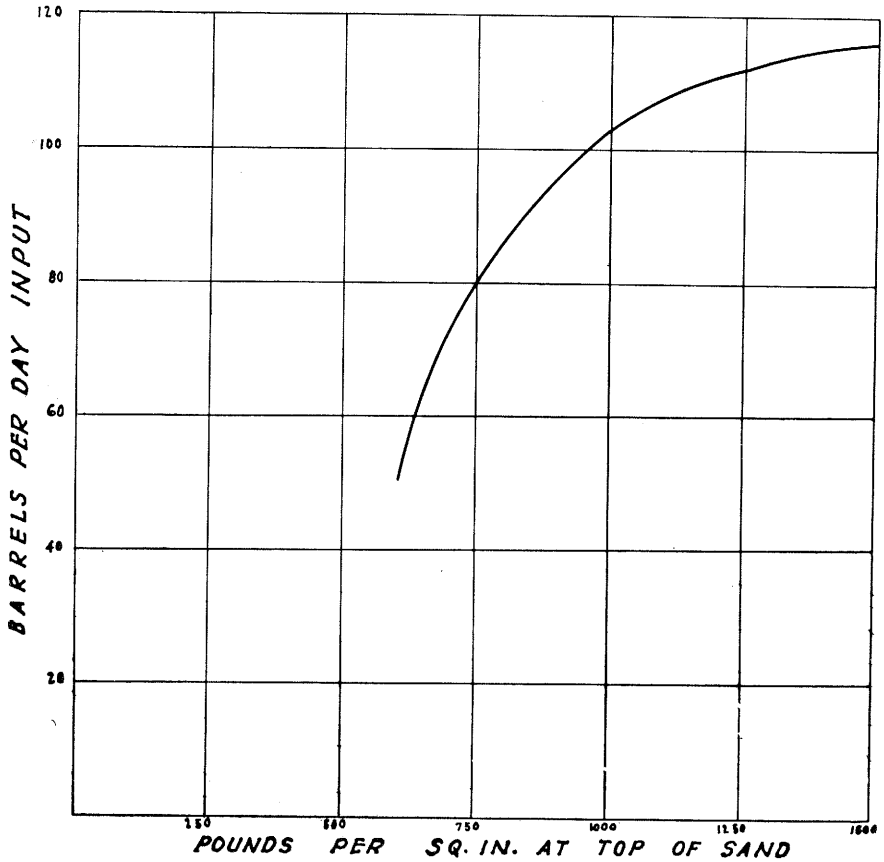

FIGURE 11.—Relationship of pressure at the top of the sand to water input for Bradford sand possessing a thickness of 23 feet, an average porosity of 10.95 per cent, and average permeability of 4 millidarcys.

The cost of development of a water-flooding project must be taken into account in the same manner as the property cost or valuation. Development costs are not only dependent upon the well spacing but they are also directly proportional to the drilling depth. There are partially depleted fields in West Virginia at the present time producing from the Berea sand, which would undoubtedly respond favorably to water-flooding. However, the drilling depth is approximately twice the drilling depth in the Bradford field, which has delayed development up to the present time. With the assurance of a better crude price, these fields will undoubtedly be flooded. The shallow depth of the Bartlesville sand in northeastern Oklahoma and southeastern Kansas has made possible the profitable development of water-flooding operations in these areas, notwithstanding the lower price paid for the crude.

The time required to deplete a five-spot or any other type of intensive flood can be predetermined with reasonable accuracy to meet the requirements of the operator, by varying the dimensions of the spacing pattern. A close spacing with normal water pressure will give rapid results, and is frequently used where it is desired to make a rapid return of the capital invested in land and development, or to build up a large production for the purpose of property sale. A wide spacing pattern possesses the material advantage of lowering the cost of development, and the longer productive life of widely spaced floods permits a better opportunity for obtaining an average price for the oil produced. In the Bradford field, where sand conditions permit, there has been a gradual but definite trend toward wider spacing patterns. In figure 12 the production of typical wells from five-spot floods of different spacing is given. Most intensive floods in the Bradford field have been so spaced that the property will be depleted within an operating period of five to six years.

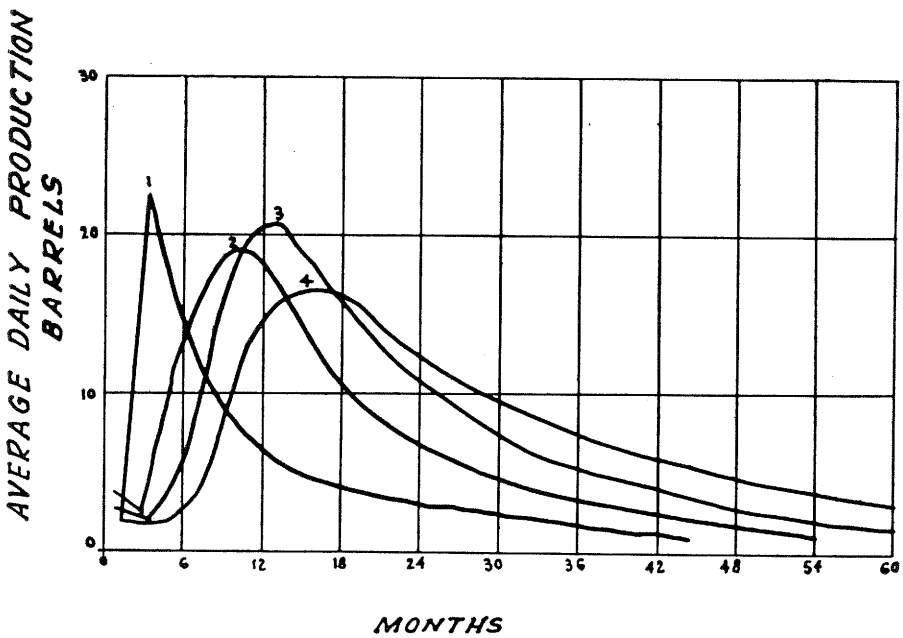

FIGURE 12.—Oil production curves from five-spot flood wells of varying spacing pattern. In curve No. 1 the water intake wells are spaced 180 feet apart; curve No. 2, 250 feet apart; curve No. 3, 300 feet apart; and curve No. 4, 350 feet apart.

WATER SUPPLY

The requirements of a satisfactory water for flooding operations may be briefly stated: the water must be in ample quantity, and must not cause plugging up or choking of the oil pay. The water used is primarily responsible

for the results obtained from water-flooding, and it is therefore very evident that the quality of the water has a most important bearing upon the effectiveness of the flood. It can be shown in many instances, both in the Bradford field and in northeastern Oklahoma, that the failure of water floods to produce the amount of oil anticipated is directly attributable to the poor quality of water used. The necessity for an adequate supply of pure water should therefore be very evident, particularly when it is realized that the water requirements for an intensive flood are sometimes in excess of the rainfall over the operated area.

During the earlier period of flooding operations in the Bradford field, the water was introduced into the sand by merely cutting the surface ceasing in the intake wells and allowing the water to flow down the hole to the top of the sand. Upon the more general adoption of intensive methods of development this method was soon discarded for the reasons that the water coming from the surface rocks tended to carry mud and silt with it, thereby plugging the sand; because it was found that in many cases the volume of water available was not sufficient for efficient flooding operations; and because it was found in many cases to be most advantageous to apply additional pressure, over and above the normal hydrostatic pressure, to the sand. It was soon realized that the ground water supplies in many parts of the field were not adequate to maintain large scale flooding operations, and the supply has therefore been supplemented by a trunk water pipe line system originating in the nearby Allegheny Valley.

Appreciating that there is not enough ground water available for flooding operations in the Bradford field, which is located in a region which has an average annual rainfall of about 45 inches, it can be readily realized how important it will be to establish ample water resources for contemplated water-flooding operations in fields located in more arid regions. In many parts of the mid-Continent region, river water appears to be the only source of supply, but the use of river water will in most instances require the construction of large settling reservoirs to permit the removal of most of the suspended matter and the use of water-treating plants. It has also been suggested that salt water might be used for flooding purposes. This is a possibility, but great care must be used in the introduction of salt water into an oil sand for most oil sands carry certain amounts of precipitated mineral salts which will go into solution with the water introduced up to the limits of their individual solubility product constants. A saturated solution might therefore likely be formed which would tend to lose part of its carried burden of mineral salts by the evaporative effect of expanding gas as the water comes into the producing wells, resulting in the precipitation of a coating of salts on the face of the sand. This action has been known to take place in the eastern fields, and it requires costly periodic cleaning out of the wells in order to maintain production.

Any water purification for flooding purposes involves the removal from the raw water of any substance or property which would tend to make it plug the sand and so impede the constant flow of water. Most ground waters carry a small amount of suspended matter and varying amounts of soluble iron and other mineral salts. Under the old system of water-flooding, where the water did not come in contact with the atmosphere, plugging action by chemical precipitation probably was not a very serious problem. However, with the adoption of intensive methods of development, resulting in a correspondent increased demand for water, the old system of subsurface type floods had to be abandoned, and the water required for flooding purposes obtained either from shallow wells on the property, or, if sufficient ground water was not available, from some outside source.

Although this method of handling the water problem insures an adequate supply to each intake well, it has the great disadvantage that any soluble ferrous salts present in the water are oxidized to insoluble ferric salts when the water is flowed from wells by compressed air. The formation of these insoluble gelatinous compounds plugged the sand in many wells in the Bradford field and it soon became evident that they must be removed. This is accomplished by the use of a high pressure, vertical type sand filter.

However, the filter alone does not solve the problem of sand plugging inasmuch as the water produced from wells by flowing with compressed air, even after leaving the filter, is essentially saturated with carbon dioxide and oxygen. It will, therefore, react with the steel tubing of the pipe line between the pumping station and the intake wells to form more insoluble iron compounds which are practically the same as those formed from the soluble salts in the raw water. For this reason the flowing of water from wells is being discontinued and turbine pumps installed for lifting the water, rather than compressors. By this method the water is not aerated and consequently does not corrode the pipe lines to any appreciable extent. Where compressors are still used for flowing water, it is very desirable to deposit a thin film of calcium carbonate on the inside of the pipe by the introduction of small quantities of quick lime into the water after it has left the filter, thereby artifically increasing the pH of the water. Another way to prevent corrosion and thereby eliminate the deposition of plugging material on the face of the sand is to run the water slowly through a large container filled with crushed limestone, which will remove most of the dissolved carbon dioxide.

The water generally used for flooding purposes in the Bradford field has a very low concentration of other dissolved mineral salts even when the very objectionable iron compounds are included. The chief acid radical is bicarbonate with very minor amounts of sulfates and chlorides. Fortunately, there are no soluble carbonate salts present in the ground water, for if there were they would readily react with the large amounts of calcium and magnesium chloride, which are present in the sand, to form insoluble carbonate salts.

The possibility of reactions between soluble salts in the flood water and salts precipitated in the oil pay must not be overlooked. If appreciable quantities of soluble carbonate salts are found to be present in the flooding water, they should most certainly be removed by chemical treatment for they will readily react with any calcium or magnesium chloride present in the sand, forming insoluble carbonates which would likely have a definite tendency to plug the sand.

DRILLING PRACTICE AND SURFACE EQUIPMENT

The development of properties for water-flooding purposes will not be greatly different from the form of development used for the drilling of natural producing wells, and under ordinary circumstances will not present any serious engineering problems. The water intake wells are generally drilled first. Such casing as is required is set in the customary manner, and after the sand is penetrated, the well is shot with nitro-glycerine in quantities approximately similar to those which have been previously used in the field. In the Bradford field, from 100 to 150 quarts are customarily used. After the hole has been cleaned out, two-inch tubing is run with a hook-wall packer on the end of the bottom joint. The packer is set as nearly as possible at the top of the sand section that is intended to be flooded, and from ten to twenty sacks of cement are used to cement the packer securely in place. The tubing is generally clamped to the conductor, the surface water string of casing being usually pulled and a big hole plug placed at the casing seat, and a meter box put over the hole with a flow meter enclosed so that all water going into the well may be accurately measured. The intake wells are then connected up to the water distribution system, which must be buried below frost level to permit distribution during the winter months.

The oil wells are completed in a similar manner as the water intake wells except that the tubing is not cemented in the hole. Pumping is ordinarily done by band-wheel powers and Oklahoma-type pumping jacks. The oil and such water as is produced during the later life of the flood are run into small receiving tanks where the oil production is gauged and the water siphoned off, and the oil then run into the stock tanks on the lease.

Pumps of the vertical triplex type are generally used for distributing the water to the intake wells, but on some larger properties in the Bradford field centrifugal pumps have been installed. Power for running the pumps and band wheels is ordinarily supplied by single cylinder two- or four-cycle gas engines. Where there is a shortage of gas, multi-cylinder gas engines of the four-cycle type may be used, resulting in a much lower fuel consumption, and where there is any fuel shortage, Diesel engines or electric motors must be used.

OPERATION OF WATER-FLOOD PROPERTIES

After the development work on a property is completed, the water is simultaneously turned into the intake wells, generally with no extra pressure in excess of the weight of the water in the tubing. As the sand becomes more nearly saturated with water, it is usually customary to increase the pressure gradually since more energy is required to move the larger volume of fluid in the sand. After the water has been going into the sand for a varying period of from four to eight months, depending on the well spacing and the physical properties of the sand, an appreciable increase in oil production occurs which ordinarily reaches its peak from 16 to 18 months after the water has been first introduced into the sand. In closely-spaced floods, the peak of production is very sharp with a correspondingly rapid decline in oil production and increase in water production after the peak of oil production has been reached, whereas in widely-spaced floods, the peak is not so prominent and the decline much slower.

Under normal conditions, the operation of water flood properties is comparatively simple, and outside of the usual maintenance of wells and equipment, requires a minimum amount of labor. After the depletion of the property, much of the equipment can be salvaged, and it is customary to use this material over and over again on other nearby or adjacent floods.

The only outstanding recent improvement in production technology in the Bradford field is the back-pressuring and flowing of the producing wells, rather than pumping. It is possibly too early as yet to state definitely how the results from back-pressuring and flowing the oil wells will compare with normal flooding operations, but it is indicated that the oil recovery will be approximately the same, and it is certain that the operation of properties by this method will reduce development costs very materially, since pumping equipment is not needed.

The application of back-pressuring and flowing methods to a property merely represents the utilization of the water pressure to flow the wells. After the sand becomes saturated with fluid by the introduction of water, a condition of hydraulic control exists in the sand. That is, the pressure applied at the intake well is transmitted throughout the entire sand body, being only diminished by the frictional resistance to fluid movement encountered in the sand. The amount of water required to fill completely the pore spaces of the sand can be approximately calculated from the analyses of cores, and when this point has been reached, the pressure at the intake wells is increased sufficiently to raise the fluid level in the producing wells to the point where they will flow. In back-pressuring, the wells may be flowed openly up to the amount of oil desired, or the oil may be produced through small chokes, thereby maintaining constant production while at the same time keeping a back-pressure on the sand at the producing wells.

One other production method which has found rather wide application in the Allegany fields, and which has been used to a smaller extent in the Bradford field is the use of the delayed system of drilling the oil wells in water-flooding operations. The application of the delayed system of drilling the oil wells came as a logical improvement to the methods previously employed for increasing the recovery of oil. The utilization of this method was originally planned as a means for controlling a definitely known and very troublesome sand condition, but subsequently it has been applied in uniform sand areas with satisfactory results. All data so far obtained indicates that the delayed drilling of the oil wells will increase the effectiveness of water-flooding operations, providing the water is introduced into the sand uniformly through each intake well and thereby does not concentrate the oil off center in the five-spot square.

The first delayed flood was tried on a property in the Allegany field, where old drilling records showed a very good sand section, but on which water-flooding had yielded very poor returns. A study of cores of the sand from this property showed that the lower part of the sand, comprising some four feet, was highly permeable, and that the upper main section was relatively tight, although well saturated with oil. The cores also showed that the water introduced into the sand had been moving almost exclusively through the lower, highly permeable part, without affecting the upper part. This condition was responsible for rapid water movement into the producing wells with an average oil recovery of only about 1,300 barrels per acre.

It was conceived that if the drilling of the oil wells could be delayed, and if a constant water pressure maintained at the intake wells, the water, having no outlet, would begin to flood the tighter parts of the sand after the looser parts had been thoroughly saturated with fluid. The method was tried, and it was found that this very thing happened. The oil was apparently first concentrated near the center of the five-spot square in the lower highly permeable member, and then was concentrated in the same manner in the tighter main body of the sand. Oil recovery was increased to slightly over 4,000 barrels per acre, thereby changing what had been a distinct failure to a fairly profitable operation.

Following the success of the first delayed flood, several other delayed floods have been started, some of them being located on properties where far more uniform sand conditions exist than were found on the property where the first experiment was carried out. None of these floods has as yet been depleted, but the production data so far available indicate the oil recovery will be increased approximately 20 per cent over that which would have been obtained by conventional methods of operation, and that the water production has been materially reduced.

The production from delayed floods corresponds much more closely to natural production than does the production from conventional water-floods. Unless the producing wells are flowed by the back-pressuring and flowing method, the largest production will be obtained immediately after the oil well is drilled. The production then declines as oil is removed from the sand, and water eventually comes into the hole, but it has been found that the appearance of water is considerably delayed beyond the time it would normally appear, and usually does not show up until a greater part of the recoverable oil has been obtained, thereby reducing lifting costs.

APPLICATION OF ELECTRICAL WELL LOGGING

In November, 1936, the Schlumberger Well Surveying Corporation of Houston, Texas, stationed an experimental party in the Bradford field to ascertain whether measurements of the physical properties of oil sands such as porosity, permeability, and saturation could not be made by electrical logging devices as well as by core analyses, the latter being heretofore the only known method of obtaining this most valuable and necessary information. The research undertaken by Schlumberger is by no means completed, but the information so far obtained has indicated such a practical application to water-flooding that no discussion would be complete without setting forth some of the results which have been obtained. The Schlumberger Well Surveying Corporation has most generously made available to the writer, for the purpose of this paper, much data including a report prepared by its engineer, W. J. Gillingham. The writer summarizes the data that have been furnished, and in part quotes directly from Gillingham's report.

Electrical log records afford the easiest and most accurate means of formation correlation yet obtainable. In the Bradford field, and in fact in most of the Appalachian oil fields the large number of wells drilled and the general consistency of the formations have made the correlation of beds and formations between wells in any one field a relatively simple matter. It has been found, however, that by combining the resistivity diagrams and the spontaneous electrical phenomenon effect diagrams, the latter being generally called the S. P. effect, that it is possible to distinguish very closely between interbedded oil sands and shale beds thereby giving a quick and accurate measurement of the total sand thickness in any well. Appalachian oil sands usually show a high resistivity and S. P. effect, while shales show minima on both diagrams. This is nicely illustrated in figure 13 where a log obtained by coring is plotted beside a log from the same well, determined from a careful examination of the resistivity and S. P. effect curves. It can be readily seen how the electrical log picks up the shale breaks, and shows the thickness of every sand bed even more accurately than the core log, owing to the elimination of errors brought about by the loss of core and in core measurement.

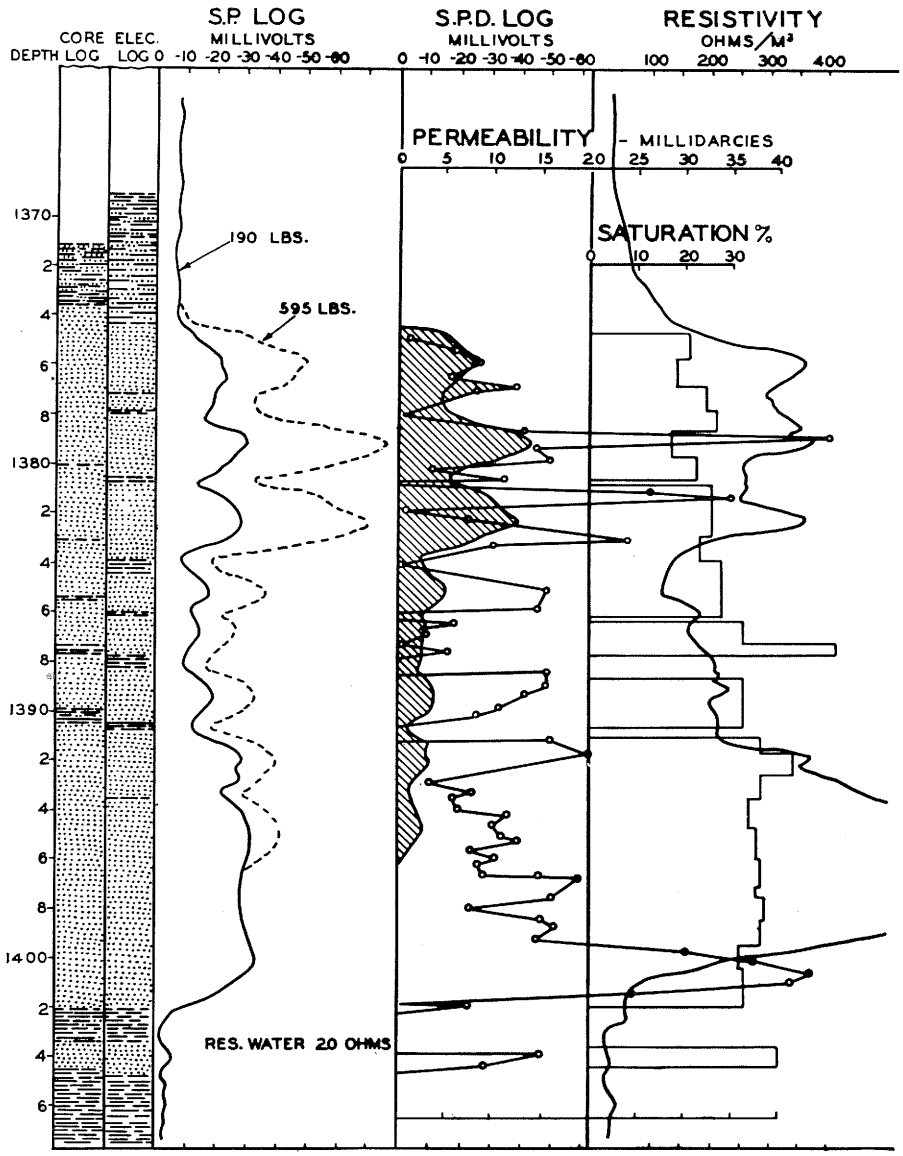

FIGURE 13.—Graphical comparison between a core log and electrical log for a well located in the Bolivar field, Allegany County, New York.

From the foregoing it should be quite evident that electrical logging surveys of wells already drilled on unflooded properties or otherwise untested new fields will give most valuable information regarding the actual thickness of pay sand, as well as indicate some of the sand's more important physical characteristics, without going to the cost and time of drilling test wells and taking cores. By making several electrical surveys on old wells not only can the exact thickness of the sand and shale be determined, but also an idea of how sand conditions are varying all over the property or throughout the field can be obtained. By this means it can readily be decided whether or not the property or field is even worth coring, and if so the best locations for core wells can be selected.

The spontaneous electrical phenomenon or S. P. effect, previously referred to, is due to two causes, electrofiltration effect and electrochemical action. When an electrolyte is caused to flow through a permeable medium an electromotive force occurs between the two sides of the medium. This EMF, which is called the electrofiltration effect, is proportional to the pressure, to the electrical resistivity of the filtering fluid, and inversely proportional to its viscosity. If two solutions of different saline content are in contact, an electromotive force is generated by the interchange of ions, and this EMF is called the electrochemical action. Thus if fresh water is introduced into a well and is brought in contact with salt water in the sand an electromotive force is generated. Usually both phenomena have the same sign, negative, and add together. The resulting S. P. effect measured is the sum of the two. Both phenomena are occurring in front of a permeable saline-bearing sand when fresh water is being introduced into it, so that a peak of electromotive force is usually recorded on the diagram whenever porous and permeable formations are encountered.

The electrofiltration effect gives a measure of the amount of water entering the sand at the position where the recording device is located, and hence, since the sand body will be under a constant hydrostatic pressure, providing the hole is kept filled with water, will give some idea of the permeability. Unfortunately, however, the EMF recorded by the S. P. diagram includes both the electrofiltration effect and the electrochemical action. It is, however, possible to eliminate the effect of the electrochemical action, and thereby give a more accurate determination of the sand permeability, by making two runs of the recording instrument under different hydrostatic pressure. The electrochemical action is the same in each case, and the difference between the two readings therefore will depend solely on the electrofiltration effect. Since measurements are made continuously, this parameter can be measured throughout the sand body. The measurements can be readily made in the field with different water pressures applied to the sand, and thereby the S. P. and the S. P. differential, hereafter referred to as the S. P. D., can be plotted.

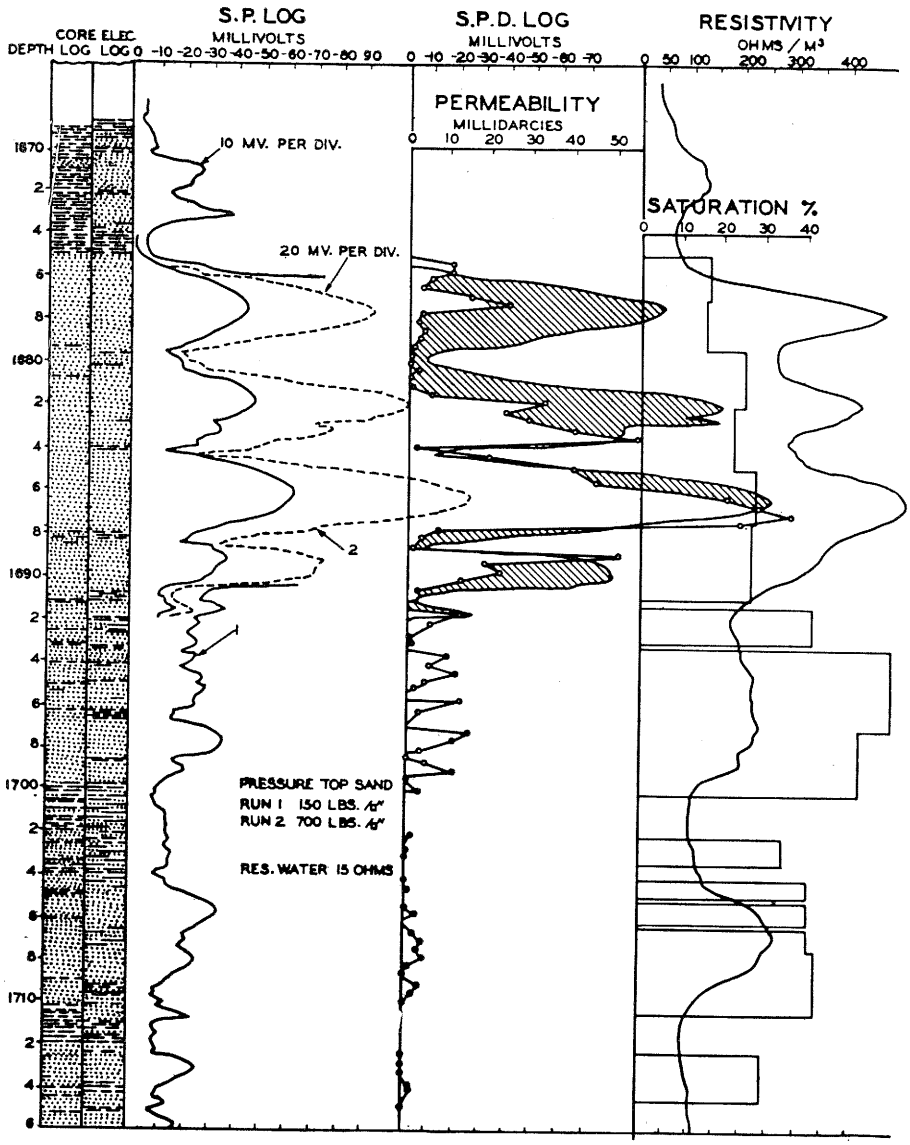

FIGURE 14.—Electrical log of a well in the Bradford field showing how gas pay and oil pay in the sand may be differentiated.

In figure 13 the "electrical permeability", or more accurately the S. P. D., shows a very close agreement with the permeability determinations obtained from core analyses, excepting in the very loose streak in the lower part of the sand. From experimental evidence it has been ascertained that a sand of very low permeability but having a high oil saturation will fail to show any S. P. D. on the electrical diagram, whereas if the oil saturation is low a distinct S. P. D. will be obtained. The reason for this may be readily explained by the fact that a large volume of oil in a highly porous sand will certainly modify to some extent the manner in which the sand will take water. The S. P. D. diagram indicates most conclusively that the water, in the instance referred to, was not moving into the highly oil-saturated beds at the rate it would normally travel were the beds free from oil, or only partially saturated. It undoubtedly would require a series of tests after the water had been moving into the sand for some time to definitely determine the S. P. D. throughout the entire thickness of the sand body. The important feature that is indicated by figure 13 is that when water is first introduced into an intake well it will commence to move most rapidly through the beds of lowest oil content.

The fact that the electrical log shows the moderately permeable but highly saturated zones as impermeable members might appear to be a serious drawback; actually in some cases it is a distinct advantage. This is particularly true in detecting the presence of gas pays in the sand which must be packed off to permit effective flooding action in the oil saturated parts. Since the gas pay will take so much more water than the oil pay its presence may be easily recognized on the electrical log on account of the large S. P. D. generated. Figure 14 gives an actual example. The section from 1,675 to 1,691 shows a very large S. P. D. on account of it being a barren gas pay. The moderately permeable section from 1,691 to 1,700 feet is well saturated and therefore shows no S. P. D. The best packer point, around 1,691 feet, may therefore be easily chosen. It is interesting to note that the electrical log presented in figure 14 conforms very closely to the results shown in figure 13, in that the two sand sections shown in figure 14, from 1,675 to 1,679 and from 1,694 to 1,698, both have approximately the same permeability as indicated from the results of the core analysis, but give an entirely different S. P. D. diagram. On the upper low-saturated section a large S. P. D. is obtained, while on the lower more highly saturated section, no S. P. D. can be observed.

The relationship between S. P. D. capacity and actual water flow can be easily proved from actual observations made in the field. In figure 15 the results of an electrical survey of a well drilled into the Richburg sand in the Bolivar Field, Allegany County, New York, is shown. In this survey measurements were made at eight different pressures at the top of the sand ranging from 595 pounds per square inch to 1,295 pounds per square inch.

The results of this series of tests indicate most conclusively that increasing the pressure causes a steady increase in the S. P. The capacity in foot-millivolts of the electrical diagram in relation to the pressures employed has been computed and plotted as shown in figure 16. The straight line resulting shows that the S. P. filtration effect is directly proportional to the pressure.

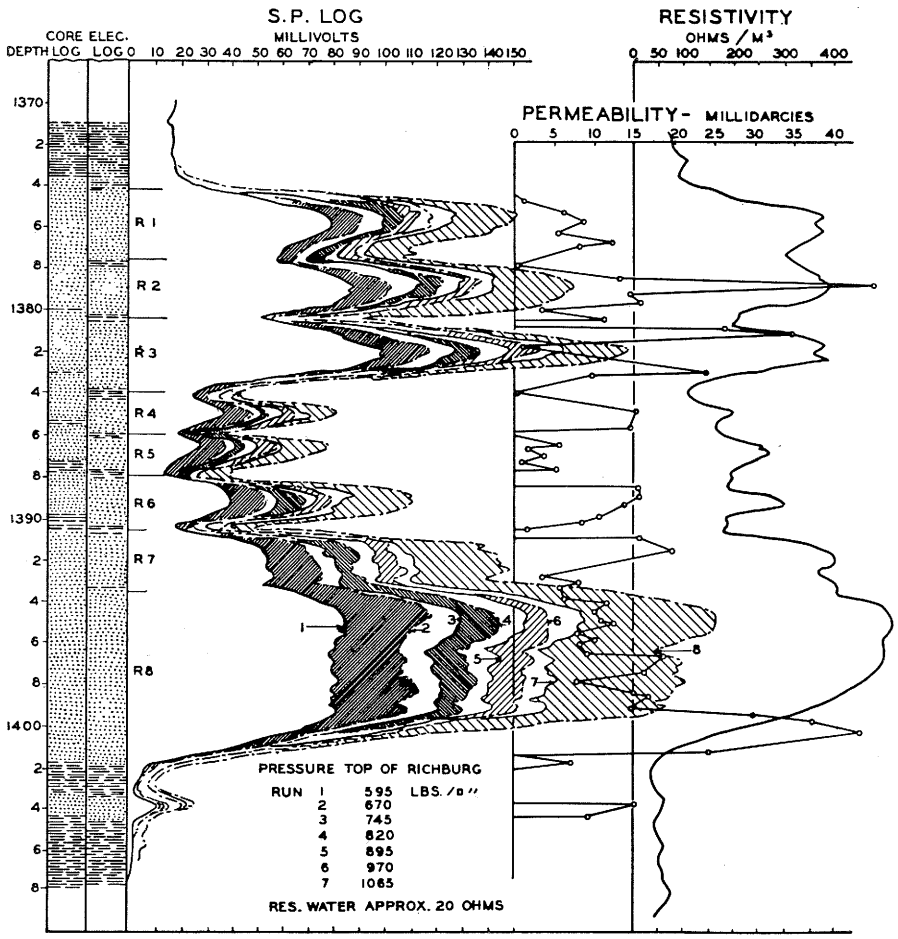

FIGURE 15.—Electrical survey showing the effects of different water pressures on the S. P. diagram in a well located in the Bolivar field, Allegany County, New York.

In this same well, illustrated in figure 15, the actual water intake was measured while the survey was in progress, and in figure 17 the capacity has been plotted against water intake. Here again the relationship is actually linear, showing that the S. P. D. or electrical permeability is directly proportional to the actual water intake. This being the case there seems to be no

question but that electrical logs can give a very accurate picture of fluid movement into the sand body.

In this particular well, first shown in figure 15, the S. P. D.'s of some of the individual sand sections have been plotted against varying pressures, as illustrated in figure 18. Lines of different slant are obtained according to the different permeability of each individual sand bed, and it will be noted that they do not exactly fall in regular order. Although it might be generally expected that sand beds of higher permeability will take more water than beds

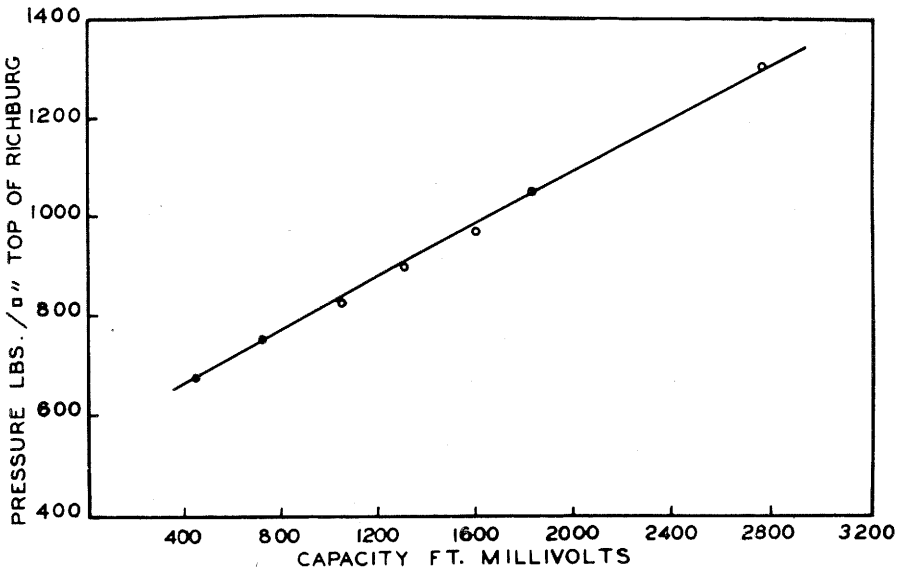

FIGURE 16.—Relationship between pressure at the top of the sand and electrical capacity in foot-millivolts.

of lower permeability, it would appear from the electrical log data that the relationship is not a linear one; i. e., input is not directly proportional to permeability.

Up to the present time no definite correlation can be shown between the resistivity diagrams and oil saturation in electrical surveys of wells in the Bradford and Allegany fields. The reason for this apparently is because of the fresh water used in flooding. Fresh water is very resistant, and a sand partially or entirely filled with fresh water may show as high a resistivity as a sand saturated with oil.

The fact that by a modification of the regular electrical well-surveying procedure an accurate measurement of fluid flow into the sand can be obtained means that much of the data that could formerly be obtained only from core analyses can equally well be obtained by electrical surveys. For example,

it has long been a controversial point as to what is the minimum sand permeability that can be effectively flooded. Usually 1 millidarcy has been accepted as the lowest floodable limit, but in figure 19 the electrical log conclusively shows that except for the section of sand from 1,339 to 1,343, which had an average permeability of 0.1 millidarcy, the entire sand body was being flooded, notwithstanding the fact that laboratory analyses showed that 50 per cent of the sand had a permeability of less than 1 millidarcy.

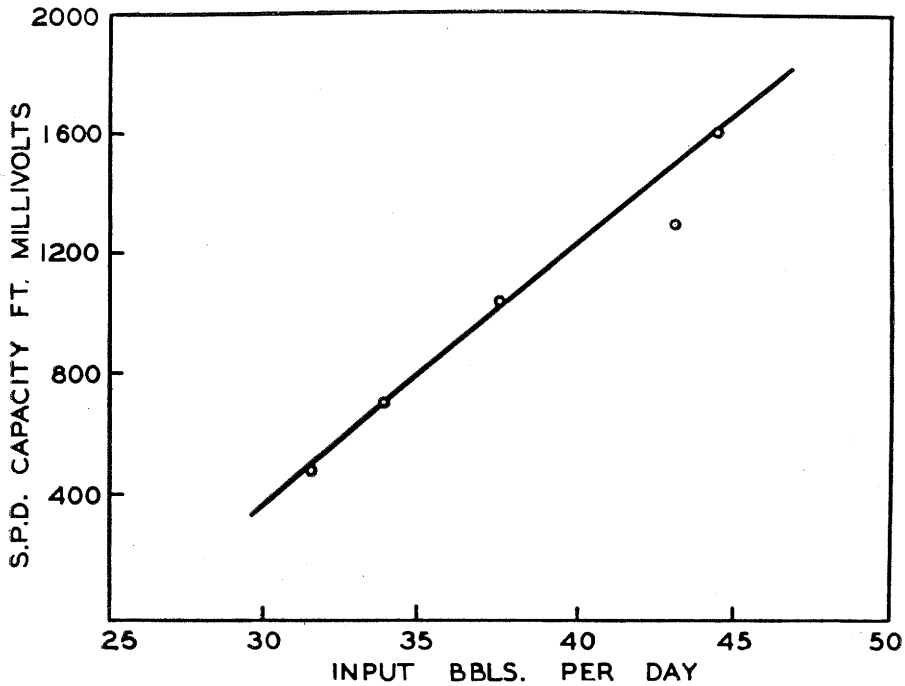

FIGURE 17.—S. P. D. capacity in foot-millivolts in relation to water input in barrels per day.

Not only have electrical surveys shown that sands of very low permeability may be flooded, but they also may be used to determine the proper pressure that should be applied to the sand to obtain effective flooding action. The electrical log will clearly indicate the best pressure that can be employed to introduce water uniformly through the sand. It also, by showing the tighter parts of the sand, can serve as a guide to the proper shooting procedure.

One feature of water-flooding operations which is always the source of trouble, unless controlled by delayed drilling or by back-pressuring, is rapid water encroachment through the more permeable beds of the sand. Where core analyses are not available, the Schlumberger Well Surveying Corporation has employed the Dale apparatus to determine the horizon in a producing

well through which the water is coming. This instrument consists of a photoelectric cell and a light bulb which is lowered into the hole, and between which the fluid in the hole is forced to circulate. Any variation in the translucency of the fluid in the hole is shown by the photoelectric cell.

To use the Dale apparatus the well is first conditioned by filling the hole with an opaque fluid, usually muddy water, and then running the instrument through it down to the level of the producing sand, and thereafter gradually

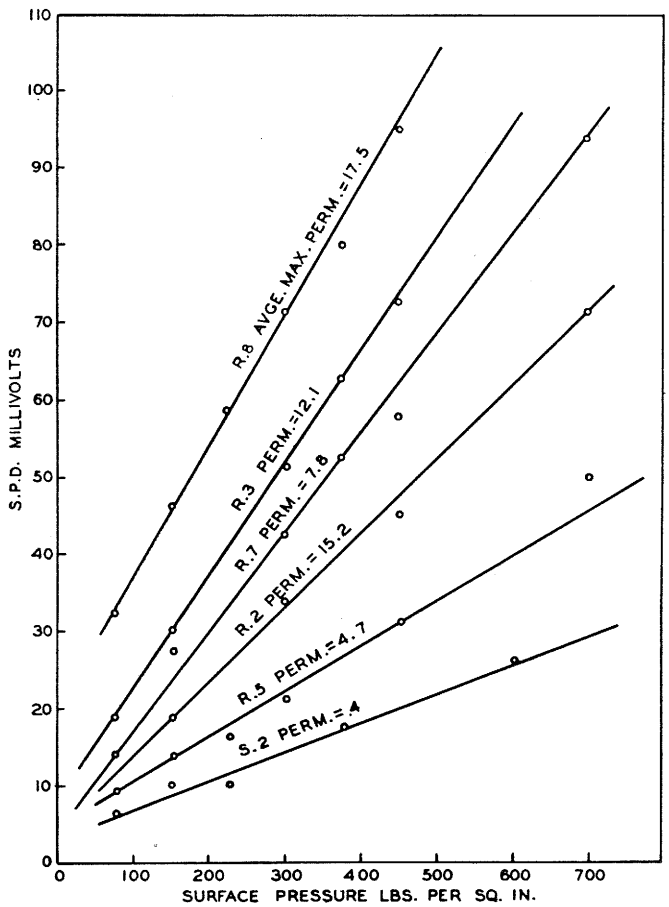

FIGURE 18.—Relationship between S. P. D. in millivolts and surface pressure for individual sand beds of varying permeability.

lowering it as readings are taken. As water filters in from any particular bed and dilutes the opaque fluid rendering it translucent, the instrument records an anomaly, and therefore defines exactly the point in the sand through which the water is traveling. Measures may then be taken to plug off the offending sand member and thereby reduce lifting costs materially.

The results so far obtained clearly indicate that electrical surveys may be most advantageously employed in water-flooding operations. The problem of accurately measuring the oil saturation of the sand remains to be solved, but the utility of electrical logs for determining other important physical characteristics of the producing sand is already so evident and can be so easily made that electrical surveys will undoubtedly be very widely employed in future operations both in the eastern fields, and in new water-flooding projects in the mid-Continent region.

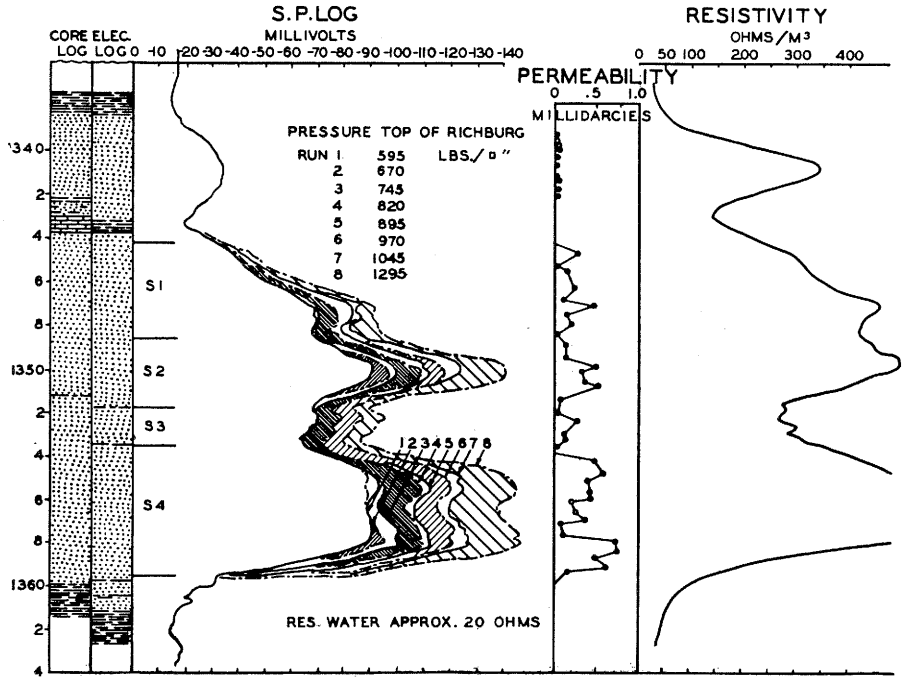

FIGURE 19.—Electrical log of a well drilled to the Stray sand in the Bolivar field, Alleghany County, New York, showing flooding action in sand beds possessing a permeability of less than 1 millidarcy.

CONCLUSION

The estimated natural production of the Bradford field has been slightly over two hundred million barrels of oil. It is conservatively estimated that water-flooding will provide a total additional recovery of somewhat over three hundred million barrels of oil. At the present time, about one hundred million barrels of crude have been produced from the field by flooding operations, leaving an amount practically equal to the entire natural production of the field yet to be recovered. In other words, the application of water-flooding to the entire field may be expected to recover at least one and one-half times as much oil as was yielded by natural production over a period of almost seventy years. On individual properties this increase is sometimes substantially greater, the recovery by water-flooding being as high as twice the amount produced by natural production. Such being the case, it can be stated with little fear of contradiction that water-flooding has proved to be the most important agent of conservation of this nation's oil resources, insofar as its application to the older fields is concerned, that has ever been developed.

Water-flooding operations come more closely to corresponding to manufacturing industry than any other part of the business of producing oil does. It is possible to estimate quite closely the amount of oil that can be recovered, and land and development costs may be accurately determined in advance of any development. The only unpredictable factor is, of course, the price that can be obtained for the product, and it should be apparent to all that this is an uncertainty that is inherent to almost every other line of business.

RECENT DEVELOPMENTS IN WATER FLOODING IN ILLINOIS OIL FIELDS*

By

Frederick Squires

Associate Petroleum Engineer, Illinois State Geological Survey

Will water power revive our oil sands? To answer this question evidence of natural floods on the McClosky, an artificial flood at Carlyle and accidental floods at Allendale will be presented.

McCLOSKY

Figure 20 shows all McClosky production in Lawrence County. This simple kind of a drawing is used because ordinary contour maps often are confusing. In the early days, an old-time prospector when at the postoffice, had the good luck to find a structure map of the area, with lots on the ball. He then drilled on a terrific high, opening a new field with an enormous well and claimed that he did it all on geology. Imagine his embarrassment when the postmaster showed him that his contour map was a weather forecast!

In these days anything about the McClosky is news—because it is the producing horizon at Clay City and Noble, and the history of the old field may repeat itself in the new, as history has a way of doing. What then are McClosky characteristics? Figure 20 shows that production is spotted, even on favorable structure. It is also true that wells of great initial production are surrounded by sharply declining production due to abrupt reductions in permeability. Part of the oil is water driven. Since the new field is under a thousand feet more head, McClosky water characteristics will be intensified and with wide-open withdrawal of oil and gas, the faster water penetration may shorten the lives of basin wells.

McClosky floods have been discovered in the Applegate, McClosky, Murphy and St. Francisville areas. For each of them contours have been drawn on fluid levels of equal height. A comparison of contours, from higher to lower, shows the direction of water movement. These areas of different levels are illustrated on the drawings by concentric colored bands, the lightest being the highest.

A great deal of information, especially on their great productions, is available from Survey publications on the Applegate and McClosky floods. An unusual characteristic of the Murphy area is that many big wells declined and were abandoned before the water-push had time to reach them. The St. Francisville flood is only an infant, but has already greatly increased production. The area was proved to be McClosky lime by its favorable reaction to acid, and suggests tests with acid, in small quantities, to differentiate

* This paper has been published since the Conference in The Weekly Derrick, Feb. 3, 1938, from which the illustrations are used.

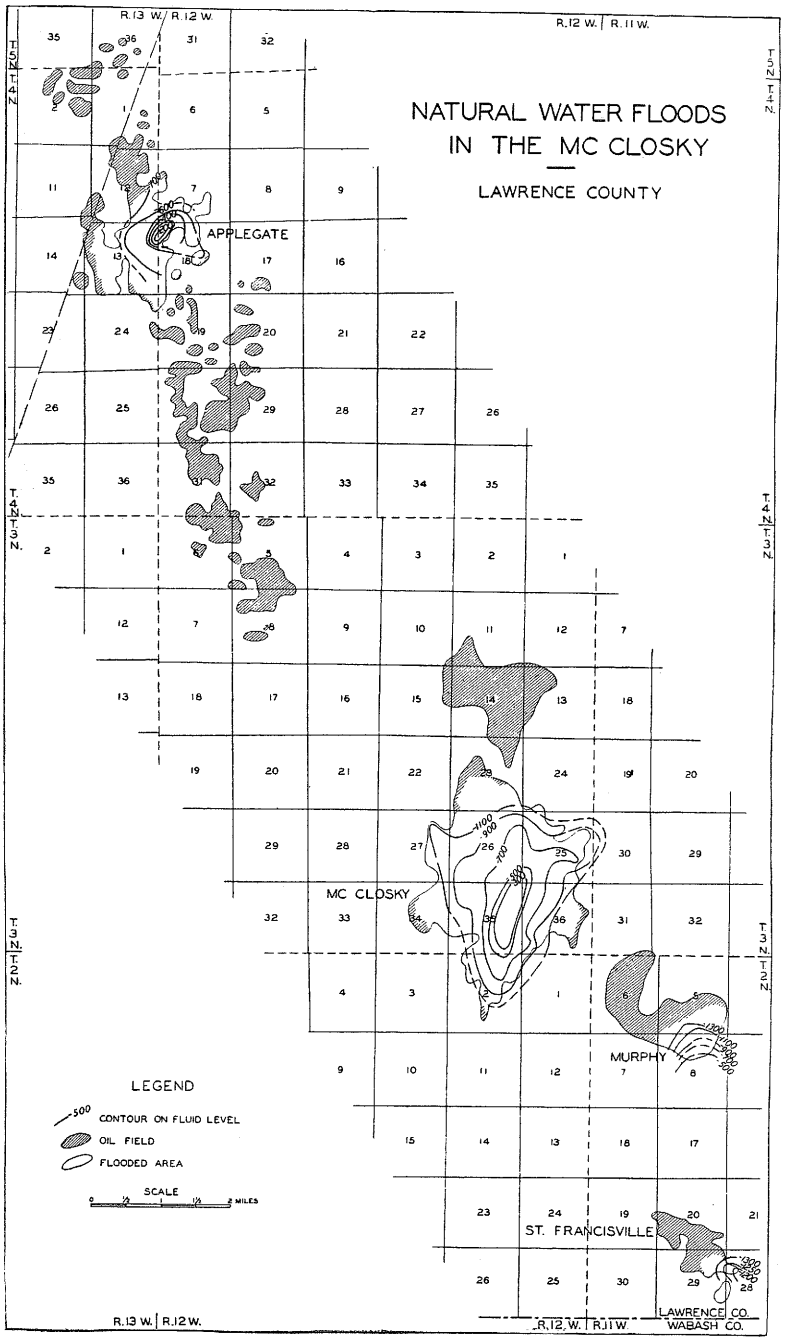
NATURAL WATER FLOODS
IN THE MC CLOSKY
LAWRENCE COUNTY
R.13 W. | R.12 W.
R.12 W. | R.11 W.
T.5 N. | T.4 N.
T.4 N. | T.3 N.
T.3 N. | T.2 N.
APPLEGATE
MC CLOSKY
MURPHY
ST. FRANCISVILLE
LEGEND
500 CONTOUR ON FLUID LEVEL
OIL FIELD
FLOODED AREA
SCALE
0 ½ 1 1½ 2 MILES
LAWRENCE CO.
WABASH CO.

FIGURE 20.

between any true sand, and McClosky lime, by the absence or presence of carbon dioxide in the casing-head gas of the tested well. Identification of St. Francisville as McClosky and therefore 250 feet higher than previously believed to be the case, *gives* considerable structural significance to the area. In three cases out of four, water invaded from high on structure directed there by greater permeability.

Floor characteristics of the McClosky are these: Water travels fast, oil production is always benefitted. Only part of the area has been flooded. Therefore, the obvious deductions are (1) that the remaining McClosky should be intentionally flooded; (2) that this can be done without new drilling, by using alternate wells for flooding and pumping; and (3) that recoveries, if at all like natural floods, will amount to millions. Repressuring with gas or air should also be tried.

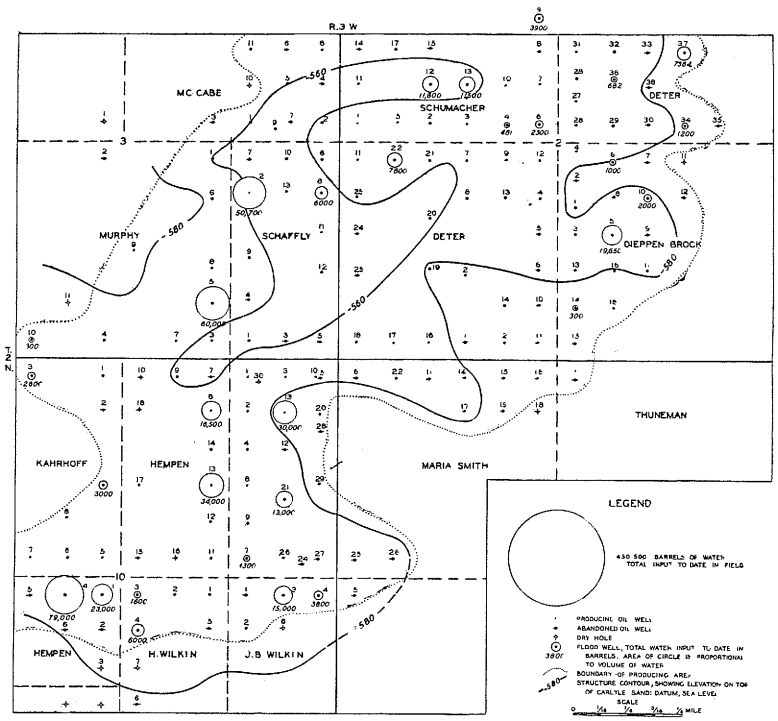

FIGURE 21.—Applied flood at Carlyle pool, showing comparison of flooded area to total area.

CARLYLE

An applied flood is being developed by the Ohio Oil Company which is intended ultimately to cover the whole Carlyle pool of eight hundred acres (fig. 21). The structure, an outline of the producing area, and the wells are

shown. The field has produced 3,500 barrels of oil to the acre and the wells have an average age of 25 years. Considerable water has been produced with the oil. The average initial production of 50 barrels per well has declined to one. The average sand thickness is 17 feet. The developed field has 190 wells, of which about half are still pumping. Experimental air repressuring has been tried. The wells are now being gas-pumped to increase the scanty gas supply, oil engines replacing gas engines for power. Such was the situation when flooding began.

A half million barrels of water have been pumped in, under pressures up to five hundred pounds, plus a static head of a thousand feet. The greatest input is about a thousand barrels a day.

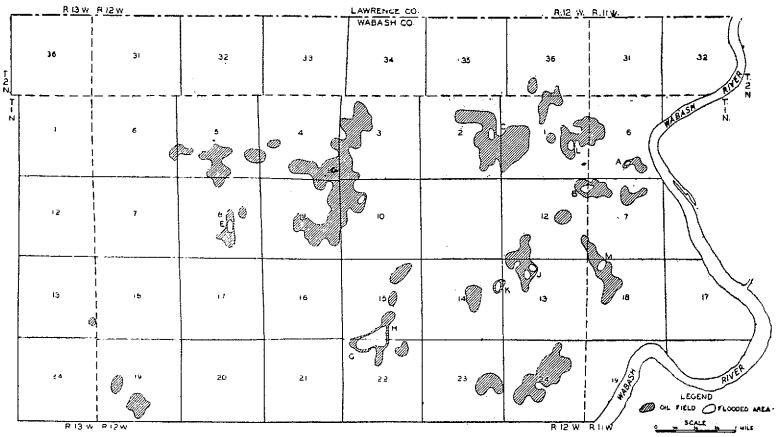

FIGURE 22.—Occurrence of Biehl sand and floods in the Allendale field.

Water distribution in the sand is proportional to the size of the colored circle around each input well. Each circle indicates the total amount pumped into that particular well. The sand, at 15 per cent porosity, would have 2½ feet of voids and each circle represents the area of the top of a cylinder, 2½ feet high, which would accomodate the total water-input. The large circle indicates the top of a cylinder that would contain all the water pumped into the whole property, and the smallness of this circle, compared to the total area of sand, explains the slowness of results.

A comparison of fluid levels in 1933 and 1937 shows that there has been an average rise of fifteen feet and a similar comparison of pumping time shows a 25 per cent increase. This operation, covering considerable time, has returned only 600 barrels of water per acre into a sand from which has been taken out 3,500 barrels of oil.

ALLENDALE

Figure 19 shows the most significant happening in the old Illinois field, floods on the Biehl sand at Allendale. The map shows the field, its structure

and wells. The discovery well was completed in 1912 and by 1926, 200 wells had been drilled, followed by an equal number up to now. Three hundred are still pumping. These wells have an average age of fourteen years and an average production of 2,500 barrels to the acre. The average initial production of 70 barrels a day had declined to two barrels. The average thickness of the sand is 29 feet, which yields little salt water. It is almost gasless and is gas-pumped to increase the fuel supply, but in most cases the power is obtained from oil engines. Repressuring has been tried on two properties with good results. Such is the picture of Allendale when flooding began.

Conditions at Allendale illustrate how water, when it breaks through the pipe which cases off the water sand, rises in the well to an average height of 1,200 feet and floods the Biehl sand under an average pressure of nearly 600 pounds. The volume of water entering the Biehl sand is, of course, unknown.

The direction of the water movement from well to well is shown on the sections through the sands, and demonstrates that permeability, not structure, is the controlling factor. The Biehl varies in thickness, but the flood often chooses the direction of thinning rather than thickening sand. Many floods go faster up structure than down. The average rate of travel is one location in three months, about the same as observed in the McClosky at the beginning of water invasion.

To date, no flooding well has influenced the oil production of more than a single pumping well, except on the Jake Smith and Alice Biehl leases. There a deliberate flooding program has been adopted, and several flooding wells are being used to move oil to each producing well from several directions simultaneously.

Figure 23 is a set of graphs showing the oil production resulting from six floods. They illustrate four conditions: (1) flood production increasing; (2) flood production past its peak and declining because the pumping well is making an increasing amount of water; (3) flood production declining because the motive power has been shut off by plugging the water well; and (4) flood production reaching its peak and declining to nothing, because the pumping well has been abandoned.

These graphs show productions totalling over 58,000 barrels with three curves still going up and only one back to normal, but even under these conditions, there is an increase of more than 6,000 barrels each for the nine wells. If the whole field of 300 wells was flooded, with alternate flooding and pumping wells, and the same rate of increase held good, the field would produce a million barrels of oil. This does not take into consideration the oil recovered from water drives which would operate on every pumping well from its other three sides.

The grave fault of Allendale flooding is uncontrolled water. In the flooded-out well shown on the graph the oil came, down-dip, into the pump-

ing well too fast to be pumped out. An advantage is that, like the McClosky, the sand is so permeable that new drilling is unnecessary, resulting in the most profitable of all flooding programs.

Water is available from the nearby Wabash River and in parts of the field from inexhaustible water-bearing gravel beds. All operators in the field are sold on water flooding for a final clean-up. Experience has shown the great necessity for a systematic program of controlled flooding for the whole field.

Will water revive our oil sands? Illinois is a water-power field. Accidental floods have been uniformly successful. Natural floods are everywhere welcomed. A few years ago Bradford water-flooders, unable to expand longer on their home grounds, hunted for and found flooding territory in Kansas and Oklahoma. The very trains that carried them through Illinois rumbled over today's greatest oil play! Perhaps that's just the lesson needed to direct attention of operators to today's greatest flood play. When Noah heard rumors of a flood, he did something about it!

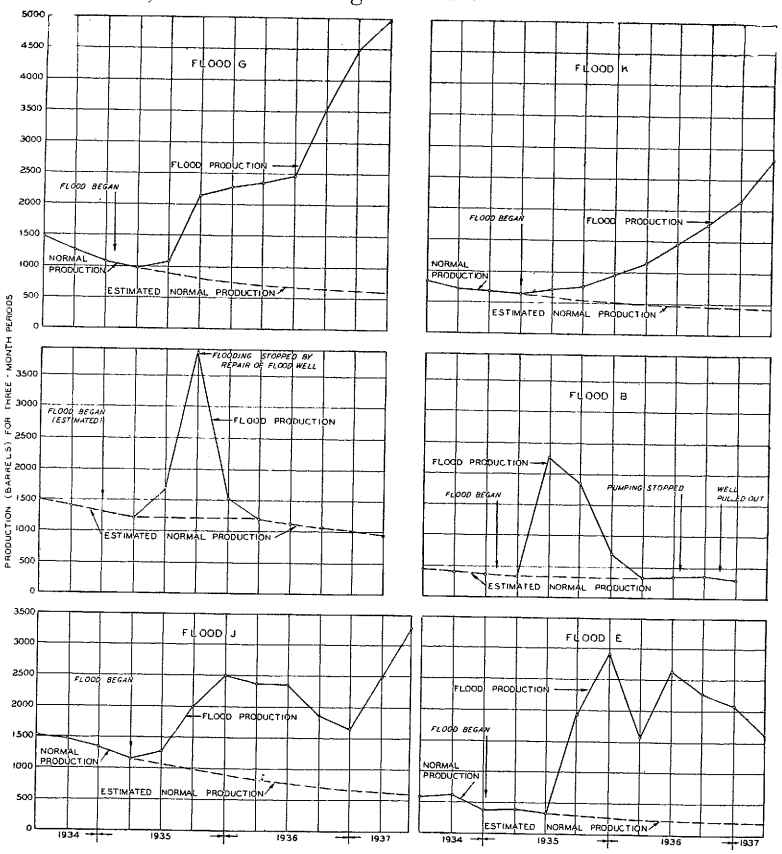

FIGURE 23.—Graphs showing flood production from the Biehl sand, Allendale.

STATE REGULATION OF OIL AND GAS PRODUCTION FOR THE PREVENTION OF PHYSICAL WASTE

By

William Bell

Bell Brothers, Robinson; President, Illinois-Indiana Petroleum Association; and Representative of Governor Henry Horner on the Interstate Oil Compact Commission

Persons disliking unregulated financial or business conditions they find uncongenial refer to them as being controlled by the law of the jungle where tooth and claw rule and might is right. On the other hand, if regulation exists, some must resent that and allege strait jacket methods, strangulation of natural and normal business life, and the death of personal initiative.

In the oil producing business we are learning some important facts growing out of the magnitude of our country and of our industry. Until a comparatively recent time the oil producer prided himself on his rugged individualism, with everyone taking care of himself. But the time came when most oil producers found that that principle had about put them out of business and they began to yearn for control and supervision centered somewhere. Producers found that certain rugged individuals had become rugged enough to largely control the situation in their own favor, at the same time ignoring the interests of other producers and the public. Conservation authorities, as well as producers, became alarmed at the narrow, selfish attitude of certain States and the ruthless actions of certain producing interests. Conditions in the industry, during the period referred to, were so bad that there were numerous meetings and conferences for the purpose of developing plans which would result in better conservation of our petroleum resources and the stabilization of the petroleum industry. A conference of conservation interests was held at Colorado Springs in June 1929, and in March 1933, a conference of governors of oil producing states was held at Washington for the purpose of starting a movement to control production of petroleum and prevent the waste then occurring. Out of that developed a committee of fifteen which submitted a report, recommending a program to the President. Based on these recommendations, the President wrote a letter to all the governors of the oil producing states under date of April 3, 1933, requesting them to take such action as necessary to carry out the recommendations and stating that

he was prepared to recommend to Congress legislation prohibiting the transportation in interstate and foreign commerce of any oil or products thereof produced or manufactured in any state in violation of the laws thereof.

In August, 1933, the petroleum Code under N R A was established and for a time the industry operated under a form of control by the Federal Government. Later Supreme Court decisions pointed out in unmistakable terms that production could not be controlled by Washington, that mere production was not commerce, and if mere production be not commerce, that it follows that mere production cannot be rightfully termed interstate commerce; and therefore mere production is not a matter of Congressional concern since Congress just does not have the power delegated to it to control mere production. That right and that duty belong to the State alone. When it became clearly apparent to the oil industry that Federal control was neither constitutional nor desirable, sensible, thoughtful people of the industry began to cast about for some method to do all that could be done toward conservation in a legal, constitutional way. The "Interstate Compact", or "Treaty among the States", method was pointed out by Governor Marland of Oklahoma as being the proper method to pursue.

During the latter part of 1934 representatives of large oil producing states, under the leadership of Governor Marland of Oklahoma and Governor Allred of Texas were endeavoring to establish an agreement among oil producing states and at Dallas, Texas, on Feb. 16, 1935, an Interstate Oil Compact was executed by the Governors of Oklahoma and Texas and qualified representatives of the Governor of New Mexico. Attending this conference and agreeing to recommend the Compact to their legislatures and governors, were representatives of Colorado, Illinois and Kansas. Later these States joined the Compact by appropriate legislative action. All the states, before the expiration of the two years provided for in the original Compact, have acted to extend the Compact for another two years from September 1, 1937. Both the original and the extension were promptly approved by Congress and the President.

The organization of the Interstate Oil Compact was most timely because in May, 1935 the Supreme Court ruled that the N R A was unconstitutional, thereby removing Government control under the Code. The Interstate Oil Compact was then functioning smoothly and efficiently. Instead of panic and chaos in the oil business because of the decision removing Government control, there was no period whatever of uncertainty or unsettlement and no bad effects followed that Court decision. Business in petroleum went placidly on relying confidently on the Compact, and results fully justified that confidence.

Colonel E. O. Thompson, the Chairman of the Interstate Oil Compact Commission, an international authority on petroleum problems, has said in reference to the Compact: "Those who drew the Compact had been through

a maze of legal difficulties, both at the Court House and in Washington in the Congressional Halls; and when the Compact was drawn, they made certain to set out in the Compact or Treaty, in Article II, that the purpose of this Compact is to conserve oil and gas by the prevention of physical waste thereof from any cause, it being the idea and the deliberate opinion of those who drew the Compact that state authority, particularly in some of the oil producing states, could not go further than to prevent the actual physical waste in the production of oil and gas." It was therefore set out simply in Article III, that the states who signed the treaty or any state that should come in at a later date, would enact laws, or if the laws had already been enacted, then they would agree to continue the same in force, to accomplish within reasonable limits the prevention of:

(a) The operation of any oil well with an inefficient gas-oil ratio.
(b) The drowning with water of any stratum capable of producing oil or gas, or both oil and gas in paying quantities.
(c) The avoidable escape into the open air or the wasteful burning of gas from a natural well.
(d) The creation of unnecessary fire hazards.
(e) The drilling, equipping, locating, spacing or operating of a well or wells so as to bring about physical waste of oil or gas or loss in the ultimate recovery thereof.
(f) The inefficient, excessive or improper use of the reservoir energy in producing any well.

The enumeration of the foregoing subjects shall not limit the scope of the authority of any state. Article V of the oil states' treaty was written as a result of much study of the law and the cases to the end that the oil states' compact commission would never be used, directly or indirectly, for the purpose of making oil scarce in order to make it dear. Therefore, I think it well at this time to quote Article V in full. Here it is:

> It is not the purpose of this Compact to authorize the states joining herein to limit the production of oil or gas for the purpose of stabilizing or fixing the price thereof, or create or perpetuate monopoly, or to promote regimentation, but is limited to the purpose of conserving oil and gas and preventing the avoidable waste thereof within reasonable limitations.

In carrying out this plan, the states have incorporated in their laws various provisions to prevent waste, as for instance in the New Mexico act Section 1, reads "The production or handling of crude petroleum oil or natural gas, or the handling of products thereof, in such a manner or under such conditions or in such amounts as to constitute or result in waste is each hereby prohibited."

Section 2. As used in this act, the term "waste," in addition to its ordinary meaning, shall include:

> (a) "Underground waste" as those words are generally understood in the oil business, and in any event to embrace the inefficient, excessive or improper use or dissipation of the reservoir energy, including gas energy and water drive, of any pool, and the locating,

spacing, drilling, equipping, operating or producing, of any well or wells in a manner to reduce or tend to reduce the total quantity of crude petroleum or natural gas ultimately recoverable from any pool.

(b) "Surface waste" as those words are generally understood in the oil business, and in any event to embrace the unnecessary or excessive surface loss or destruction without beneficial use, however caused, of natural gas, crude petroleum oil or any product thereof, but including the loss or destruction, without beneficial use, resulting from evaporation, seepage, leakage or fire, especially such loss or destruction incident to or resulting from the manner of spacing, equipping, operating or producing, well or wells or incident to or resulting from the use of inefficient storage or from the production of crude petroleum in excess of the reasonable market demand.

(c) The production of crude petroleum oil in this State in excess of the reasonable market demand for such crude petroleum oil. Such excess production causes or results in waste which is prohibited by this Act. The words "reasonable market demand" as used herein shall be construed to mean the demand for such crude petroleum oil for reasonable current requirements for current consumption and use within or outside the state, together with the demand for such amounts as are reasonable necessary for building up or maintaining reasonable storage reserves of crude petroleum oil or the products thereof, or both such crude petroleum oil and products.

This New Mexico law is considered one of the best and the petroleum conservation laws of other large producing states are excellent and well adapted to the needs of their respective states.

Illinois will have the benefit of the experience of these other states and can study their laws when ready to adopt legislation of its own. The State has been a member of the Interstate Oil Compact practically from the beginning and has given its support to the Compact's objectives in every way possible to it, being deeply interested in the results sought by the Compact both as producer and consumer of petroleum. Our treaty with the other oil producing states binds us in effect to provide, within a reasonable time, appropriate laws for accomplishing the purposes of the Compact in this State in cooperation with the other states. The reason we now have no such laws is that, in the early part of the century, when we had large flush production, control measures of the present nature had never been dreamed of. In the meantime our production has declined to the stripper stage such laws were not needed.

Now that new fields are being developed in Illinois, serious consideration must be given to these changed conditions. The high character of those who represent the producing interests in our new fields leads us to believe that they will cooperate closely along the lines set up by the Interstate Oil Compact and these other producing states. The record shows that Governor Horner is deeply interested in these matters and that his policy for Illinois is real conservation of the State's natural resources and their best possible utilization. Hence, we feel that we will have, at the proper time, the very efficient support of our Governor in obtaining conservation legislation similar in purpose to that enacted in other oil producing states, through which will be protected the interests of the State, the industry, and the public.

CHANGING LEGAL CONCEPTS AFFECTING THE OIL AND GAS INDUSTRY

By

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Due to the peculiar physical and economic facts of oil and gas, the business of producing and marketing them has always been something of a problem child among the industries, from both a legal and an economic viewpoint. Because of these facts, the struggle of the courts to determine the nature of the landowner's legal interest in oil and gas and to determine the legal relations between the landowner and lessee as fixed by the lease, has been long and arduous, and still continues. Unlike other businesses where both supply and demand normally govern the amount of production, only supply, until very recent times, has governed the amount of oil and gas produced. Unrestrained drilling and unlimited production in new fields have always resulted in periods of production in excess of market demand and transportation facilities, with attendant physical and economic waste.

Early in the development of the oil industry the legislatures of the oil and gas producing states evinced some interest in the prevention of physical waste by acts requiring the plugging of abandoned wells, the casing of wells, the shutting in of wells to prevent the escape of oil and gas, the use of vacuum pumps, restrictions upon the production of gas, limitations upon the use of gas, and regulation of methods of drilling and operating wells. The growth of this policy of conservation of oil and gas through legislative enactment has been a gradual one, and the particularization of regulation has increased in some proportion to the increased knowledge of the physical facts of these substances. Originally, the enforcement of conservation statutes was left to the ordinary prosecuting officers of the county, although in some instances civil remedies were given to adjacent landowners. Later, in the principal oil and gas states, commissions were created and given authority to enforce the statutes and to make and enforce rules and regulations for the prevention of waste.

The intensive program of conservation through which the industry is now passing received its original impetus from the letter of President Coolidge of December 19, 1924, creating the Oil Conservation Board. This letter was not written in one of the periods of great over-production, but the writer called attention to the fact that waste was taking place in the production of oil and gas, and that a continued supply of petroleum and its products was

vitally necessary to the common welfare and to the national defense. Various committees representing the oil industry, the legal profession, and governmental agencies set about to study the problem and suggest remedies for the existing evil. Before anything of a beneficial nature was actually accomplished, successive discoveries of new fields in California, Oklahoma and Texas resulted in another period of great over-production, with all of its attendant evils. As a result, the concern expressed in President Coolidge's letter that the supply of oil might soon be exhausted undoubtedly lost its urgency, but a new urge for conservation arose from a glutted market and low prices.

During the last decade the legislatures of most of the principal oil and gas producing states have amended and revised their conservation statutes again and again, trying to find remedies for the prevention of physical and economic waste of oil and gas. These statutes have redefined and classified waste so as to include physical waste, economic waste, waste due to production in excess of market demand, and waste of reservoir energy; have authorized administrative agencies to limit production to market demand for the prevention of waste, and to prorate such limited production among producers from a common source of supply and between various sources of supply in the state on some reasonable basis. Administrative agencies have been given greater powers in the regulation of the business of production and marketing; the Federal Government has aided by prohibiting the transportation in interstate commerce of natural gas and petroleum produced in violation of state conservation acts. If in one sentence the purpose of all this legislation could be stated, it would seem to be to control and limit the production of oil and gas for the prevention of waste, and at the same time give to each landowner or his lessee the opportunity to produce their just and equitable share of the recoverable oil and gas in any common source of supply. The existing statutory provisions perhaps do not completely accomplish this. More complete control of production is being sought through compacts between states. In every phase of the search for proper conservation legislation during this period—in hearings before legislative committees, investigations by the industry and the legal profession, and in the thousands of law suits contesting the validity of statutes, regulations and orders of administrative bodies—it has been insisted again and again that the chief impediments to proper conservation measures have been the legal interests of the landowner respecting oil and gas and the legal relations between lessor and lessee as established by the early decisions of the courts.

The opponents of conservation, in contesting the constitutionality of statutes and validity of regulations — for the time being, rugged individualists—have set up these legal relations and interests and demanded their protection under the Constitution. The conservationist, of whatever variety, has looked upon these relations and interests with loathing, because

they have thwarted him in his quest for the perfect conservation measure. Both parties, for no very good reason, have dubbed these legal relations and interests "the law of capture"; to one the term is undoubtedly one of endearment, to the other an epithet of hate. The conservationists have considered and discussed various ways and means of ridding conservation legislation of these impediments, but they have not examined these relations and interests and the judicial process by which they were created for the purpose of determining whether or not they really are obstructive forces. Such is the purpose of this discussion.

The physical aggregate ordinarily designated "land", embraces more than the surface and the soil immediately thereunder. In addition to these, it is composed of various lesser physical aggregates such as air, light and space above the surface; water and growing things on the surface; and water and minerals, including oil and gas, beneath the surface. Any attempt to discover the nature of the landowner's legal interest respecting a distinguishable part of this total physical aggregate should begin, perhaps, with the hypothesis that one who has ownership or dominion over, or an absolute estate in, the total physical aggregate bounded by vertical planes projecting through the surface boundaries, extending upward to the infinite and downward to the earth's core, has legal rights that all others may not enter within these boundaries, and legal privileges as against all others of doing as he pleases therein. Such hyopthesis can never have been true in any legal system. It was announced long before situations arose by which its truth could be established and before the growth of civilization and the increasing knowledge of man made necessary the establishment of many legal principles proving its falsity. The shadow of its apparent truth has only survived in the form of the euphonious Latin phrase, *cuius est solum est usque ad caelam et ad inferos,* to haunt and misguide the unwary. To determine the nature of the landowner's legal interests, in these distinguishable physical aggregates, it was long ago concluded that they must be considered apart and on the basis of their physical and economic facts. The law of property is often referred to as the conservative and backward branch of the law, yet the history of social progress may be traced to the action of the courts, for the most part without the aid of statute, in fixing the legal relations of the landowner respecting these lesser physical aggregates. The law of nuisance, of riparian rights, of underground and surface waters, of lateral and subjacent support, the landowner's interest in solid minerals and in oil and gas, have all been established by this process. The presently developing law of the air is the most recent illustration.

When judges have been confronted with situations respecting these new physical aggregates, they all have not acted the same. Some have failed to comprehend the factual situations, have resorted to false analogies, and have

reached results whose only merit may be certainty. Others have had the power of mind to see the economic and physical facts of the particular subject matter, and to formulate a social policy based thereon, but have not had the mental courage to state plainly the reasons for their conclusions and have struggled to the limits of logic to place their decisions on the basis of precedent. Occasionally there have been judges who have analyzed the facts, formulated the policy thereon, and have had the courage to give the real reasons for their decisions.

When oil and gas became of commercial importance in this country and courts were first called upon to render decisions which had the effect of determining the nature of the landowner's property interest, there were no other known physical aggregates having the same physical and economic facts. All judges resorted to analogies with other physical subject matter for one purpose or another, although none of these analogies were true. Oil and gas were compared to solid minerals because they were said to be minerals and beneath the surface, and from this analogy it was deduced that they were subject to absolute ownership. They were compared to water because of their liquid nature, and from this it was concluded that the landowner had what was termed a "qualified" ownership of them. They were compared to wild animals because of their fugitive nature, and from this it was suggested that they were not even a proper subject of property. This analogy is the genesis of the capture terminology. The ardent conservationist of today, acquainted with all the known physical and economic facts of oil and gas, as disclosed by scientific research and practical operations, has, no doubt, considerable difficulty in understanding and appreciating the limited knowledge of the judges respecting these facts. The principal physical facts of oil and gas, with which the courts were familiar, were their liquid and volatile nature and their chemical composition. From these facts it could be easily deduced that they furnished no support to the surface, like solid minerals; they added nothing to the productivity of the soil and the use and enjoyment of the land for agricultural or residence purposes, like water; and that they were migratory in character. Even their migratory character was apparently much overestimated. It is now a well-known fact that oil and gas do not migrate from natural causes, but only do so when a well penetrates the structure, causing a reduction of pressure at the point of the well opening, yet there is language in some of the opinions indicating that the courts considered they had the natural power to propel themselves from place to place within the earth's structure.

Likewise, the courts were conversant with but few economic facts of oil and gas. Because of their liquid character and chemical composition, their economic values could be realized only throughout production. These values or uses were for heat, light and lubrication. These were horse and buggy

days, and apparently no one foresaw that with the perfection of the internal combustion engine, oil and gas would become the principal source of the world's motive power. Little thought was given to the extent of the supply or the possibilities of its exhaustion, for these substances were not of sufficient importance that their exhaustion would have crippled industry and have been regarded as a national calamity.

It was with such knowledge of the economic and physical facts of oil and gas that the courts in some of the early cases were asked to enjoin B from pumping oil or gas, or from locating his wells near the boundaries of his land because in so doing he would take some of the oil and gas from A's land. It is true that these judges resorted to false analogies of oil and gas to other substances to give some semblance of authoritative precedent to their decisions, but their conclusions must have been based upon the simple logic that if A can enjoin B from taking oil and gas because in so doing he may take some of A's oil or gas, then B can enjoin A for a similar reason, and most of the oil and gas must remain where nature placed it, to the injury of A and B and society generally. If those courts had known the physical characteristics of the oil and gas reservoir; that the chief propulsive forces in the production of oil are the pressures of edge-water and the expansive force of gas; that a proper utilization of these natural forces by each operator, through drilling methods, spacing of wells, and maintenance of back pressures, is necessary to secure the greatest ultimate production of oil and gas by all land owners within the structure; that drilling and production could be so controlled that no unreasonable noncompensated drainage would occur and that each landowner by such production methods would have the opportunity to recover his fair share of the oil or gas within the structure without crowding his property line with wells to prevent their escape; does anyone believe that they would have held that the landowner has absolute privileges of drilling wells at any place on his land to take oil and gas, regardless of the fact that much of the oil or gas so taken comes from his neighbor's land? But with the facts they had before them, they had no justifiable basis upon which to limit the privileges of the landowner or lessee in the method or amount of oil and gas that he took from the land.

It is true that in some of the older cases the courts ignored the physical facts of oil and gas as they were presented, and made erroneous decisions for that very reason. Perhaps the most notable example of this is the Pennsylvania case of Hague v. Wheeler. There the defendant threatened to open a nonproductive gas well on his land, the effect of which would be to reduce the pressure in the gas reservoir so as to prevent the plaintiff, an adjacent landowner, from marketing gas from his well. The evidence in this case disclosed physical facts of gas upon which the court should have recognized the legal rights of the plantiff in the common structure under the land and the legal

duties of the defendant not to violate those rights by waste of gas and injury to the structure through an open well on his land. But the court, mislead by its analogy of oil and gas to solid minerals, completely disregarded the peculiar physical facts of gas, and refused to recognize any right in the plaintiff or duties in the defendant as to the method or manner of taking. Yet in several other jurisdictions, where the physical facts have been made known to the courts, they have recognized a common law duty of a landowner to operate his land in the production of oil or gas so as not to injure the oil and gas reservoir and prevent others from taking from the common source of supply. It was in this group of cases that the courts established the rights of each landowner in the common structure that others not injure that structure by their methods of production on their own lands, and established duties in all operators not to waste oil or gas contrary to public interest. It is upon these principles that the constitutionality of practically all conservation legislation has been supported.

One may ask why the courts did not continue rendering opinions further establishing legal relations of landowners respecting oil and gas, upon the basis of further knowledge of the physical and economic facts. The answer is simple—such cases were not presented. The policy of conservation was growing, and as quickly as the increasing knowledge of these substances disclosed new methods of preventing waste, they were enacted into statute, as society could not await the creation of these legal relations by the slow judicial process, and the function of the courts became interpretative rather than creative.

Suppose in the light of all of the existing knowledge of the facts of oil and gas and of the physical characteristics of the oil and gas reservoir, and in the light of the known judicial processes by which legal interests are created, the cases which are said to have announced the so-called "rule of capture" were to be retried today in any of the principal oil and gas states, in the absence of any conservation legislation. That is, suppose A seeks to enjoin B from drilling a well on his own land near the boundary of A's land, and from operating the same to its full capacity. A shows, in support of the injunction, that B, by drilling wells on his land in the center of drilling units of certain acreage, limiting the production of such wells to a certain per cent of their open flow, and by a proper utilization of the reservoir energy, will secure his just and equitable share of the oil or gas from the common source of supply, and will suffer no non-compensated loss from drainage through wells on adjoining tracts. And suppose further that A clearly establishes that by the drilling and unlimited operation of the proposed well, drainage from A's land will take place, his rights will be violated by injury to the oil and gas reservoir, and physical waste will result to the detriment of society. Would the injunction be granted? One may well hesitate to predict what

any particular judge might hold in such a case. The judge who has the mental acumen to analyze the physical and economic facts as presented to him and to see that the best interests of A and B and of society in general is best served by a decree for the plantiff would grant such decree, and in so doing would be merely proceeding along the path made by judges who have for centuries kept the law apace with social progress. If this prediction is a safe one, why worry further about the so-called "law of capture" in so far as it is alleged to have been created in cases defining the legal relations of the landowner respecting oil and gas?

In determining the nature of the legal relations created by oil and gas leases, the courts have been influenced by the same rudimentary physical and economic facts of oil and gas upon which they first defined the landowner's legal interest respecting them. From the basis of these facts may be noted several other factors which influenced the formation and evolution of the lease and its interpretation and construction by the courts. With the most modern scientific methods of locating earth structures, it is impossible now, as it was in the beginning of the oil industry, for anyone to know, prior to actual drilling and production, of the existence and amount of oil or gas within, or capable of being produced from, a particular tract of land. These facts make it unwise from the standpoint of either the landowner or the producer to contract for the sale of the oil and gas in the land for a present cash consideration. Consequently the basic contract of oil and gas production, the lease, was so framed as to permit the lessee to explore the land upon the payment of a nominal consideration, but in the event of production, both might share in the proceeds. The principal consideration for which the lessor executed the lease was the royalties or rentals payable on production. Out of knowledge of the fact that oil and gas might escape or be taken by operations on neighboring lands, and the further fact that the lessor could only receive the consideration for which he executed the lease by production and the payment of royalties, the courts repeatedly stated that the predominant intention of the parties to such leases was the testing and development of the land, and that such leases should be so construed as to promote development and prevent delay.

This policy of the courts, which may be termed the policy of production or development, had its influence in the evolution of every important clause of the oil and gas lease as it exists today. This influence is particularly noticeable in the enforcement of express and implied covenants of the lease for testing and development. If leases contained express covenants for the drilling of test wells, if such covenants were made conditions by express forfeiture provisions, or if they stated limitations upon which they would terminate for failure to drill, the courts enforced them by judgments for damages or decrees of cancellation. Where leases did not contain express covenants and conditions

designed to force development, the courts implied them. The principal covenants so implied were to drill test wells, to drill additional wells after discovery in paying quantities, to drill offset wells to protect the land from drainage, and to market the oil and gas produced. For breaches of these covenants the courts gave a judgment for damages, or a decree for total or partial cancellation of the lease upon the theories of inadequacy of legal remedies, implied forfeiture, or abandonment.

The implied covenants of the lease, particularly the covenants to drill additional and protection wells, required some standard by which to measure their performance. In some of the early Pennsylvania and West Virginia cases, the view was expressed that the lessee's pecuniary interest in the production of oil and gas was such that his business judgment, exercised in good faith, was a sufficient guaranty to the lessor of the proper performance of these implied duties. But in other jurisdictions an objective test was preferred. Finally it became the established rule in a majority of the states that the oil and gas lessee in the performance of the implied covenants of the lease should do "whatever, in the circumstances, would be reasonably expected of an operator of ordinary prudence, having regard to the interests of both the lessor and the lessee."

In many cases setting forth their reasons for implying covenants for diligent operation, the courts have made statements to the effect that such diligence is necessary for the "common benefit," "common advantage," or "mutual interest," of the lessor and the lessee. From such language, standing alone, it might appear that the courts had in mind that the lessee should so develop and operate the property as to secure the greatest ultimate production of oil and gas, but when read in connection with the accompanying language, these statements appear to mean no more than that both are to gain by the production and sale of oil or gas before they are taken by adjoining owners.

In some of their opinions the courts have stated in detail such circumstances as should be taken into consideration by a jury in determining what a reasonably prudent operator would have done in a given situation. It may appear from these statements, such as the quantity of oil capable of being produced from the lease, the market demand and means of transportation, the extent and result of operations on the lease and surrounding lands, the character of the oil sand, and the usages of the business that they should be interpreted to mean that the lessee should so operate the premises as to secure the greatest ultimate production of oil or gas, but construed in the light of the known purpose of diligent operation so frequently and forcibly expressed by the courts, their only purpose is to aid the jury in determining whether it would be profitable for the lessee to drill and operate additional wells, the profit to the lessor being assumed.

This policy of the courts, enforcing development by lessees, has continued in unabated operation from the beginning of the industry with little apparent regard for the conflicting policies of conservation. The same judges which have interpreted oil and gas leases have passed on the constitutionality of conservation legislation. They are fully aware of the physical and economic facts of oil and gas. They have repeatedly recognized the correlative rights and duties of landowners and lessees in an oil and gas reservoir, and that such rights should not be violated by improper drilling and production methods. But when some of these same judges have before them the question of enforcement of implied covenants of a lease to drill additional and protection wells, they seem totally oblivious of the policy of conservation. In theory, at least, this conflict in policy is such that a judge may find himself in the anomalous position of one day forcing a lessee to drill and operate a well, if the jury decides that such well could be reasonably expected to yield a profit over and above the cost of drilling and operating, and on another day punishing the same lessee for the violation of a statute or regulation forbidding the drilling and operating of the same well.

The conservationist may well complain that the legal relations between the lessor and the lessee, as established through the interpretation of the lease by the courts, present a serious hindrance to conservation. It is believed, however, that the courts themselves can and should remove these hindrances. They implied covenants in leases for development, measured their performance by objective standards, and enforced their performance for the avowed purposes of serving what they conceived to be the best interests of the lessor and the lessee, and through them the best interests of society generally. It now appears that the forced drilling and operation of a well merely because it is expected to produce oil or gas in paying quantities, is contrary to the best interests of the lessor and the lessee because it may injure the oil and gas reservoir, preventing the greatest possible ultimate recovery of oil or gas therefrom, and violating the rights of other landowners, and is contrary to the best interests of society because it often results in physical and economic waste. The courts have the power, and in the light of modern knowledge respecting the physical and economic facts of oil and gas, they have the duty to effect some changes in the legal relations between the lessor and the lessee. If, instead of holding that a lessee owes his lessor the duty to drill and operate a well when it may be reasonably expected that such a well will produce a profit, the court holds that the lessee owes his lessor the legal duty and also has the legal privilege to drill and operate wells on the premises at such times, in such locations, and in such a manner as to secure the greatest ultimate production of oil or gas without waste or injury to the oil or gas reservoir, the interests of the lessor and the lessee would be better served, and the prevention of physical and economic waste more easily accomplished.

Such a change in the legal relations between the lessor and the lessee would by no means remove all of the obstacles to proposed conservation legislation. It would not remove the constitutional objections to compulsory unit development, but if every lessee owes his lessor the duty to drill and operate the land by the best known practices for the prevention of waste, and every lessor cannot object to the observances of these practices, voluntary agreements for unit development can be more easily accomplished.

ECONOMIC ASPECTS OF THE HEATING OIL MARKET*

By

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The quantity of fuel oil used for domestic heating in the Illinois fuel area in 1936 was 25,282,000 barrels, divided as follows among the states:

State	Barrels
Illinois	11,505,000
Indiana	1,487,000
Wisconsin	3,117,000
Minnesota	3,439,000
Iowa	1,207,000
Missouri	4,527,000
Total	25,282,000

The principal areas of consumption are near the refineries such as the Chicago area, St. Louis, Kansas City, or in Wisconsin and Minnesota cities accessible by rail and water transportation.

In addition to the use of fuel oil, there is a considerable consumption of so-called range oils for cooking and for use in small, portable heaters. This particular type of oil is becoming exceedingly popular if judged by the rate of growth of consumption in recent years. From a national consumption of 3,000,000 barrels in 1930 it has increased to 27,292,000 barrels in 1936. It is used most abundantly in the New England States but is rapidly finding increased markets in the Middle West also. Total consumption in the states comprising the Illinois fuel market area was 593,000 barrels in 1934, 1,111,000 barrels in 1935, and 1,505,000 barrels in 1936. The total quantity of oils used in commercial and domestic heating and for cooking in the Illinois coal market area amounted to 26,787,000 barrels in 1936. Consumption of heating oils in the United States in the meantime has risen from 43 million barrels in 1930 to approximately 100 million barrels in 1936.

Trends in Consumption.—Consumption of heating oils in the Illinois coal market area have increased rapidly since 1926. In the states of Illinois, Indiana, Wisconsin, Minnesota, Iowa and Missouri, consumption rose from 2,925,000 barrels in 1926 to 25,282,000 in 1936. Similar increases in consumption are shown in such important fuel consuming areas as New England and the Middle Atlantic States of New York, New Jersey and

* This paper has been published since the Conference in Coal-Heat, vol. 32, no. 5, pp. 10-14, 1937.

TABLE 1—CONSUMPTION OF HEATING OILS
(Thousands of barrels, 42 gallons each)

Year	Gas oil and distillate fuel	Range oil
1930	43,279	3,000
1931	40,578	4,529
1932	44,264	6,841
1933	50,140	10,629
1934	60,822	15,576
1935	76,853	21,526
1936	99,257	27,292

Pennsylvania. It is particularly significant that increase in fuel oil consumption occurs almost exclusively in the commercial and domestic heating field, whereas its use in manufacturing and transportation has remained practically constant. This is shown in table 2.

The upward trend of oil for heating purposes raises the question of the extent to which it may compete further with coal, and this leads directly into the nature of heating oil supply.

Heating oil for domestic use is obtained from the refinery fraction known as gas oil and distillate fuel. This fraction has a distillation range higher than kerosene and lower than the residual fuel oils. It may invade the distillation range in which kerosene now occurs and on the heavy end, it may include a portion of the fraction now included in residual oils. The distribution of refined products in 1936 from crude oils run to stills was as follows:

Product	Barrels	Per cent
Gasoline	504,724,000	47.2
Kerosene	56,082,000	5.2
Gas oil and distillate fuels	125,650,000	11.8
Residual oils	285,688,000	26.7
Lubricants	30,811,000	2.9
Solid residues, still gas and losses	.....	6.2
Total run to stills	1,068,134,000	100.0

The fraction from which heating oils are obtained represents, under 1936 conditions, 11.8 per cent of the crude run to stills.

Increased production of gas oil and distillate fuel from which oils are obtained has amply provided for a growing demand. This increase, since 1931, has been obtained both by increasing runs to stills and raising the percentage of crude oil refined into the gas oil and distillate fuel fraction. This is shown in table 3, for the United States and for the Illinois-Indiana-Kentucky refinery district.

TABLE 2—CONSUMPTION OF FUEL OILS IN THE UNITED STATES[a]

(Thousands of barrels)

Year	Total	For domestic heating	For other use	Used for domestic heating (Per cent)
1930	376,361	43,279	324,082	11.8
1931	329,137	40,578	288,559	12.3
1932	301,570	44,264	257,306	14.7
1933	308,347	50,140	258,207	16.2
1934	330,321	60,822	269,499	18.4
1935	365,985	76,853	289,131	21.0
1936	408,991	99,257	309,734	24.2

a Mineral Market Reports, No. M. M. S. 600, U. S. Bureau of Mines, Oct. 26, 1937.

TABLE 3—PRODUCTION OF GAS OIL AND DISTILLATE FUELS, 1931-1937

(Thousands of barrels)

Year	United States			Illinois-Indiana-Kentucky area		
	Crude run to stills	Fuel yield	Per cent	Crude run to stills	Fuel yield	Per cent
1931	834,608	83,822	9.4	.....	.....	.....
1932	819,997	69,467	8.5	106,758	8,008	7.5
1933	861,251	78,920	9.2	117,073	8,991	7.7
1934	895,636	94,972	10.6	119,166	11,593	9.7
1935	965,785	100,381	10.4	129,798	11,867	9.1
1936	1,068,134	125,650	11.8	147,724	16,124	10.9
1937[a]	566,911	68,450	12.1	.....	.....	.....

a Six months.

The growth of all heating is also shown by the rate of sales of new burners. Data are available for the years 1934 to 1937, as indicated in table 4.

TABLE 4—OIL BURNERS SHIPPED IN THE UNITED STATES, 1934-1937

Year	Number
1934	96,633
1935	134,649
1936	192,274
1937	187,478

Another indication of the growing domestic oil market, in addition to oil sales and burner shipments, is the total number of burner installations, by years. These are approximately as shown in the table on page 144[a].

Year	Installations	Year	Installations
1926	240,000	1932	840,000
1927	325,000	1933	920,000
1928	425,000	1934	1,010,000
1929	540,000	1935	1,150,000
1930	670,000	1936	1,345,000
1931	760,000		

a Lamp, June, 1937.

Consumption of oil for heating purposes now is about equal to one-fourth of oil consumption as a motor fuel. The heating oil fraction of crude has become a cash crop of the oil industry next in importance to gasoline. It is desirable, therefore, that the supply and market characteristics of this product of the oil refining industry be subjected to examination.

The Nature of the Market.—The demand for heating oils is more highly seasonal than other major refined oil products—gasoline and residual fuel oil. There appears to be a close correlation between outside temperature conditions and domestic fuel consumption. An actual test of fuel consumption (natural gas in this case) and monthly variations in temperature was made by the Peoples Gas Light and Coke Company in Chicago. Table 5 and figure 27 show the per cent of total degree-days for the heating season from September to June and also the per cent of fuel consumed. The close correlation between the two is apparent.

TABLE 5—COMPARISON OF ACTUAL CONSUMPTION (PER CENT) TO NUMBER OF DEGREE-DAYS (PER CENT) BY MONTHS FOR A HEATING SEASON, ON ONE INSTALLATION

Month	Degree days	Per cent of season's degree days	Actual consumption (Cu. ft.)	Per cent of season's consumption
September	85	1.4	2,900	1.0
October	343	5.7	17,000	5.95
November	900	14.8	43,500	15.2
December	1,059	17.4	49,000	17.1
January	891	14.7	44,100	15.4
February[a]	1,144	18.8	54,200	18.9
March	878	14.4	40,900	14.3
April	558	9.2	25,800	9.0
May	200	3.3	8,600	3.0
June	20	.3	400	.15
Total	6,078		286,400	

a February was unusually cold during the season figured above.

The hypothetical demand for 11,505,000 barrels of heating oil consumed in Illinois in 1936, using the average degree-day distribution for the city of Chicago would be as shown in table 6.

The actual demand for fuel oil will be modified, from the above hypothetical demand by purchases made before the heating season begins, summer purchases by those householders who have large storage tanks in their houses, and by commercial users.

The apparent monthly demand upon the output of refineries in the Illinois-Indiana-Kentucky refinery district is shown in table 7. The effect of severe winter weather in January and February of 1936 is shown by the high demands in these months and the near depletion of stocks. Consumption in these months exceeded those of January and February in 1937, although presumably there were more oil burners in operation in the latter year. High output of crude oil and heavy runs to stills enabled the refineries to build up stocks so that supply for the heating season of 1937–38 appears to be ample.

TABLE 6—MONTHLY DISTRIBUTION OF THE HEATING SEASON IN CHICAGO BAND ON DEGREE-DAY BELOW 65°

Month	Average temperature (—65°F)	Degree-days	Per cent of season's degree-days	Hypothetical fuel oil consumption (Barrels)
September	.....	.....	.....	.....
October	11	341	5.45	627,000
November	25	750	12.00	1,379,000
December	36	1,116	17.83	2,050,000
January	41	1,271	20.31	2,335,000
February	39	1,092	17.45	2,007,000
March	29	899	14.35	1,659,000
April	18	540	8.63	992,000
May	8	248	3.96	456,000
June	.....	.....	.....	.....
Total	.....	6,257		11,505,000

Demand and Price.—Prices of domestic heating oils fall somewhere between 6½ to 7½ cents per gallon, depending upon location, season of the year and quantity purchased. The coal price equivalent of an average oil price of 7 cents, assuming for the time being, equal deficiencies in combustion, varies from $11.50 per ton for 10,000 B.t.u. coal to $14.00 for 12,500 B.t.u. coal.[1] If a higher efficiency is assumed for oil, the coal cost equivalent would be correspondingly less. Heating oils, at present prices, therefore appear to fall in a class of higher than average priced domestic coal. The rate of oil burner installation indicates that this price level does not have an adverse effect upon the use of oil for heating houses nor has it curtailed the sale of new burner installations. The consumer is willing to pay a fairly high price

[1] After table by C. V. Beck, and published by *Coal Heat.*

for the convenience afforded by oil heat. The position may change, however, if prices of heating oil should rise substantially.

A record of heating oil costs in a new six-room, two-story frame dwelling in Urbana, Illinois, for five years—1932–33 to 1936–37—shows a consumption of 5,860 gallons at a cost of $402.79, or an average consumption of 1,172 gallons per year and an average annual cost of $80.56.[2]

It may be of interest to calculate the cost of heating this home with assumed higher prices for oil.

[2] Data by lessee.

TABLE 7—GAS OIL AND FUEL DISTILLATE
(Thousands of barrels)

Year—Month	Production	Stocks	Change in stocks	Apparent consumption
1935—				
January	1,148	2,770	—508	1,656
February	813	2,012	—250	1,063
March	1,132	2,258	+246	886
April	735	2,062	—256	991
May	945	2,163	+101	844
June	944	2,510	+347	597
July	1,043	3,014	+504	539
August	794	2,937	— 77	871
September	879	2,696	—241	1,120
October	1,131	2,578	—118	1,249
November	1,098	2,367	—211	1,309
December	1,205	1,776	—591	1,796
1936—				
January	1,334	1,148	—628	1,962
February	1,699	907	—241	1,940
March	1,270	1,075	+168	1,102
April	1,159	1,074	— 1	1,160
May	1,355	1,548	+474	881
June	1,249	2,100	+552	697
July	1,198	2,650	+550	648
August	1,317	3,052	+402	915
September	1,315	3,205	+153	1,162
October	1,449	3,165	— 40	1,489
November	1,353	2,962	—203	1,556
December	1,476	2,508	—454	1,930
1937—				
January	1,514	2,217	—391	1,805
February	1,344	2,000	—217	1,561
March	1,319	1,698	—302	1,621
April	1,309	1,771	+ 73	1,236
May	1,351	2,147	+376	975
June	1,349	2,643	+496	854
July	1,408	3,214	+571	837
August	1,432	3,669	+455	977
September	1,444	3,733	+ 64	1,380
October	1,522	3,628	—105	1,627
November	1,300	2,995	—633	1,933
December	1,741	2,538	—457	2,198

TABLE 8—COST OF HEATING A HOME ASSUMING HIGHER OIL PRICES

Gallons of oil used	Cost, cents (Per gallon)	Total cost (5 years)	Average annual cost
1172 (5 year average)	.....	.....	.....
5,860	6.88[a]	$402.79[a]	$ 80.56[a]
5,860	8.00[b]	468.80	93.35
5,860	9.00[b]	527.40	105.48
5,860	10.00[b]	586.00	117.20

a Data by lessee.
b Assumed prices.

A similar type of house, also of frame construction equipped with a hand-fired coal furnace, used 8 tons of coal of about 14,000 B.t.u. and average cost of $65.00 per year for the two-year period.

For these cases, at least, the cost of heating oil was about 25 per cent above that of a high rank coal. We shall not attempt to forecast the point of price difference where householders will prefer coal to oil. It would vary with the individual. In those communities served by natural gas, a pronounced rise in price of fuel oil will bring about increased competition from gas as well as from coal.

Now, with respect to possible price changes of these three fuels, it depends upon relation of demand to available supply. A shortage of coal need not be anticipated. Present facilities are more than adequate to supply current needs and reserves are ample. The question of petroleum supply appears to be more critical. Estimates of natural gas supply are less well established than those of coal, but the immediate outlook seems to point to an adequate supply for at least 20 years.

TABLE 9—TRENDS IN PRODUCTION, CONSUMPTION, AND STOCKS OF CRUDE PETROLEUM AND REFINED PRODUCTS, 1932-1936
(Millions of barrels)

Production	1932	1936	Change (Per cent)
Crude oil output	785.2	1,098.5	+40
Crude run to stills	820.0	1,068.1	+30
Consumption—			
Gasoline	373.9	479.7	+28
Fuel oil	301.6	408.9	+35
Stocks—			
Crude oil	339.9	288.1	—15
Gasoline	51.1	56.4	+10
Gas oil and distillate fuel	14.3	19.9	+39
Residual fuel oil	116.4	84.2	—28
(Total refined products)	181.8	160.5	—11
Heating oil consumption	44.3	90.0	+100
Combined consumption of gasoline and heating oil	418.2	569.7	+36

Supply.—In considering the question of supplying the increasing demand for heating oils together with meeting also a sustained or increasing demand for gasoline, we are compelled to consider the adequacy of annual supply at existing price levels or at least not much higher than existing price levels. The record over the past few years shows that a growing heating oil demand has been met by increasing the gas oil and distillate fuel fraction and also by an increased crude run to stills since 1932.

Table 9 has been prepared to show the trend of production, consumption, and change in stocks of crude oil and its principal products from 1932 to 1936. During this period the use of oil for domestic and commercial heating doubled in quantity.

An examination of this table shows that increased production of petroleum has kept pace with increased demand for gasoline, but that heating oil consumption has risen more rapidly. This is reflected in a decrease of crude oil stocks of 15 per cent. The total stocks of refined products have dropped also, although gasoline and gas oil stocks show an increase, but not out of keeping with increased demand.

Increased consumption of the two major cash crops of the oil industry —gasoline and heating oils—in this period was 36 per cent.

The more than proportional increased demand in heating oil has been supplied, from 1932 to 1936, by drawing from the lighter portions of the residual fuel oil stock. In spite of this reserve source, the severe winter weather caused a heavy drain upon stocks of the gas oil and distillate fuel fraction. In the Illinois-Indiana-Kentucky refinery district, for example, stocks in the hands of refiners in February, 1936, fell to 907,000 barrels while apparent consumption for that month was 1,940,000 barrels. The heavy increase in runs to stills in 1936 and 1937 served to replenish the supply so that there were ample stocks in 1936–37 and the industry is entering the heating season of 1937–38 with ample but not excessive stocks on hand. This is accounted for by the event of a considerably milder winter in 1936–37 and an increased run to stills. The present fairly ample supply is accounted for by an increased run to stills of 10.5 per cent in the first 7 months of 1937 over 1936. The change in stocks of crude oil and principal refined products since December 31, 1936, in millions of barrels is as follows:

	December 31, 1936	July 31, 1937	Change (Per cent)
Crude petroleum.....	288.1	308.7	+20.6
Gasoline.....	56.4	70.1	+24.4
Gas oil and distillate fuel	19.9	23.6	+23.6
Residual fuel oil.....	84.1	84.2	0.0

From the above data, the record for 1937 would appear to be one of overproduction. As a matter of fact, this must be accepted somewhat with qualifications.

It is probably desirable to reduce crude stocks somewhat below the level of 309 million barrels. The gasoline figure also seems unnecessarily high at a date when seasonal consumption is declining. With regard to heating oils as represented by the gas oil and distillate fuel fraction, there appears to be no excess in comparison with previous years and also in comparison with estimated demand. Stocks on hand July 31, 1937, and two previous years, and estimated consumption of heating oil for the calendar year is as follows:

Date	Stocks on hand (Thousands of barrels)	Consumption (Thousands of barrels)
July 31, 1935.....	22,915	76,853
July 31, 1936.....	24,814	99,257
July 31, 1937.....	23,637	115,000

Under present conditions, therefore, the country will enter the 1937–38 heating season with sufficient but not excessive supplies of heating oils. If heating oils demand continues to increase, however, two problems arise which must be considered by the oil industry, namely:

(1) The adjustment of refinery runs to prevent an excessive seasonal accumulation of gasoline and heating oil stocks.

(2) The question of an adequate annual supply of crude oil to meet the expected increase in demand of gasoline and heating oils. This problem may be several years in making its appearance, but eventually it will affect supply and price of heating oils.

A substantial increase in demand of heating oils, if such occurs, must be provided by the following means, each of which will be analyzed:

(1) Diversion of gasoline cracking stock into heating oil market and increased runs to stills.

(2) Further conversion of residual fuel oils into heating oils.

(3) An increase of petroleum output.

Considering the first source of heating oils, *i.e.,* the diversion of gasoline cracking stock into the heating oil market, this is possible only under overstocked conditions such as appeared in 1937. Furthermore, this must be combined with the economic advantage, or necessity of preventing too large seasonal accumulation of stocks. Figure 25 will aid in clarifying this point. This figure shows the seasonal trend of gasoline and gas oil stocks for 1935 and 1936.

As long as the demand for heating oil increases faster than the demand for gasoline, under present refining practices, the seasonal accumulation of stocks will become more pronounced each year and with it a temptation to break prices. The seasonal fluctuation in demand for heating oils as compared with residual fuel oils is also shown in Figures 24 and 26. As long as the heating oil demand was a minor factor in the market, this was not serious, but now that it has risen to 20 per cent of the gasoline demand and

promises to go higher this becomes serious. The alternative to this condition is to vary refinery runs seasonally so as to reduce percentage of gasoline output in the winter season and to increase heating oils output correspond-

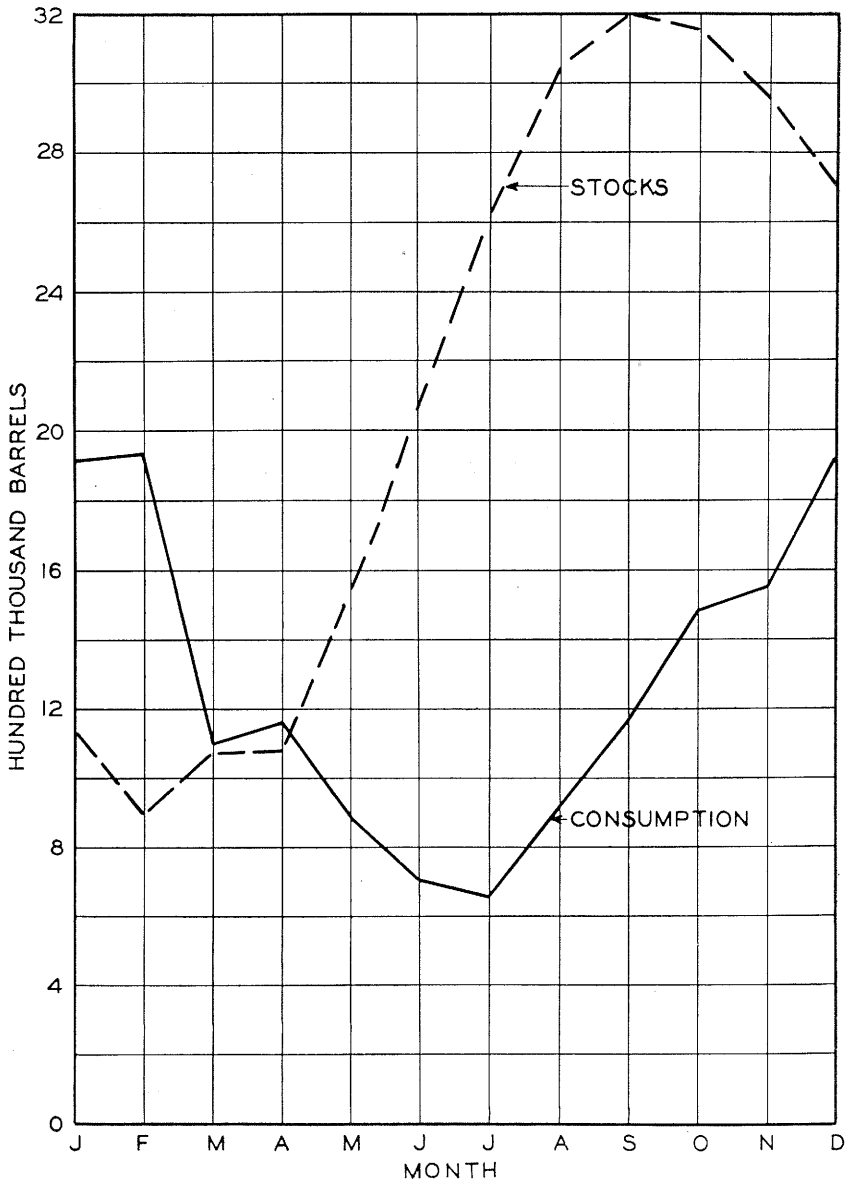

FIGURE 24.—Stocks and indicated consumption of gas oil and distillate fuel in 1936, in the refining district of the Central West.

ingly. This can be obtained from stock which is now cracked into gasoline. Let us repeat, this is feasible only when runs to stills are so large that an unwieldy surplus of immediately available gasoline is being produced. If the seasonal stock gasoline supply is not excessive and can be sold at a profit over holding costs in the following summer, the refiner must then choose between the alternative of carrying storage cost on gasoline that can ultimately be sold, or immediately disposing of an uncracked portion for heating oils at a lower per gallon cost. In other words, is cracking stock plus cracking costs plus holding costs more profitable with gasoline at 5 cents than immediate sale of the product as heating oil at 3½ cents?

The utilization of cracking stock for heating oil purposes is conditional upon a supply of crude ample for both gasoline and heating oil markets. This immediately raises two questions: How much oil will be needed for these markets in the near future, and what are the prospects of future oil output?

Consumption in the Immediate Future.—There is submitted herewith a provisional table (No. 10) of anticipated consumption of gasoline and heating oils.

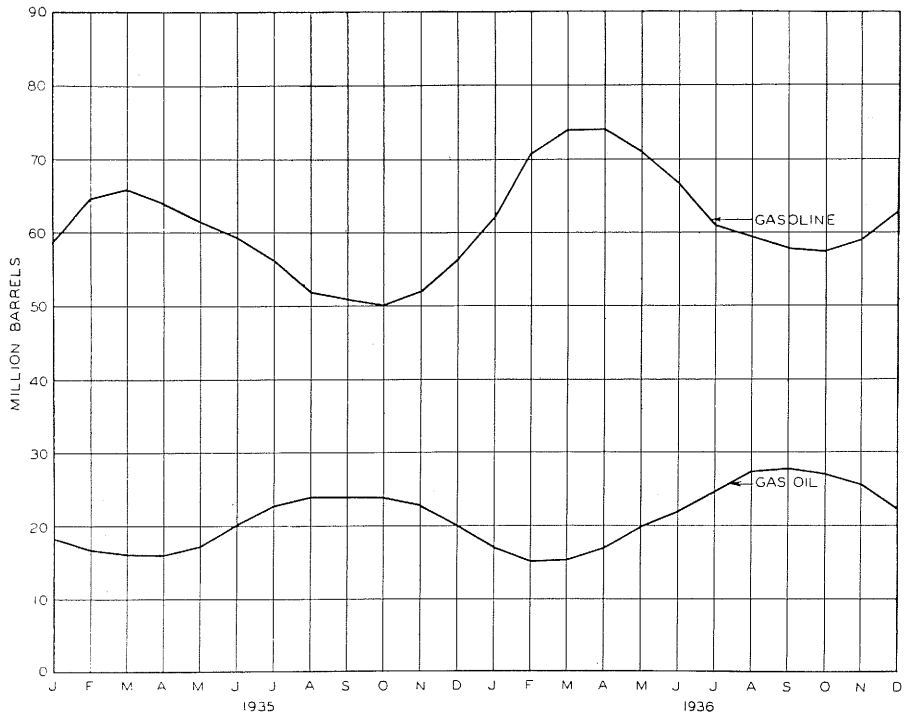

FIGURE 25.—Stocks of gasoline, gas oil, and distillate fuel in 1935 and 1936.

This is not intended to be an elaborate forecast of the demand for these two refined products in the next five years. Too many things can happen in such a space of time to alter trends substantially. Since 1931, gasoline consumption has increased an average of 4 per cent annually. For the next five years an average annual increase of 2 per cent is assumed. Heating oils have increased an average of 22 per cent since 1931. An average annual increase of 10 per cent is assumed for the next five years. Such a tentative schedule is believed to be conservative and provides us, at least, with a tentative basis of calculating crude requirements. This rises from 1,170 million barrels in 1937 to 1,340 million barrels in 1941 (or about 3,700,000 barrels per day), assuming the same ratio of refined products to crude runs as today. This requires an increase of petroleum output of 10 per cent at the end of five years, not a very large order in terms of what has been done in the past.

TABLE 10—ANTICIPATED CONSUMPTION OF GASOLINE AND HEATING OILS
(Millions of barrels)

Year	Gasoline consumption	Heating oil consumption	Total demand	Crude requirements
1937	520	105	625	1,170
1938	530	116	646	1,210
1939	540	127	667	1,250
1940	550	140	690	1,300
1941	560	154	714	1,340

This is, however, entirely speculative. Oil burner installation may increase at a more rapid pace or again it may not. Much depends upon price and this hinges upon the relation of annual supply to current demand.

Whether demand rises to a conservative level of 3,700,000 barrels per day or exceeds that and reaches as much as 4,000,000 barrels per day, the crucial question is that of the ability of the oil industry to find a billion and a quarter barrels of oil each year to replenish the annual withdrawals from the known reserve. In this connection, the analysis by W. E. Pratt of the Standard Oil Company of New Jersey, of the discovery rates in oil finding is illuminating. The data, as presented by Pratt, is summarized in table 11.

Of particular significance is the high discovery rate, both of total estimated reserve and number of pools in the period from 1926 to 1930 and the sharp decline in the five-year period thereafter. Secondly, it should be noticed that from 1931 to 1935 (and this holds true for 1936 also) the rate of discovery has fallen below production.

The known petroleum reserve is now estimated at 13 billion barrels. This may be called a working balance. Each year new discoveries add to this reserve and annual withdrawals subtract from it. The net balance is

TABLE 11—DISCOVERY RATES IN OIL FINDING

Year	Average annual production (Millions of barrels)	Average annual discoveries (Millions of barrels)	Number of major fields discovered	Ratio of production to discovery
1901-1905	101	345	10	3.4
1906-1910	173	300	5	1.7
1911-1915	248	435	18	1.8
1916-1920	362	660	23	1.8
1921-1925	648	875	40	1.4
1926-1930	896	2,165	59	2.5
1931-1935	889	725	41	0.8
Total	.....	.....	196	

constantly varying. If the 1931–35 rate of production and discovery of petroleum is maintained this working balance would decline slowly and be extended 50 years or more. This is merely speculative. Of immediate interest is the relation of this working balance to possible sustained production. While the 13 billion appears to be a large and unwieldy balance, the point of interest is not the size of the total balance but the annual availability of that balance. To quote Mr. Pratt:[3]

> "If oil is to be produced efficiently, that is, if recovery is to be reasonably complete and unit cost low, it must be produced at a rate slower than in the past. The optimum rate of production for a given pool depends, among other factors, on the size of the reserve. The rate of production necessary to meet our national needs has risen until our present reserves are hardly large enough to permit efficient production at the required rate. This fact is coming to be recognized despite our current ability to produce, temporarily, in excess of market demand. We need all of our present reserve, or more, to permit efficient production at our present rate of consumption."

If Mr. Pratt's conclusions are correct, the danger point of efficient, low-cost productions is approaching and one of two things must occur: (1) A rate of production higher than the economic rate of recovery with the effect of hastening the depletion of low-cost oil reserves and setting forward the date of higher prices; or (2) production at a lower level with a consequent shortage of oil for the present type of market demand.

Now it is necessary to explain carefully the meaning of the term "shortage" and the effect upon the oil market. There will result no severe dislocation of the oil market or of those industrial enterprises using oil as fuel. A slight decline of production below present level of consumption

[3] Pratt, W. E., Discovery rates in oil finding: Bull. Am. Assoc. Petroleum Geologists, vol. 21, pp. 697-705, 1937.

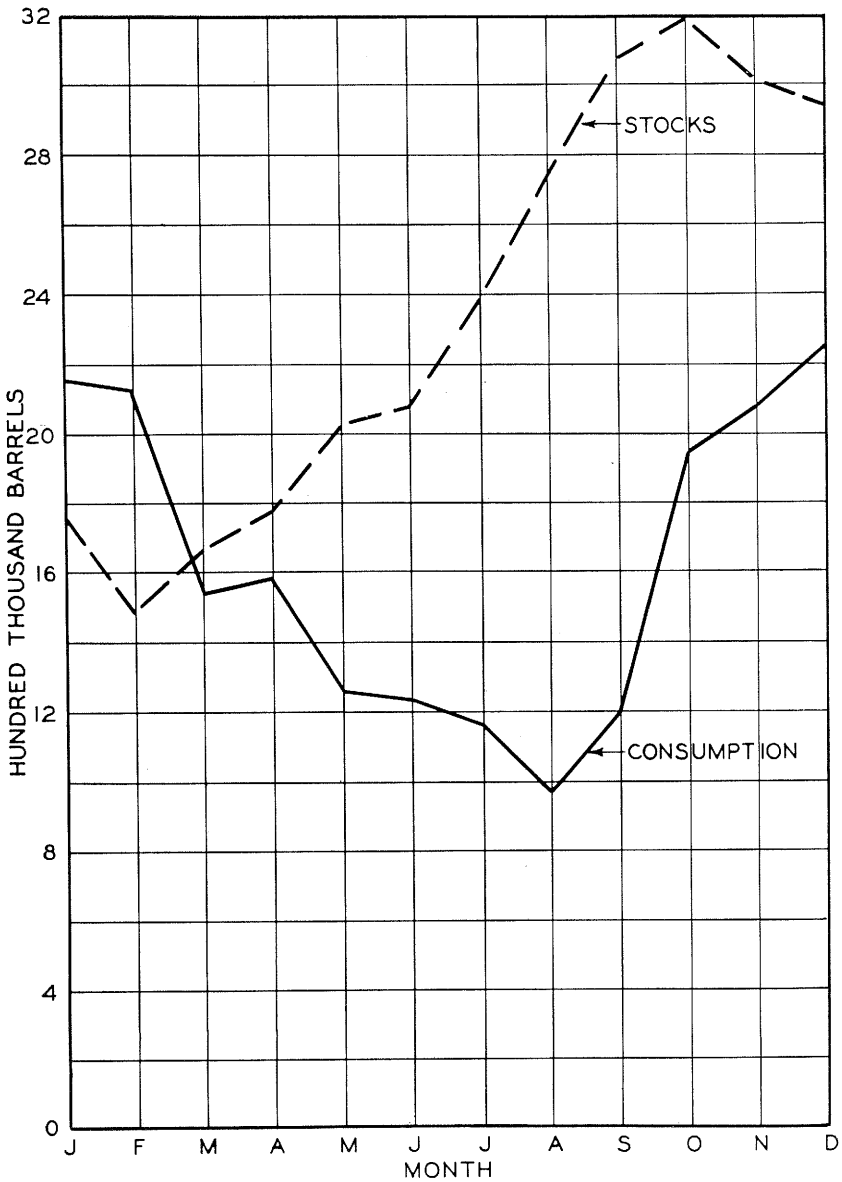

FIGURE 26.—Stocks and indicated consumption of residual fuel oil in 1936, in the refining district of the Central West.

at this stage merely means that oil sold as dump fuel or, in competition with coal, will be withdrawn from these uses with little difficulty and diverted to preferred oil markets. There will need to be a higher recovery of gasoline to maintain motor fuel demand, either through more cracking, polymerization or, eventually, even hydrogenation of heavy residual oils. But this condition, when it arrives, will be accompanied by higher prices of gasoline and gasoline-making stock. The motor fuel market will absorb some of the product now going into heating oils and a price rise in the latter will follow.

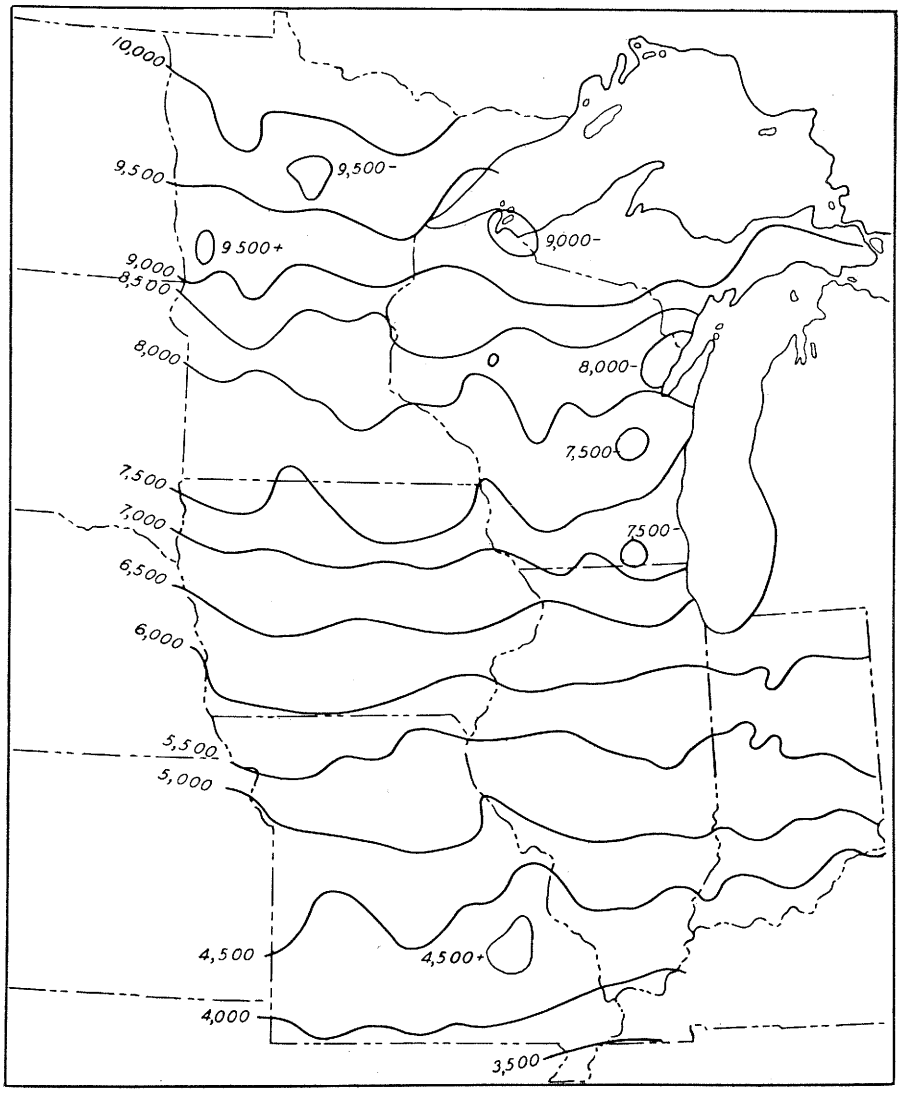

FIGURE 27.—A degree-day map of the Illinois coal market area.

We have not mentioned, in this connection, the possible effect of expansion in the use of Diesel engines. Data on the amount of oil used by Diesel installations is meagre and we do not know that it is a significant factor in the total energy market. It is probable that the Diesel engine can stand a higher price level than the domestic fuel market and to the extent that the Diesel installations become a factor in the oil market, the competition among oil users will become stronger.

CONCLUSION

The oil industry may, by 1941, be geared up to supply between 152 to 180 million barrels of heating oil to householders, as compared with about 100 million barrels in 1936. In the meantime gasoline demand will also have risen and a substantial change in the character of the oil market is to be expected. A pronounced rise in price, if it occurs, will result in the reversion to coal of certain fuel consumers now using oil.

The first to change will be the manufacturing industries. This will affect mainly the heavy residual oils. This group would be followed by public utilities, and where local supplies are available, by oil refineries and railroads. Domestic heating use will tend to change more slowly. The householder is not as likely to scrap equipment as readily as a manufacturer or a railroad.

For the oil industry, a rise in price of heating oils will not become critical unless oil burner installation proceeds so rapidly that a serious unbalance between demand and supply occurs. The ensuing price rise that would result would have the effect of bringing about a considerable reversion to other types of fuel and bring demand for heating oils below the point that the industry is equipped and prepared to supply.

CURRENT DEVELOPMENTS IN CLAY AND CLAY PRODUCTS

COMPARATIVE STATUS OF CLAY MINERALOGY IN EUROPE AND THE UNITED STATES

By

R. E. Grim

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It was the writer's privilege to attend the scientific sessions and excursions of the International Geological Congress in Russia this past summer. A number of European laboratories in which the constitution of clay is actively being studied were visited before and after the activities of the Congress. In the time allotted some of the ideas and thoughts gained as a result of these visits will be presented. At the outset, however, it is necessary to consider very briefly and in very general terms the present concepts on the mineral constitution of clays.

The problem of the mineral composition of clays is a very old one and one that has occupied the attention of investigators for many years. It is rather easy to identify the coarser constituents of clay by means of the petrographic microscope but it is not easy to investigate the constitution of the finest—the so-called colloidal fractions of the clays. It is this finest fraction that is most important in determining what the properties of a given clay shall be. Early work on this problem was mainly chemical in nature and a large body of valuable data are available as a result of this study. It did not, however, provide an adequate picture of the constitution, particularly the mineral constitution of this material, and it was not possible to explain satisfactorily the variations in the properties which different clays are known to possess on the basis of this early work.

About ten years ago with the advent of X-ray diffraction analysis a new procedure was made available for studying the finest fraction of clays and shales. Since that time there has been renewed interest in this problem and several laboratories in various countries have been actively engaged in investigating the exact constitution of clays. In the last few years microscopic technique has been improved so that now it is possible to carry the petrographic analyses with the microscope to smaller particles than was formerly possible. Also it has been found possible to apply microscopic technique to aggregates of extremely minute particles which cannot be seen individually.

In addition to these improvements the use of the supercentrifuge has been applied to clay researches and this apparatus has permitted the relative purification of mineral constituents in the colloid size range. All of this recent work has served to establish the thesis that clays and shales are essentially composed of extremely minute particles of one or more of a group of minerals which have come to be known as the clay minerals. The most important clay minerals are kaolinite, montmorillonite-beidellite and their iron end member nontronite, and illite. There are other clay minerals but information to date would suggest that these three are the most important ones. Clays and shales may contain varying amounts of quartz, calcite, organic material, etc., in addition to the clay minerals, which are mainly compounds of alumina, silica, and water.

One of the important pieces of work being done in European laboratories is the mineralogical analysis of all types of clays with these new techniques. Here in Illinois we are carrying on similar work in our attempt to catalog completely the kinds of clays we have in the State and the types of clay which may be used in various industries and which are not now produced in Illinois. The exact procedure used in making these mineral analyses is not the same in all laboratories. In Germany it is generally felt that X-ray analyses alone are sufficient to determine the mineral composition of clays. Here we are of the opinion that a satisfactory determination of the mineral composition of clays and shales can only be gained by X-ray, optical and chemical analyses.

All of this work on the constitution of clays is leading, or in some cases has already led, to the investigation of the influence of specific clay minerals on the ceramic and physical properties of clays. It is important to know what properties a clay composed of montmorillonite will have which a clay composed of kaolinite will not have, etc. A considerable amount of work in this direction has been done and is being done in our own laboratory and in certain laboratories in Germany. This work has indicated the conclusion that the clay mineral constituent is perhaps the most important factor determining the properties of the clay itself. For example, in general clays composed of kaolinite are refractory, not very plastic, and possess low bonding strength, whereas clays composed of montmorillonite are very plastic, not refractory, and have high bonding power. The information being gained from this work would seem to indicate that for the first time we are obtaining a reasonable answer to the question—why do certain clays possess the properties they do? It is becoming possible, for example, to understand why the famous Gros Almerode glass pot clays possess a long vitrification range and low shrinkage. The answer seems to be the presence of a large amount of very small quartz grains, the size of the particles of the chief constituent (kaolinite), and the presence of a small amount of montmorillonite.

In order to fully understand the influence of various clay minerals on physical properties it is necessary to know in detail all of the characteristics of the pure clay minerals themselves and at the present time a large amount of work is being done on this problem in laboratories in England, Holland, France, and Germany. As a result we are beginning to obtain a satisfactory picture of the lattice structure of these minerals. There are many problems still to be solved before these structures will be fully understood. By following the work of Pauling a considerable body of information on this subject is now available. A large amount of work has been done in the past on the influence of heat on kaolins in which kaolinite is the chief constituent. At the present time the influence of heat on the other clay minerals is actively being investigated. This work is of great importance as it forms the basis of an understanding of refractoriness in clays. It is also necessary to completely understand the durability of clays which are used in preparing synthetic molding sands, and it forms the basis of attempts which are continually being made to use clays as the source of metallic aluminum. In this connection it is interesting to note the work which has been done in this country on the influence of variations in particle size of certain clay minerals as they are subjected to elevated temperatures. The results of this work are not yet clear and at the present time data obtained in certain European laboratories do not seem to check results obtained by American investigators.

In the last three or four years active work has been carried forward in Germany and in two American laboratories on the synthesis of clay minerals. Unfortunately the work of the German laboratory which up until now has been most active in this field has been halted; perhaps it will be taken up elsewhere in that country. It has been possible to produce synthetically a large enough amount of kaolinite to produce some burned ware from it. The object of burning the ware was to determine the ceramic properties of the synthetic kaolinite. There is no thought yet of any commercial application but the work will bear close watching. This work on the synthesis of clay minerals has greatly increased our understanding of the conditions under which these minerals form in nature, and the range in which they are stable.

Various mineral materials possess a property which is known as base exchange capacity. Perhaps the phenomena of base exchange can be visualized best by reference to the zeolite or permutite water softeners. Water is hard because it contains calcium compounds, popularly known as "lime." As the hard water passes through the zeolite softener the calcium of the water is exchanged for sodium which the zeolite originally contained. That is to say, sodium goes from the zeolite to the water in exchange for calcium which goes from the water to the zeolite thereby softening the water. Passing a salt solution through the softener reverses the process, reviving the softener. Soil investigators have known for many years that the colloidal fraction of

most soils possess this property of carrying bases which are exchangeable under certain conditions for other bases. About five years ago a group of German investigators presented an outstanding contribution to the study of the constitution of clays and shales in which they pointed out the capacity of various clay minerals to carry exchangeable bases. They also indicated the exchange capacity of various types of clay and made the further extremely important contribution by indicating that the physical properties of clays with appreciable base exchange capacity varied with the exchangeable base that was present. For example, given clays will have different plasticities depending upon whether sodium or calcium is present in the clay as the exchangeable base. Of course it has been known by ceramists for many years that some properties of clays could be varied by treating them with acids and alkalis but the concept of base exchange in clays provides, perhaps for the first time, a satisfactory fundamental basis for understanding exactly how the properties are influenced by various chemicals. It seems to the writer that this is a fundamental approach to an understanding of clay properties which holds great promise for the development of means whereby the properties of a given clay may be controlled and improved.

At the present time a very large amount of work is being done in many laboratories on the general subject of base exchange in relation to clay constitution. Already we have information which would indicate the exchange capacity of the different clay minerals. Work is actively being carried on in an attempt to determine the reasons why clay minerals possess their characteristic exchange capacities. Various papers have appeared and work is being continued in an attempt to determine the relation of exchangeable bases to the lattice structures of the minerals. Thus an English investigator, who in the last few months has moved to this country, has suggested that base exchange is related to the presence of an expanding lattice structure which certain clay minerals possess. By an expanding lattice is meant the property of certain clay minerals to expand in one direction with the addition of small amounts of water. The whole problem of the causes of base exchange and the factors controlling it is at the present time, far from being solved. The work now being done will, it is hoped, enable us to fully understand base exchange.

In the Survey laboratory investigations are in progress studying the influence of specific exchangeable bases on the physical and ceramic properties of clays. It is planned to determine if possible exactly how exchangeable calcium, sodium and other alkalis and alkaline earths will influence the properties of Illinois clays and shales. It was a pleasure to learn this summer that a similar piece of research is just being started on English clays. In Germany also work in several laboratories is being carried forward in this direction.

One point in regard to base exchange in which there is considerable interest and considerable disagreement among investigators at the present time is the influence of extreme grinding on exchange capacity. On the basis of their work, one American laboratory has concluded that the exchange capacity of certain minerals can be very greatly increased by extreme grinding. The importance of such a finding is evident in view of the importance of exchangeable bases and base exchange generally on the physical properties of clays. Various German investigators have attempted to duplicate this work and so far have not been able to obtain the same results as the American investigators. Perhaps within the next year or two more will be known about this matter.

In recent years there has been a great deal of interest in European countries in bentonite. The literature of the last year or two is filled with references to new deposits of bentonite which have been found. Germany, for example, has found that it has large scattered deposits of this type of clay. Russia has large deposits of bentonite. The interesting feature of much natural German bentonite is that it possesses few of the physical properties characteristic of American bentonites for the reason that it contains calcium as the exchangeable base whereas much of our bentonite contains sodium as the exchangeable base. Some German bentonite producers are now treating their clay in order to exchange its calcium for sodium before it is put on the market.

German and Austrian engineers interested in soil mechanics have been doing some interesting work in recent years by passing an electrical current through clay, noting its effect on the physical properties. They have shown, for example, that with this treatment it is possible to increase the loading strength of a very plastic clay. This work is being carried further and at the present time some very interesting research is being done in Austria on the influence of electrical current on other physical properties of clays and clay suspensions. It is the writer's opinion that such work will warrant careful watching to see whether or not it has any practical application in the utilization of clay and shales.

The rather widespread use of natural rocks for refractory purposes was one of the impressive things revealed in talking with European clay men. As is well known, that is being done to some extent in this country—certain hard stones have been used for refractory purposes—but there seemed to be more interest in such refractory material in those countries than in our own. Germany, for example, is using rather extensively a slightly laminated sandstone for this purpose. One of the desirable properties possessed by this rock is its ability to break rather easily into slabs an inch or two in thickness. In Russia it was interesting to learn of the use of a slightly weathered igneous rock for refractory purposes in an unfired condition. It wasn't

possible to learn very much about this material but it was understood that the natural material is quarried in regular blocks and then heated to a temperature of only a few hundred degrees Centigrade before it is used for furnace linings. A distinct impression of the growing importance of raw and semi-raw rocks for refractory purposes was gained.

During the visit to Germany the writer was fortunate enough to visit the Gros Almerode clay deposit near Kassell which is well known for the production of glass pot clays. This clay occurs between beds of low grade coal and in somewhat the same way as does the underclay in this State. Great care is taken in this clay producing plant to insure uniformity of the product produced. As the clay comes from the mine it is moved along a conveyor belt where impurities are picked out by hand, and the larger pieces of clay are broken apart by hand in order that no impurity shall escape detection. Much of this clay is burned at the plant and sold as grog for making glass pots. After the clay comes from the kiln it is again hand picked in order to remove all impurities.

One of the reasons for the visit to this plant was that it contains one of the few electro-osmosis installations for the purification of clays. Briefly this is a procedure making use of the difference in electrical properties of the clay mineral particles and the impurities for the elimination of the latter. The process is quite expensive, however, and can only be used on a product which commands a very high price.

It was the writer's good fortune to travel about 13,000 miles in Russia this summer in the two months spent there. A visit to the Ceramic Research Institute at Kharkov could not be arranged and consequently it is not possible to discuss the work being done there. As a result of conversations with various Russian scientists it is believed that the Russians have done little work on their clays up to the present time. They seem to be just beginning the intensive search for various types of clays and the intensive studies of the properties of the clays which the country possesses. It is logical that the search for and the study of clays should follow the intensive search for metallic resources. The Russians in the last ten or fifteen years have intensively searched their country for natural resources. They claim that there are 40,000 geologists in Russia and although this figure cannot be vouched for, there are certainly a lot of them and a great amount of study is being done on their natural resources. These are not only being studied in the field—their properties are being studied in the laboratory. Research institutes for every conceivable branch of science have been established; frequently not one for a given field, but several, located in different parts of the country. Russian scientific literature is appearing in tremendous volumes. It will be increasingly important for those engaged in clay research in this country to follow the results of the work on Russian clay investigations.

PROGRESS, POSSIBILITIES AND LIMITATIONS IN THE BENEFICIATION OF CLAYS

By

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When your Chairman asked me to talk on the beneficiation of the common clays, I demurred, stating that I should prefer to eliminate the word "common" from the title, thinking, of course, to include those pottery clays on which so much work has been done in the recent past. Dr. Leighton reminded me in the meantime that a large proportion of the attendance was interested in information having to do with the common clays and their use in industry. Realizing the limited time at my disposal, I have accordingly decided to stress the common clays, although I shall review briefly the work on the pottery clays to give us a background for a study of the common clays. I shall have time to do little more than tabulate the things that have been done in the field.

I should like to expand the term "beneficiation" in this instance to include any process or device which will render the clay better suited to the production of a marketable ware. This is probably an undue expansion of the more technical meaning of the term, but we shall consider it in this light in the present manuscript. The concentration engineer will probably have a much more narrow conception of "beneficiation", including only those modern processes which have to do with flotation, tabling, electrostatic, and electromagnetic methods. The ceramic engineer, on the contrary, is interested in the problem from the standpoint of product only.

The difficulties encountered in the fabrication of a ceramic product have to do with the way the material flows through the die, how it dries and fires. All this, on the other hand, usually harks back to the properties of the raw material, although certain modifications in the handling of the material may account for failure in the product.

Dr. Ralston reports that the U. S. Bureau of Mines did considerable work on the froth flotation of North Carolina kaolin in cooperation with one of the companies producing the kaolin. He reports that froth flotation using the cationic type reagents recovers the clay in six stages: (1) colloidal clay, (2) kaolinite, (3) weathered mica, (4) unweathered muscovite, (5) quartz, and (6) feldspar. The recovery is made by using different concentrations of the reagent. Whether this method of handling the clay would be

an advantage would depend upon quite a few items, the most important being a study of the middlings obtained between each fraction. The separation could doubtlessly be halted before the weathered mica fraction which would give all the useable clay fraction and leave the other fractions for use in other fields. The drawback with any of these highly specialized flotation methods is to secure a favorable market for the by-products. To digress only a moment, we find that the by-products from the concentration of cyanite, such as the mica, the garnets, and the sand, constitute the real problem in the economical production of a high grade cyanite. The same problem is met in the beneficiation of the North Carolina kaolin. These kaolins contain only 15 to 18 per cent of recoverable kaolin, about 10 per cent mica, and a varying percentage of feldspar of questionable utility, although it is just possible that it will be of a grade useable by the soap manufacturers.

A second method of handling these kaolins consists of deflocculating, cleaning, and flocculating them, much the same as is done in the Zettlitz area of Czechoslovakia. A product is thus obtained that will be quite acceptable to the pottery industry. At one or two of the Zettlitz plants the clay is dewatered in an electro-osmotic filter instead of filter presses, as is the custom in this country. The electro-osmotic process was tried out on the Carolina kaolin with excellent results, but it was thought to be unnecessary to produce a high grade product from the raw material available.

Marketing the by-products to advantage is seen to be a vital problem when you consider that only from 15 to 18 per cent of the mined material comes out as pottery clay. The production of a fine-grained material from the hard granular kaolin is a problem that has worried the producers of kaolin. Recently two or three methods have been worked on, but are held as plant secrets by the respective companies.

One of the Georgia kaolin companies used to have an elaborate system of beneficiation which, to the casual observer, worked wonders, but it has been abandoned, so I presume there were some drawbacks which were economically insurmountable. The clay was taken from the pit and put through a rod mill and from there it went to a cone classifier, and then to a Dorr thickener, where it was partially dewatered. This was followed by complete dewatering on a rotary filter. The filter consisted of a revolving drum which dipped into the thick clay slip. The drum was heated internally. The clay was removed from the drum to an endless belt which carried it to a rotary drier.

Mr. Stull, while with the Bureau of Mines, worked out a cone classifier that was used by a company to produce a superior product from their Georgia kaolin deposit. The theory of the apparatus was based on the fact that the clay stream was introduced tangentially. Mr. Stull explained that

the material as it sank, due to the influence of gravity, was swished in layers of water traveling at different rates, thus causing the mica particles to dive as well as sink because of their gravity. The influx of the clay-bearing water was some inches below the overflow. The sand and mica were accordingly settled out in the cone and the clay-bearing water was received in a trough around the periphery of the cone. The clay slip was deflocculated at the outset and flocculated in the storage tank that followed the cone classifier. The concentrated slip was, of course, filtered in presses.

The use of an air-floated ball clays adds economy and convenience to the mixing of the clay batch in that bodies formerly mixed wet can now be mixed dry. The recent development of machines for mixing the dry batch has made such a procedure possible. This illustrates that a clay which can be used in a simple way in a plant process can stand some added beneficiation cost.

Another method largely used consists of deflocculating the clay and degritting the slip, the latter process throwing out approximately 15 per cent of the crude material. The remainder is then separated into two fractions by centrifugals under controlled conditions. The coarse fraction is used by the paper industry in manufacturing a more highly ink-receptive sheet. The ceramic trade also uses this fraction, as it has low shrinkage, fast casting qualities and helps in the filtering of high ball clay bodies. The fine fraction is used entirely by the paper industry to obtain a high gloss on coated paper.

With these few observations on the cleaning of the kaolins we shall now consider the progress that has already been made on common clays. In the northern part of the United States there is a belt of glacial clays. These clays have been transported by the glacial drift and deposited as moraine material. They carry as incidental those materials picked up along the path of the glacier. A great deal of the surface clay of northwestern Ohio, Indiana, and Illinois is of this type. These clays are infested with pebbles, the most objectionable of which are the lime pebbles. When the clays are made into a ware and exposed to the elements, we have "popping" due to the slow slaking of the lime. The slaking can be controlled by fine grinding, firing to an advanced temperature, or by the addition of chemicals to the clay which causes a vitrification at the lime-clay interface. The Germans have a treatment that inhibits popping. They immerse the fired ware in water, which causes a quick slaking, which apparently the brick structure is able to withstand. All this sounds very simple, but experience has taught that it is a relatively expensive job to fine grind the material sufficiently to obviate the objectionable features.

An additional objection to the use of these clays is that a high lime clay has a short firing range. This objection, when coupled with the necessity of firing to an advanced temperature, renders the clay very difficult to handle.

With these things in mind, it is common experience that pebbles must be avoided in the harvesting of the clay or must be removed before the clay is ready to be made into ware. To this end, a great many things have been tried.

The simplest and most direct remedy is accomplished by a piece of equipment known as a clay cleaner and brick machine. Clays of this type are wet during certain seasons of the year, and if undried, come to the machine in a semiplastic condition. These clay cleaners will handle the wet clay reasonably efficiently. The better ones consist of a series of rolls, the underlying principle being that the larger pebbles are removed in the conical rolls and the smaller pebbles are ground through a pair or pairs of smooth rolls. From this point the clay enters the brick machine proper and is pugged and delivered to the molds.

As you can readily see, this type of machine eliminates only the larger pebbles and imperfectly grinds the smaller. If the clay does not have too great a proportion of fine pebbles, the product is acceptable; if the proportion of fine pebbles is excessive, the ware is either unusable or on the borderline of usability. Plants in Chicago, Detroit, Toledo, and Cleveland have used these machines.

The best way of handling these clays consists of drying them in rotary driers. The dried clay is freed of the pebbles in a dry pan—usually a pan with the mullers raised so as not to crush the pebbles. The clay is then screened through a revolving screen and delivered to the pug mill. These pebbles are often so clean that they can be sold as cement aggregate.

A very old method and one never largely used consists of a whipping device which cleans the clay and eliminates the pebbles. The only record we have of the use of such a machine is given by Mr. Richardson at a plant in Minnesota of which he was superintendent. Mr. Richardson is quite convinced that it is one of the best devices yet brought forward for cleaning crude clays of pebbles.

Another suggested device is a machine made in Germany and in England which consists of a series of slots in the end of the barrel of an extruding machine much the same as the slots in the present day de-airing machines. These slots are one-sixteenth of an inch or less and so stop the passage of the pebbles. The barrel is opened periodically, and the pebbles cleaned out. It would seem likely that the method would cut down production unduly, but is a suggestion that has worked in small production plants.

One or two cases of washing have been reported in the literature. A variety of methods might be used. The commonest is to blunge the clay, screen out the pebbles, and allow the slip to settle, after which it is used as a pebble-free raw material. Drawings showing such a device are available and can be had for the asking.

A modification taken from the kaolin washeries would be to float the clay with an electrolyte in the blunger, screen, and flocculate it, causing rapid settling followed by the removal of the supernatant liquid.

These five methods are, with an infinite number of modifications, commercially the most widely accepted procedures for handling the problem of pebble removal.

Several investigators have tried the action of common salt on the lime to inhibit slaking. Common salt and other chemicals are put in the pug water and during firing, flux the lime to form a high lime soda glass which forms a vitreous interface between the clay body and the lime, thus reducing the harmful popping. Mr. Heath in our laboratory showed quite graphically the effects of using salt on clays containing lime pebbles of various size, from ten mesh down to forty-eight mesh. He also showed the effect of various degrees of firing.

One of the oldest and most efficient ways of beneficiation (our definition of beneficiation) is to mix one clay with another to give it the properties desired to make it act properly in the machine, in the driers, or in the kiln. A strong plastic clay is often added to a weak clay. A clay that shrinks unduly is some times corrected by the addition of sand or a sandy clay. Another method of handling the clays that have too high a shrinkage is to calcine them at a low temperature, thus driving off the mechanically held water. The heating destroys the colloidality of the clay, making it less plastic.

Certain strata of a pit often have to be avoided to give a clay that will make a good product. Not far from here is a plant that was having undue drier and kiln losses. After a large amount of study it was found that the upper few inches of their shallow pit had to be eliminated, if these kiln losses were to be stopped—this in spite of the fact that this top clay was one of the most remarkable clays I have ever seen. It had a dry modulus of rupture of 1,800 pounds per square inch. This clay, however, caused the losses suffered in their driers and kilns.

One of the most popular and recent methods of treating clays to improve the quality of the product is the partial elimination of air in the pug mill. Machines for doing this are now being made by nearly all the clay machinery manufacturers. The first successful commercial machine was put out by the Bonnot Company some ten years ago. We at Ohio State had a hand in proving the efficiency of this machine. De-airing will eliminate such difficulties as blisters and will apparently eliminate lamination in ware, although with a good many clays the laminations are still there but are not apparent to the casual observer. The clay usually flows through the die much more readily and the column has a very tough, flexible texture. The clay industry was astounded at the first experiments showing the possibility of

extruding long unsupported columns, and small columns that could be tied in knots. The experiments were very spectacular.

While de-airing has doubtlessly done a great deal for the clay industry, it has not been a panacea for the clay worker. As you would suspect, the more tightly knit column will produce a ware that will vitrify more readily than the unde-aired column. The product is much more difficult to cool in the kilns than is the ordinary clay product. It has meant that frequently changes have had to be made in the drying and firing conditions. Where these changes in operation have been made successfully, de-airing is an unquestionable benefit in the manufacture of clay products.

There are some clays which have a tendency to crack in the drying, no matter how slowly they may be dried or under what atmospheric conditions. Often these are clays which are nearest the centers of consumption and constitute a tempting source for the production of common clay products. There are a good many things which can be done to such clays to render them more workable. In recent years the chemists have taught us a good deal about pH control and base exchange in clays. The soils chemists have been especially active in the latter field and have taught us that the character of the soil can be radically changed by the addition of salts which will enter into the constitution of the clay molecule, giving it in some cases very different properties from the untreated clay. It has been the custom for quite some time for our sewer pipe manufacturers to add salt to their batch, realizing that the clay worked better in the die and that it had less tendency to crack in the driers.

We had experience with a very unmanageable clay. This clay was of a wind-blown type so common in the Southern States. Several plants had demonstrated that it was impossible to make a marketable product for any considerable length of time using the untreated clay. The cure turned out to be the addition of a small amount of acid which flocculated the clay, making it decidedly more plastic. With this procedure it was possible to dry and fire the clay safely. Recently it has been found that an accurate control of the clay is a contributing factor in working the common clays.

Recently a great many reagents have come on the markets which can be used to advantage if the character of the clay is known and if technical knowledge is applied. Several of these reagents, such as the sulfonates, increase the rate of penetration of water into the clay body and are called penetrating or spreading agents. There is quite a difference of opinion among physical chemists regarding film formation, but whatever the explanation is, it has been found possible to use these reagents to advantage with many clays while they are useless with others. A recent outstanding example was the tendency of a clay to set up on the walls of the brick machine to such an extent that the die had to be removed and the barrel cleaned

every few hours. The addition of a penetrating agent caused the water to seep through this hard cake, causing it to soften and loosen from the barrel.

There are a great many reagents, such as alkaline starch solution, "plasticade", ammonium alginate, and the aluminates, which tend to make certain clays much more workable and which either shorten the drying time or make the clays dry more safely. They usually affect the dry strength of the clay.

Ceramists have learned in recent years that clays are not unalterable bodies which must be used in the form in which they occur. It was formerly thought that clays were clays, and some of them could be used while others could not. There was a sort of superstition against the attempt to alter the properties of a clay. This has all passed, and the clay men are learning to work themselves out of their difficulties and are making products which were formerly unheard of with certain unmanageable clays.

A few years ago it was thought possible to beneficiate the secondary fire clays of Ohio in such a way that they could be used for the whiteware industry. These clays had been used for generations in the stoneware industry with success. They have the properties of a kaolin and a ball clay combined. They have an excess of silica which is not objectionable except in some cases; the grain size is quite acceptable to the stoneware industry. The principal objection to these clays was the fact that they contain a considerable amount of iron and that a portion of this iron appears as specks in the final ware. The thing which led us to consider their use had to do partly with the fact that most table ware is now made in cream and ivory shades. The fire clay would, of course, be off-color for a white product. With this general idea in mind, Dr. Shaw, with considerable advice from the Battelle Institute, went to work on the problem, and after trying electromagnetic, electrostatic, air separation, and wet flotation methods, finally in desperation tried the long-discarded film flotation method used in conjunction with a McQuistin tube. This method consists of running the slip through a rotating, partially immersed tube set at an angle. Various oils are used, such as kerosene and creosote. The iron specks are brought to the surface, forming a film on the water from which it is skimmed. I believe you can see the logic of the thing when you consider the small amount of material which was removed and the large amount of clay-like substance which we wish to recover. The proposition is just opposite from the usual demands of the flotation engineer. We found that the method worked beautifully in the laboratory, but have yet to persuade someone to put in the equipment required.

The dinner plates made from the cleaned clay at two or three of our potteries were entirely devoid of specks, and the clay had certain properties which seemed to make it a possible addition to the whiteware batch in small amounts.

Speaking of the further possibility of beneficiating the common clays, I should guess that it would depend upon future research work. If a clay by purification can be made to provide the raw material for a product of a higher order, as for instance, using our fire clays in the pottery industry, it is entirely likely that a reasonable price could be paid for beneficiation. If a refined clay could be used to produce a better product in the same field, such as the removal of the alkalies from a fire clay to produce a better refractory, the beneficiation would pay if the cost were not too high.

Whether the price of beneficiation can be absorbed would depend entirely upon the price received for the product made. A German plant which I visited was washing pebbles and iron concretions from their clay for the fabrication of roofing tile while they were using the clay as harvested for their common bricks because it was too expensive to clean the clay.

CONCLUSION

The matter of beneficiating a clay is a research problem. Methods, processes, machines are the things required, and we can go no further until we have them. If enough benefit is derived from the purification or alteration of the clay to pay for the costs involved, then we can expect beneficiation in a given field. If the costs exceed the benefits derived, then there will be no further beneficiation. The incentive to act involves the profit and loss sheet of anyone contemplating beneficiation.

NEW DEVELOPMENTS IN THE PROCESSING AND FORMING OF CLAY PRODUCTS

By

R. K. Hursh

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New developments in an industry that antedates written history cannot be expected to be of a radical or revolutionary character. The steps of progress are like stairs of low rise and broad tread. Change is gradual and is represented essentially by minor modifications of equipment and methods that lead to more efficient plant operation and lowered unit cost of production.

The raw materials must be taken essentially as nature has produced them. Modification of their physical and chemical properties is limited. Careful selection of the materials and control of the properties of the product by mixture of clays and by physical methods of preparation are receiving increasing attention by the manufacturers.

There is little that is new in the basic methods of manufacture of clay products. The clay is taken as it is found, tempered with water, formed into shapes that are dried and fired. Thus were the bricks made for the construction of the temple in Babylon. But the equipment used in these processes has been greatly changed and, of greater importance, methods of control of the processing and of the quality of the product have been developed. The changes have been a slow but certain evolution. It has been said that "the invention of the wheelbarrow was the most important step in the development of the brick industry." The wheelbarrow is still an important piece of equipment in the plant but it is a very different machine and the industry is fairly well out of the wheelbarrow period. When one views the conveying and transportation equipment of the modern plant, even "the horse and buggy days" seem to be well behind.

Pit operations have undergone progessive change from hand digging to the use of a variety of forms of mechanical excavators. The steam shovel has been greatly improved in flexibility and efficiency of operation by the change from the locomotive type to the caterpillar type, with a great reduction in the number of men required in its operation. Electric shovels and gasoline-electric equipment has, to a considerable extent, replaced the steam shovel. The drag-line excavator has been found an advantageous type of machine for digging clay because it operates from the top of the bank and, in many cases, performs the combined service of stripping and loading. Operating

with a sloping face, difficulties from caving of the bank are decreased but its service is limited generally to excavation of material that is not so hard as to require blasting. In England, there seems to be considerable use of a bucket and chain type of excavator that operates from the top of the bank and delivers the clay to continuous belt conveyors, eliminating car haulage. This type of machine does not seem to have found a place in clay plants in this country although it is used somewhat in the digging of canals and in irrigation projects. It lacks some of the flexibility of the shovel and dragline and is not well adapted to operations requiring selection of clays or where different materials are separately dug for mixing in required proportions at the plant. The shale planer is a near approach to this machine but operates from the bottom rather than the top of the bank.

There has been considerable development in respect to the selection of materials and mixing of different clays in definite proportions for control of the working properties and color of the fired product. Separate digging of different strata in the same pit and mixing of materials from different localities has required the installation of storage bins together with mechanical proportioning equipment. The disc feeder and several types of continuous weighing devices have found extensive use. In the face brick plant, where a variety of mixtures may be required for different color effects, and in plants where uniformity of the product requires careful selection and proportioning of two or more materials, the batch-house and mixing equipment are finding more extensive adoption.

In the grinding of clays and shales, the dry pan has retained its place as the most favored type of equipment. There has been a trend, however, to much heavier machines with increased capacity and lower costs of maintenance. Greater crushing capacity has been sought by use of wider and of heavier mullers and these, of course, necessitated heavier construction throughout the machine. In one type of dry-pan an increased crushing force and adjustment to suit the material handled is obtained by use of hydraulic jacks or rams which apply a downward pressure on the muller shafts and produce the effect of heavier mullers.

The most notable change in drypan design is, perhaps, the "so-called" grinder. The usual screen plates are replaced by an adjustable slot around the edge and inside or below the fixed rim of the pan. Instead of dropping through the openings in the floor of the pan as it is thrown out centrifugally to the side, the crushed material passes through this slot under the rim. The slot opening is adjustable but is generally larger than the screen plate slots that are normally used in dry pans. As a result, there is a much higher proportion of coarse material in the grinder product and the maximum particle size is greater. The load on the screens to which the material is fed is thereby increased and a larger amount of material is rejected and returned

to the grinder. It is claimed that, by removal of the fines as fast as they are produced, the capacity and crushing efficiency of the machine are increased. It functions primarily as a grinder and the operation of sorting or sizing the product is left entirely to the screens.

Precrushing of the lump material before delivery to the pulverizing machine has materially improved the efficiency and capacity of the grinding department. Crushers to reduce the lumps of clay to two- to four-inch size are extensively used.

Irregular and uneven feeding of material to crushing and grinding machines has been eliminated, in many cases, by installation of plate or apron feeders. By adjustment and control of the rate of feeding the crushing and grinding efficiency may be maintained at a maximum and, where the ground product goes directly to the forming machine, the entire plant operation can be kept in step.

The vibrating type of screen has been quite generally adopted, replacing the gravity screen. It is capable of a higher rate of screening per unit area and, therefore, takes up considerably less height and floor space in the plant. Less attention is usually required to keep the screen cloth clean although wet clays are likely to give considerable trouble from blinding of the screen.

The vibration may be applied either to the frame of the screen or to the screen cloth itself. In some cases, the vibration of the cloth is produced by an eccentric and the amplitude may be adjusted by the setting of the eccentric. Unbalanced pulleys may be used to give a more or less elliptical movement of the screen cloth. Cams or toothed wheels give a jarring movement in other types and hammers may be used to periodically strike the screen or an anvil attached to it. In the case of the electrically operated screens, a floating solenoid, attached to the screen cloth, is caused to vibrate by current of regulated frequency passed through the windings of an electro-magnet.

The efficiency of operation of the vibrating screen is affected by the type of material handled, the range of particle size in the feed, and by the rate and method of feeding. It has been stated that, for good operation, the depth of the material on the screen should be reduced to a thickness of one particle by the time the material has passed over one-third the length of the screen. Otherwise, it is likely that some of the fines will be carried over in the tailings. For effective operation, the slope of the screen, the amplitude of vibration and the method and rate of feeding should be adjusted to suit the particular type and characteristics of the material which is to be handled.

Some further attention to details in grinding and screening practice would, in many cases, undoubtedly result in more effective and efficient operation. Screen analyses of the grinder product, of the screen product and of the tailings furnish means of determining the proportion of fine material produced by the grinder that is separated by the screen, as well as the

ratio of the weight of material fed to the screen to the weight of product. These values provide considerable information as to the efficiency of the plant and a basis for consideration of changes that may effect improvements in the operation.

In the preparation of wet or moist clays there has been a decided trend to finer crushing to obtain a more homogeneous material and, more particularly, to break up the small pebbles that are common to the surface clays. A disintegrator of the pug-mill type is generally used for the preliminary treatment. From this the clay goes to conical rolls which are effective in separating the larger stones and then to smooth rolls for the fine crushing or grinding. To accomplish finer disintegration with this equipment, an additional set of rolls has been provided in many installations. Better and more uniform results than those of previous practice are also being secured by more careful maintenance of a single set of smooth rolls. These may be refaced at frequent intervals by a grinder attached to the frame of the crusher so that removal of the rolls is not required. The total life of the rolls has been considerably increased in some instances by this practice.

In the tempering and forming of structural clay products de-airing has been a significant development and has been the subject of much discussion. Random experiments were made with de-airing many years ago and some of these with considerable apparent success. But general interest in it and wide-spread adoption is comparatively recent. Like most developments in mechanical equipment it has not fulfilled all of the expectations or desires. In some applications where it has been tried the results have not been satisfactory. But de-airing has so proven itself as an advantageous feature in the processing of structural clay products as well as in other applications that its value is beyond question.

De-airing treatment of pugged clay in the brick machine was developed primarily as a means of eliminating laminations in the product. The slippage of layers of clay as it moved through the machine and die, or differential flow, was attributed largely to the lubricating effect of air entrained in the mass. By evacuation of the air this difficulty, it was thought by many, would be overcome. However, it was not to be expected that de-airing would entirely prevent differential flow nor insure complete rewelding of the clay at the resultant slippage planes. The treatment does materially reduce lamination, so much so that many clays show no evidence of this fault in the product.

Probably the most valuable result of de-airing treatment is the increase of cohesion, toughness and strength of the clay body. Some materials which could be used only with difficulty in stiff-mud molding can now be formed readily with de-airing equipment. The plastic strength is so increased that larger and more difficult shapes can be made and handled with ease. A further important gain is in the elimination of blistering of the clay column as it leaves the die.

The experience with de-airing in relation to power requirements seems to vary considerably. Some report no difference, some find an increase in power needed, while some have reported an increase of production with a lower power consumption than without use of de-airing. In most cases, the observations are unquestionably matters of opinion rather than results of actual measurements. Conditions and materials vary so widely, however, that it would be unsafe to draw general conclusions without some extensive investigation and actual determinations of power used under operating conditions. It is not to be expected that the same machine should be equally effective with clays of different characteristics and working properties nor that the same general equipment should serve equally well with de-aired and with nonde-aired clays. However, there has been a rather general tendency to apply de-airing treatment with little or no consideration of modifications in machine and die design that might be best adapted to the changed characteristics of the clay body. Much more attention will be required in this direction.

Even prior to the advent of de-airing much attention was given to the lamination problem and hence to the design and construction of the dies that shaped the ware. Most of the efforts in this direction have been devoted to the solution of a particular plant problem and little information concerning procedure and results has become generally available. The results of several investigations in both plant and laboratory on die designs and the effects of various combinations of augers, spacers and dies for brick and hollow ware have been published. Such compilations of data and experimental results should contribute much to improved design and better adaptation of equipment to specific conditions and problems in the formation of clay products.

The application of de-airing treatment has not been confined to stiff-mud operations but has found definite use in dry pressing as well. While dry pressing is applied much more extensively in the production of refractories than for structural clay products, its possibilities deserve consideration. Several methods have been suggested and tried but evacuation of the mold box seems to be most adaptable in industrial practice. By this treatment the density and strength of the body is considerably increased and the porosity is decreased.

The drying of clay products has been a subject of a good deal of study and investigation in the past few years. A considerable amount of information has been obtained concerning the physical processes involved in the movement of water in the clay body and the effects of variation in the drying conditions. Two rather distinct stages in drying have become evident. Shrinkage accompanies the removal of water during the first stage and the rate of water loss may be considered to decrease linearly during this period. The rate of water loss is directly dependent on the drying conditions—the temperature, relative humidity, and velocity of air movement. When the

moisture concentration at the surface of the article reaches a point at which no further shrinkage can occur, the vaporization of the remaining water occurs within the body. From this point, which may be termed the "critical point", the rate of loss decreases with a curvilinear relationship to time and the rate is determined largely by the structure of the clay body rather than by the external conditions. The first stage, the shrinkage period, is of primary importance from the standpoint of safety in the drying of clay products. Stresses may develop with rapid drying that cause cracking or permanent distortion of ware and the drying rate must be regulated by proper control of the atmospheric conditions in the dryer.

De-airing has introduced new drying problems in many industrial dryers. The greater density and the change of structure of the clay body retard the rate of water loss so that a longer drying period may be required. Slower drying in the shrinkage period may be offset by speeding up the later stage by increased drying temperatures but a definite knowledge of the drying behavior of the ware and means of control of the drying operation are essential to satisfactory results.

To a great extent, faulty operation and unsatisfactory results in dryers are due to lack of regulation and control of air movement. A number of dryers have been built and old dryers modified with the objective of better air distribution and a positive circulation through the ware setting. In some of these a number of circulating fans are arranged at different points along the length of the dryer to take air from the top of the tunnel and return it underneath the ware. A combined cross flow and longitudinal flow is thus secured. Temperature and humidity control devices can be provided to separately regulate drying conditions in the various sections.

In order to maintain a high drying rate in the hot end of a progressive tunnel dryer and more moderate conditions in the cooler section, provision is made in some cases to draw off part of the hot air midway along the tunnels and thus reduce the quantity of air passing over the ware in the early stage of drying. A somewhat similar plan is used in another installation. Here a vertical air circulation is maintained in the hot end by admitting the hot air through a series of floor ports and withdrawing part of the air through exhaust ports in the roof. The air returns to the intake of the pressure fan and is again delivered to the dryer. By thus recirculating part of the air in the hot end, a higher velocity can be maintained with faster drying as a result. At the same time, the moisture content of the air is increased sufficiently to afford moderate drying conditions for the entering wet ware which is inclined to crack in the early stages of drying.

Improvement in control of drying conditions has also been sought through regulation of the quantity of air furnished by means of variable speed drives for the fans. Variation of the fan intake opening by means of dampers

is another means of controlling the air supply. Admixture of cold air to the hot air from the cooling kiln, in order to regulate the temperature in the dryer, is secured by a thermostatically controlled air shutter or damper.

In connection with firing operations, regulation of kiln atmospheric conditions and temperature has received increasing attention. Fuel requirements have been decreased, the firing period has been reduced and better control of the color and quality of product has been secured in many plants. New firing technique has been developed, in a number of cases, to produce new color effects through flashing treatments or use of zinc or other coloring agents.

The introduction of the continuous car-tunnel kiln in structural clay products industries has been slow. A number of such kilns have been in successful operation for brick and similar products for a considerable period of years. Several installations have recently been made, some with unusual features, and the results of these are being watched with great interest. The firing of many glazed products has been especially satisfactory in the car-tunnel kiln. The availability of gas as a fuel has been particularly advantageous in this application. It is to be expected that more extensive use of this type of continuous kiln will develop in the structural clay products field.

The interest in and demand for a variety of color effects in brick and similar products has materially increased the use of glazes. The application of these has been facilitated by passing the dried ware on continuous conveyors through spraying booths. Other surface effects are produced by application of colored sands or dry facing mixtures by various methods. A sandblast is used in some cases to blow the particles into the surface of the green ware. Another method, introduced from England, applies the color by stippling the surface of the brick column and forcing the granular coloring material into the surface with steel wire brushes.

New forms and types of product have been developed in recent years. Interest in reinforced masonry has resulted in a considerable variety of special shapes adapted to use with reinforcing steel bars in the mortar. The objective is, in most cases, the preforming of slabs or beams before placing them in the structure. Tiles of various sorts for wall facing have been produced, some for attachment as a veneer, some to be used in precast slabs. Light-weight structural products of many forms and types have been introduced. One of the objectives is an easily handled unit of larger than brick size. Acoustic material for reduction of noise is another important objective. Thermal insulation material and products have been in such demand that much effort has been devoted to produce a structural unit to meet the need.

Most of these new forms and types of clay products must be considered as still in the development stage but some very definite and, perhaps, radical changes or additions in the field of structural clay products may be anticipated as a result of the research and experimental work that is in progress.

CURRENT DEVELOPMENTS IN ROCK AND ROCK PRODUCTS

PRODUCTION AND POSSIBILITIES FOR LIMESTONE RUBBLE AND ASHLAR FOR CONSTRUCTION

By

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There is nothing new under the sun, but from time to time there are changes in the ways that the old materials are used.

As stone is one of the very oldest of building materials, the world is full of massive stone structures that have endured for centuries. However, such structures are not popular today, so we may well ask ourselves whether rubble and ashlar have a present and a future.

There was a time when the builder assembled his materials in the vicinity of the site of the building. If stone abounded, he built of stone; if trees were plentiful, he built of timber; if both were hard to get and clay was available, he learned to build of brick.

The general purpose of the builder was to construct a substantial shelter. Very rarely the builder had that artistic sense which demanded that a structure must be pleasing to the eye, as well as serviceable.

Consequently, as stone is a very durable material, we have plenty of old stone buildings which are everything except beautiful. On the other hand, the occasional structure with truly beautiful lines, pleases all who behold it, although few of us can explain just why we like it.

When the builder began to buy his materials, transportation became an important element in their cost, and is more important today than ever before.

Transportation brought about competition between stone, lumber and brick, and made many changes in the methods of using those materials.

Today our lumber comes from the South and the extreme West; brick plants are to be found almost anywhere, and stone, suitable for building is found in small and rather widely separated areas.

When the world discovered that air spaces in the walls of our homes add to health and comfort, the old 16-inch stone wall houses became antiques.

Wooden structures are now mostly air space and thin sheets of ¾-inch lumber; brick has been hollowed out into modern building tile; thereby reducing transportation costs per cubic foot of building to such an extent that solid stone buildings are no longer constructed, even in those areas where good stone is plentiful.

Forty years ago, the foundation of every northern home was of brick or heavy rubble stone masonry. The perfection of portland cement in this country pushed the rubble foundation into the discard, and substituted concrete made of crushed stone or gravel.

Before the advent of concrete and structural steel, Chicago and other large cities used large quantities of rubble stone, and heavy slabs of sawed limestone. Chicago had brick in its own back yard, but depended largely upon the Joliet area for its supply of stone. Joliet tried to overcome its transportation handicap by sawing very thin slabs of stone, which were set on edge to face buildings. A few of those atrocities may be seen today in parts of Chicago's tenement district. Then the Bedford, Indiana, stone industry became active, and its cheaper cutting costs pushed Joliet sawed stone entirely out of existence.

Bedford's cheaper cutting costs and a better control of the sizes into which blocks were cut, enabled them to overcome a very great transportation handicap, and Bedford stone became a strenuous competitor of fine face brick in all classes of public buildings and even in small residences. All other types of rubble and ashlar were crowded out by materials that would make thinner walls, weighing much less per square foot of surface.

With the depression came a strange revival of rubble stone as a facing for buildings. Credit for this revival probably must be shared between the architect and the stone producer who was willing to try anything that might add a dollar to his microscopic income.

The architect had to exert himself as he had never done before, to find something that would appeal to the few owners who might be coaxed into letting a building contract. He must find something so pleasing in form, line and color, that the owner could not resist the appeal of beauty, and yet had to hold the cost down to a reasonable figure.

A stone house creates the pleasing impression of durability, but it must be modern in every other respect. Form, line and color must be given the most careful attention if the building is to be attractive, and transportation cost must approximate the transportation cost of brick.

Furthermore, the owner must feel that there is a touch of individuality to his home that is not shared in many other homes. This quest for individuality has resulted in some wierd specimens that must haunt the owner as long as he lives. So the architect must avoid extravagant innovations of that type.

One of the outstanding errors of old stone buildings is that short chunky stones were often used because longer stones were so much heavier to handle. Short stones in a wall lack the appearance of stability. They may be thoroughly bonded together, but the spectator does not get that satisfied sense of stability, unless individual stones are generally two or three times as long as they are high.

Rubble veneer, 4 inches thick, not more than 6 to 8 inches high, with lengths more than twice their heights, provides the form and the line that the architect must have to please his client, and at the same time such stones can be set in the wall by brick masons, at a cost not greatly different from the cost of setting brick.

Color is the last and possibly the most important detail that must be considered. We are all color conscious, but very few of us realize that one color scheme irritates us and another pleases us nor why we are so influenced. There is a sky-blue granite courthouse in South Carolina, which is the pride of the community. Whenever I have a nightmare, that sky blue courthouse is generally somewhere in the wierd picture. We don't expect the exteriors of our buildings to be blue, so we must make them of colors and tones that the spectator accepts as reasonable colors, if we are to produce the pleasing result.

The uniform warm buff color of Bedford stone is one of its outstanding assets in the construction of formal structures such as post offices and public buildings, because it has life and cheerfulness. Many limestones and dolomites in the Mississippi Valley offer a variety of warm tan colors that gave the architect just what is needed to convince the owner that the architect's plans for a home or a church were just what the owner wanted.

Color is of great importance. The owner with a keen appreciation of color is not satisfied with Wisconsin limestone, Ohio sandstone or Indiana limestone, because none of these competitive materials offer dense durable stone having the combination of color variety, that makes northern Illinois limestone so attractive to the architect and owner.

So it only remained for the architect to find a large enough supply of rubble veneer to insure plenty of competition and a cheap workable product.

The thin-bedded limestones of southern Wisconsin and northern Illinois afforded ideal working material, and the depression compelled stone operators to cooperate with the architect, in producing what the architect wanted.

The production of this type of stone is subject to many restrictions. It is something of a trick to cut 4-inch veneer from rough stones that lie 8 inches on their natural bed. The stone must have a uniform grain and even then the cutter must know how to handle it. There is no opportunity for machine work and quantity production. Bars and wedges are used to break the slab free from its native bed, and hammers and chisels produce the

finished product. One hundred per cent hand labor makes a production cost that staggers any one who produces crushed stone or gravel.

Windows, door openings and corners present another cutting problem because two faces must be finished on such stones. Finally fancy arches or fireplaces fall into a class of work where costs pile up above the most extravagant estimates.

The cost of breaking stones at the source of supply is much less than the same operation at the job. The main advantage is that there is much better chance to select the most desirable material as to color and size. Other savings accrue from being able to use the spalls and chips in other processes and from the fact that transportation charges are paid only on usable stone. Most ashlars are made to set on the natural bed with only enough on edge to provide contrast of color and texture. Individual stones vary in height to provide an abundance of ties and the beds and ends are clipped so that the wall joints will be moderately narrow, uniform and at right angles.

The production of this material is only the beginning of the architect's responsibility because stone masons all too often expect stone to fall into its place in the wall just as brick fall into place.

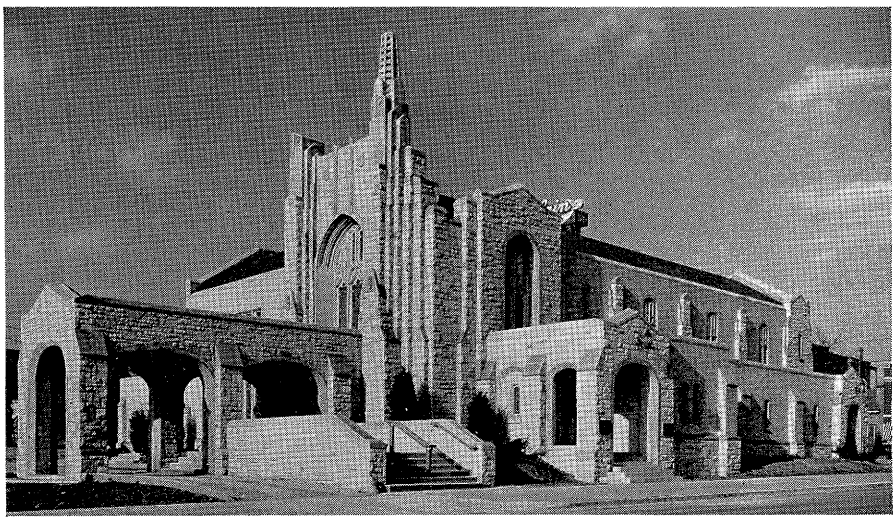

FIGURE 28.—A chapel constructed of limestone veneer on North Ashland Avenue, in Chicago. Exterior walls constructed of Lehigh rubblestone veneer and buff brick, with Bedford stone trim.

Stone must be laid carefully, with level beds, and uniform joints, and the mason must choose the individual stones with great care, if he is to give pleasing lines to his finished wall.

The possibilities for the future use of this material are rather apparent from what has just been said about its history and production. The volume

is bound to be small; when everyone has a stone house, it loses its charm of individuality. It is a luxury building material, so it will not be used when cost is the controlling factor. On the other hand, it is surprising what an insistent demand exists in certain directions for stone veneer.

It seems to be the ideal and natural material for churches built along modern lines, with steel frame and hollow tile wall backing.

The Lehigh Stone Company has been making rubble veneer for nearly four years. There has been little or no profit in its production, but we do have a rather keen satisfaction in the knowledge that many delightful gems of architecture exist as the result of efforts we have made in this field (fig. 28).

When this material is appreciated, transportation ceases to be a serious handicap. Chicago is our natural market, but Detroit, Indianapolis, Fort Wayne, East St. Louis, Rockford and Sterling proved to be within easy reach of customers who wanted Lehigh rubble veneer.

Architects, builders and owners are beginning to realize that they can combine beauty, economy and good construction by using Illinois limestone for veneering exterior walls.

Under such conditions, who can really attempt to measure its possibilities?

CURRENT RESEARCHES ON ILLINOIS STONE AND THEIR RELATION TO DEVELOPMENTS IN THE STONE INDUSTRY

By

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INTRODUCTION

As is evident from the title, this paper naturally divides itself into two parts, first, what are the broader developments affecting the Illinois stone industry, and second, how is the Survey's research program related to these developments? With reference to the first item, it is proposed to limit discussion to matters relating to raw materials and their uses.

DEVELOPMENTS IN THE STONE INDUSTRY

Probably one of the most important developments of the last decade is the increase in consumer research which has as its objectives the discovery of sources of materials which are as good as the materials in use but cheaper, or the discovery of better materials to be had at the same price. Here arises at once the producer's bogy of cheaper substitutes which may replace his product, though substitution may have a happier turn if by reason of it instead of losing a customer a producer gains one. Without doubt, consumer research is here to stay and with ample financial backing.

Consumer research, and equally also the general technical progress in the stone industry, result in new specifications and these new specifications are often written without much consideration of the producer or his raw materials. In many cases then, producer research is the only solution for the maintenance of a market.

Another development which is not new but nevertheless is significant, is the continually broadening scientific and practical knowledge regarding the best utilization of stone products. Often such knowledge comes from fields unrelated to the stone industry itself, as for example the use of ground limestone in the field of animal nutrition. It is doubtful that a stone producer discovered the basic scientific data which makes possible the statement that "a growing calf needs the equivalent of 60 pounds of calcium carbonate per

year for its proper growth and a cow yielding 3 gallons of milk per day requires the equivalent of 160 pounds of calcium carbonate per year to supply the calcium content of the milk."[1]

The rise and decline of the certain uses for stone is also a development of much consequence. Fifteen years ago the production of filter stone for sewage treatment works was unimportant in Illinois, at least production statistics fail to reveal the sale of such stone. Today filter stone is an important item to the Illinois stone industry. Another example, up till the closing years of the 19th century, the quarrying of building stone was an important industry in Illinois. After about 1900 production was very small but in the last 5 years the building stone industry has been revived and a tour around any of our larger northern Illinois towns will show why. The public and the home owner have become stone conscious.

One further recent development of note relates to the supply of soft wood. In the Lake States, Appalachian, and Southern soft wood areas, the demand for soft wood exceeds the supply. Only on the west coast does production surpass consumption. There can be no alternative other than a rise in the price of lumber in the Middle West to overcome the freight rates from the West Coast. Because the first cost of a wood home usually has been cheaper than one of stone, stone products or clay products, wood has been used extensively for construction despite the fact that a wooden structure is often conceded to be inferior from the standpoint of permanence and cost of upkeep. The first cost price difference is being leveled off, however, which means that stone, stone products and clay products are approaching a price parity with wood. Here then lies a new field for the stone and stone products industry. In all probability new developments in this field are just beginning. The field of house building is wide open to the stone and stone products industry providing it can provide a house which combines attractiveness, quality, durability, and price.

Considering then the status of the average stone quarry from the long range viewpoint and discounting the obvious effects of booms and depressions, it appears that the existence of the average quarry is a matter of losses of markets set over against gains of markets. The quarry which stands still merely balances the losses with gains; the forward moving quarry increases the gains beyond the amount necessary to offset the losses.

The question naturally arises in view of the changes in the quantities of stone used for different purposes, technologic progress, consumer preference, and the likely results of consumer research, what can the stone producer do to increase markets beyond probable losses? There is doubtless more than one way of accomplishing this end but research is unquestionably the most widely

[1] Goudge, M. F., Limestone and lime, their industrial uses: Min. & Met., vol. 18, No. 368, p. 372, August, 1937.

applicable means of so doing and probably in the long run the one which will pay the greatest returns.

The fact that this is an age where research goes hand in hand with progress requires no demonstration. There are, however, some factors regarding research that are sometimes overlooked, particularly research in a field such as stone which relates to a considerable variety of materials entering a multitude of different uses. In the first place, all successful modern research is carefully planned, not solely on the narrow plane of immediate needs, but on the broader base involving not only the requirements of the present but also the likely demands and possibilities of an unknown but eventual future. Through the plan of such research runs one central and ever present theme—the continuous, systematic, directed, accumulation, development and discovery of facts and ideas. These are the reservoir which may be tapped at will to meet new conditions and the larger it is the greater the confidence with which each new situation can be faced. And the continuity item should not be overlooked. By its very nature research is progressive and the most is accomplished by sustained research, not "fits and starts" research.

THE SURVEY'S RESEARCH PROGRAM

The State Geological Survey's research program on Illinois stone resources has been planned to encompass, in so far as the limitations of the Survey's field of activities permit, the conditions and developments previously mentioned. Because of the diversity and extent of the stone industry in Illinois, it is manifest that this program must be an all-industry research program rather than an individual quarry program. In a word, the major function of the program is the continuous assembling of data to be added to the reservoir of information regarding Illinois stone. The exact lines which receive the greatest attention vary from time to time according to the current needs. At the same time special studies which seem likely to contribute to the diversity of the stone industries or their products are likewise continually in progress.

It may be of interest to describe briefly some of the research projects under way and proposed for the year 1937-38. The work of cataloging the State's stone resources and their properties continues. With regard to limestones, recent work by the Survey has greatly enlarged the amount of information available concerning the Coal Measures limestones of the central and southern parts of the State. At the present time it is probable that data are at hand regarding the location of possibly 75 per cent of all the limestone outcrops in the State. Data regarding other stone resources is also multiplying both in quantity and quality so that in general there is emerging a comprehensive picture of the general nature and distribution of Illinois' stone resources.

In the case of limestone, it has been evident for some time as the fund of general data has been built up, that there is an ever increasing need for more and more detailed information. To meet this situation, careful, foot by foot sampling of typical and critical limestone exposures has been instituted. This procedure has been described at previous conferences and consists briefly of securing samples at intervals of one foot or less from the entire thickness of the exposure. Thus from a 100-foot face of limestone, 125 samples may be obtained. Notes regarding the deposits are taken carefully and in detail. The samples are tested in the laboratory first by rapid, rough tests, the results of which taken together with the field description of the deposits reveal many otherwise obscure data, and are the basis for the combination of individual field samples of like character into larger samples for more extensive and detailed laboratory studies. As a consequence, an intimate knowledge of Illinois limestone deposits is developing which has already demonstrated its practicability and will doubtless continue to increase in value with future developments in the stone industry.

Along somewhat the same line but emphasizing the property of weather resistance is a project recently started on the soundness of the dolomites in the general Chicago area. This is a cooperative project between the Survey, the Engineering Experiment Station of the University of Illinois, and the State Highway Division of the Department of Public Works and Buildings. The need for information regarding the probable weather resistance of limestones to be used for filter stone, building stone, concrete aggregate, railroad ballast, road metal and the like, has been felt for some time and two principal tests have been devised which are used in studying this property, namely, the freezing and thawing test and the sodium sulfate soundness test. These two tests, though not infallible when coupled with a study of the effects of weathering on the stone in natural outcrops, are the best means available for securing information regarding the probable weather resistance of a stone in advance of actual use.

The project under way is designed to be a thorough exploratory study of the soundness of the Chicago area dolomites. In recent years it has been found that Niagaran dolomite of that area, instead of being a single formation, is in reality divisible into four recognizable dolomite formations and that each of these four formations possesses reasonably uniform compositional characteristics. It is proposed to obtain representative samples taken at fairly close intervals from at least two typical, well separated exposures of each of these formations and likewise to secure any available data regarding the performance of the rock from each formation, under actual use conditions. The textural and petrographic character of these samples will be studied under the microscope and their soundness will be tested by the freezing and thawing test, the sodium sulfate test and possibly the magnesium sulfate

test. As a result it is believed important light will be thrown on the following questions:

1. Which of the Chicago area dolomite formations, in whole or in part, are likely to give superior service under exposed conditions?

2. How do the freezing and thawing, and sodium sulfate soundness tests of Chicago area dolomites compare as means of predicting soundness and how do they correlate with results of actual use?

3. What textural and petrographic properties characterize Chicago area stone having good soundness?

4. What criteria based on rapid laboratory tests such as acid etching and microscopic examination may be valuable in forecasting the probable weather resistance of the Chicago area dolomites?

While this project deals primarily with the Chicago dolomites it seems very likely that many of the results will be applicable, possibly with some modification, to other dolomites and limestones of Illinois.

Another major project which will go forward is a continuation of the investigation of the nature and properties of silicate melts resulting from the fusion of silica, alumina, lime and magnesia in varying amounts. Mention of this study has been made at previous conferences as the four-component system, especially in connection with the Survey's studies of rock wool making materials. During this last mentioned investigation only those combinations of the four components—silica, alumina, lime and magnesia—which were capable of producing rock wool were given primary consideration. It is now proposed to carry this work further to cover a wider range of compositions. Emphasis will be placed not on whether the fused products, that is the glasses, resulting from various combinations of the four components, are suitable for making rock wool, but rather it will include the finding of data regarding viscosity, thermal expansion, resistance to shock, and solubility in water and acids. The aim of the work is to determine definitely what products of possible commercial value can be produced by melting together in various proportions the compounds of the four-component system. Obviously these fused products will all be various types of glasses.

The question may well be raised why the four-component system, silica, alumina, lime and magnesia, is selected for study. The answer is that these four compounds are the chemical keystones of the greater part of the mineral resources of Illinois. Silica is the keystone in sands and sandstones, lime in limestone, lime and magnesia in dolomite, and silica and alumina in clays and shales.

Aside from glasses resulting from fusion of the compounds of the four-component system, basic data are being assembled to serve as a groundwork for a study of other means by which the members of this system can be united, such as by various combinations of heat, pressure and moisture. While the way is not yet clear, it is hoped that this groundwork will point out trails leading to the discovery of methods for synthesizing non-glassy products.

The balance of the Survey's program will be devoted to follow-up work on projects already completed, such as the study of methods for bleaching rock materials, and the investigation of rock wool making materials and to the cooperation with the Illinois stone industry in the solution of current problems as they arise.

SUMMARY

In summary then, the increase in the amount of and interest in research by the consumer, the general progress in the technical knowledge of the utilization of stone products, accompanied by more detailed specifications and demands for stone materials having special properties, and the rise and decline in the quantity of stone employed for certain uses, are significant developments in the stone industry. The likely result of these developments is the loss of one kind of stone business and the gain of another. The successful operator will keep gains in excess of losses. A continuing program of research is a lifeline to ensure continued gains. From the standpoint of raw material supplies and their greatest utilization, the Illinois Geological Survey is conducting a broad-gauged research program designed to keep the Illinois stone industry in front. The program includes the continued accumulation and cataloging of basic data regarding the stone resources of Illinois and their character, a detailed study of the "chemical stratigraphy" of Illinois limestones, investigation of the soundness of the Chicago area dolomites, and last, but by no means least, a comprehensive study of the glasses resulting from the combination by fusion of various quantities of the compounds silica, alumina, lime and magnesia—the chemical keystones of the stone resources of Illinois, together with an evaluation of the commercial possibilities of these glasses.

PROPERTIES OF ILLINOIS SOILS WHICH ARE RELATED TO THEIR NEED FOR LIMESTONE AND FACTORS CONTROLLING THE EFFECTIVENESS OF LIMESTONE[1]

By

E. E. DeTurk

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INTRODUCTION

The Illinois State Geological Survey has expended no little energy in research directed to the betterment of producers of limestone and other mineral resources. The present speaker represents another State organization whose research program is carried out in the interest of Illinois farmers—the consumers of agricultural limestone. These two great industries, the producers and the consumers of agricultural limestone, do not stand against each other, at the opposite ends of a competitive "tug-of-war." They are rather team-mates, pulling together in a common cause, and as such they may realize that what is profitable to one may turn out to be a benefit to the other. If the farmers cannot use limestone profitably, or if they cannot get the kind that they can use advantageously, the producers will have a difficult time selling it to them.

The purpose of this discussion is to attempt to portray some of the characteristics of Illinois soils upon which their lime need depends, and some of the factors that control the action of limestone in the soil, in order that we may get an accurate conception of the job that agricultural limestone is expected to do when it is applied to the soil.

SOIL DEVELOPMENT IN RELATION TO SOIL ACIDITY

The parent material of Illinois soils consists for the greater part of glacial debris, which served either directly as the raw material out of which nature fabricated our soils, or else, after being reworked and sorted by wind and water. This parent material was generally calcareous, that is, it was permeated with finely divided calcium carbonate. The rainfall during the soil-forming ages, and up to the present, has been great enough to provide water as a chemical reagent in the weathering of minerals and as a leaching agent for the movement of soluble and to some extent, insoluble products.

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[1] Contribution from Department of Agronomy, University of Illinois Agricultural Experiment Station. Published with the approval of the Director.

PROCESSES OF SOIL FORMATION

Soil formation can be imagined as consisting of three or more great waves or surges of weathering and other forces directed against the soil material, each having lasted through thousands of years. They did not come wholly one after the other, but with so much overlapping as to be largely concurrent.

One of the first of these processes was the dissolving of calcium carbonate and the leaching of it to greater and greater depths, finally carrying it out into the streams in drainage water. Another was the chemical breakdown of the silicate minerals, releasing their basic constituents, chiefly lime, in a soluble form to be lost in drainage waters unless it were protected in some way against leaching.

The insoluble product, colloidal clay, turned out to be the lime-absorbing material which protected it against leaching. Being insoluble, the mobility of this clay was low and it was retained in the surface, moving down into the subsoil only very slowly. The soil material was mildly alkaline so long as it contained calcium carbonate, having pH values ranging up to 8.0 or slightly higher. When the carbonate was first leached out the reaction was still approximately neutral and became acid slowly, only after long-continued leaching of the calcium combined with the clay. Other processes of the soil development are equally important but the ones mentioned are of particular interest in the study of soil acidity and liming.

BASE-EXCHANGE CLAY

As stated previously the protecting agent in the soil against the leaching of basic material is the colloidal clay. The clay particles have a surface attraction for the basic elements, calcium, magnesium, sodium and potassium, and also for hydrogen, the acid element. The capacity for adsorbing these elements is definitely limited in any given soil, and when an excess of one of them comes along in solution it pushes the others off and takes their place. This is called base exchange. Carbonated water (carbonic acid), resulting from the decay of organic matter, furnishes the principal acid hydrogen of soil water to displace the adsorbed or replaceable calcium. In these reactions the calcium forms a chemical union with the clay and we may call it calcium clay, just as the product of neutralizing sulfuric acid with calcium is called calcium sulfate. The hydrogen-saturated clay may be called hydrogen-clay or acid-clay.

When the calcium carbonate is first leached out of the soil, the soil is still neutral or slightly alkaline, because the clay is saturated, or nearly so, with calcium. It is only when the adsorbed calcium is finally forced off the clay particles—a much slower process—that the soil gradually becomes acid; and the lower the degree of base-saturation becomes, the more tenaciously is

the remaining calcium retained. If the base absorbing capacity of a soil is approximately 80 per cent saturated with calcium and other bases, the remaining 20 per cent being acid hydrogen, the soil is neutral. If it is more than 80 per cent saturated, it is alkaline, and if less than 80 per cent saturated, it is acid. These values are not the same for all soils. Many soils are neutral for instance, at 75 per cent saturation.

In general, the soils of northern Illinois are younger than those farther south. Consequently, one frequently finds soils in the northern third of the State which are calcareous at the surface, and quite generally calcium carbonate is found within less than five feet of the surface. Also, soils which have lost their calcium carbonate, but which are still approximately neutral, are not uncommon. As one goes southward, carbonates are found to have been leached out to greater and greater depths. The surface soil has become more intensely acid and the acidity extends deeper than in the younger soils to the north. Figure 29 shows the base-exchange relations in the surface soil of a number of the most important and extensive soil types in Illinois.

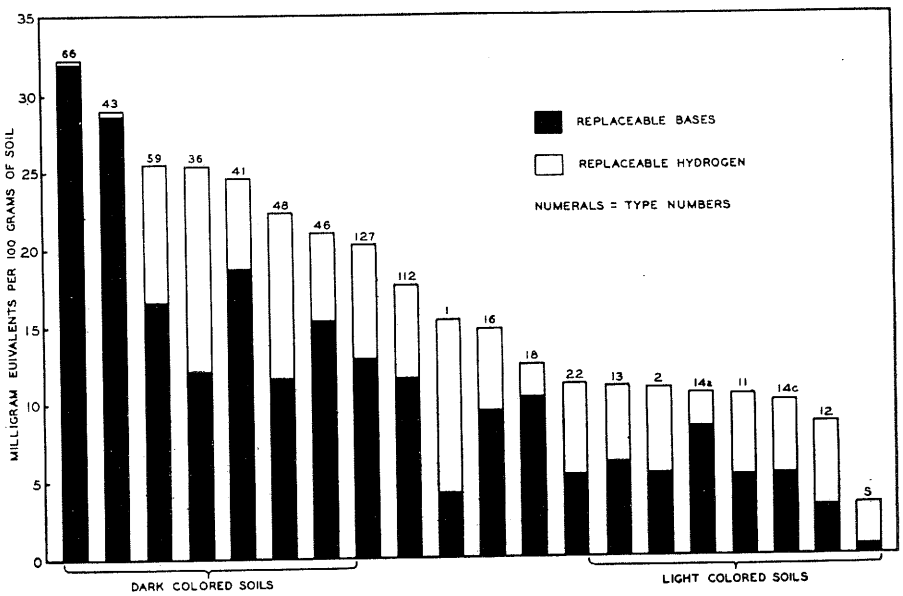

FIGURE 29.—Exchange capacity and degree of base saturation in some Illinois surface soils.

Knowledge of the regional variations in soil acidity is of only limited value to the farmer in determining his own liming needs. Some soil types are fairly uniform in lime requirement throughout their extent. Others are quite variable. Moreover, there may be several soil types on the same forty-acre field. Because of the local variations in lime needs, farmers of Illinois have found it profitable to test before liming. Significant savings have been

made not only by avoiding the liming of sweet soils, but also by not sowing clover seed which would have been wasted on acid soils. The educational value of soil testing has been proved also. Many a farmer received his first stimulus to use limestone by collecting samples from his field, testing them with his own hands in a neighborhood soil-testing meeting and drawing a soil acidity map of the field.

LIMING A SOUR SOIL

The limestone in a soil actually does no good until it dissolves. The most important solvent in the soil is carbonated water or carbonic acid. When limestone dissolves in carbonic acid the product is calcium bicarbonate. Magnesium, which would be provided by dolomitic limestone, shall be considered as taking part in these reactions as well as calcium, and forming the corresponding magnesium compounds. When limestone is mixed with an acid soil it first dissolves as calcium bicarbonate and the calcium then displaces the absorbed hydrogen from the acid clay particles changing it to calcium clay. The conditions which control the rate of this change are extremely important from a practical point of view. It can be made to take place instantaneously, as when a solution of a calcium salt is poured through a thin layer of soil on a filter. Professor W. H. McIntire, in Tennessee, found that when the limestone was reduced to a fine powder, very thoroughly mixed with moist soil and then kept moist but undisturbed, seven weeks were required to effect the complete interaction between the soil and the limestone. When the farmer applies limestone it is neither reduced to a powder nor thoroughly mixed with the soil. Under field conditions the complete reaction between the soil and limestone may, and frequently does, require two to four years. But it is not necessary that the neutralization of the acid soil be entirely complete in order to secure satisfactory growth of acid-sensitive crops such as alfalfa and sweet clover. An understanding of the conditions which must exist for their growth necessitates a study of limestone fineness. The results of work carried out at the Illinois Agricultural Experiment Station will throw some light on this question.

RELATION OF PARTICLE SIZE TO EFFECTIVENESS

It has been pointed out that the neutralization of acid soil consists of changing its acid-clay to calcium-clay, the calcium being derived from applied limestone or other liming material. It should also be noted that this process must take place for the most part while the soil is undisturbed, for even if a cultivated crop such as corn is being grown any particular portion of soil in the field is stirred by means of tillage implements only some half-dozen times in a year and each time during only one or two seconds, while the

harrow or cultivator is passing along. It is obvious that under these conditions the reaction between limestone and soil must depend upon the diffusion of the dissolved calcium from the limestone particle into the soil until it is fixed by a clay particle. The next calcium to dissolve after the first film of soil around the particle is neutralized must dissolve in essentially neutral conditions and pass through this neutralized film to reach more acid soil to be neutralized. The first question to be answered is, "How far out from a limestone particle will the calcium penetrate into the soil and neutralize it?"

To answer this question a polished slab of limestone was buried in moist, acid soil in a jar and sealed to prevent drying out. Several of these were set up and examined one by one after varying periods of time, during which they were kept at approximately constant temperature (about 70° F.). The results are shown in table 1.

TABLE 1—PENETRATION OF NEUTRALIZING EFFECT OF LIMESTONE INTO UNDISTURBED SOIL

Time after placement of slab (Days)	Upward from slab		Downward from slab	
	Distance A (Cm.)	Distance B (Cm.)	Distance A (Cm.)	Distance B (Cm.)
259	0.3	0.6	0.2	0.5
528	0.8	1.7	0.4	0.7
Boulder[a]	.....	.....	0.8	1.7

Distance A—Distance of effective, but not complete neutralization.
Distance B—Greatest distance at which a measurable reduction in acidity occured.
a—Measurements made under a small natural limestone boulder found buried about two feet below the surface in an apparently virgin roadside area in Champaign County. It had evidently been in place a great many years.

These data indicate that each particle of a limestone application quickly surrounds itself with a roundish mass of more or less neutralized soil (completely neutralized at the center) which in the course of a year grows to a size ranging from one-half inch up to one and one-fourth inches in diameter. Whenever all of these neutralized masses of soil overlap, the soil will be completely neutralized. But this may require three or more years, as experimental studies on field soils have shown.

An important consideration in limestone fineness is thus the number of particles in a given volume of soil to serve as nuclei for the development of these neutralized areas in the soil mass. As an illustration, suppose a ¼-inch cube of limestone were reduced to 100-mesh cubes, i.e., particles which would just pass through a 100-mesh sieve, with no dust or finer particles included. Each particle would measure 0.0058 inch on a side. One ¼-inch cube would make approximately 80,000 such particles, capable of forming 80,000 neutral centers in the soil if perfectly distributed. But to get 80,000 neutral centers in the soil by using ¼-inch particles of limestone would require 120 pounds of them.

Another method of showing the relation of particle size to neutralization of acid soils is to compute the volume of soil which each limestone particle would have to neutralize in a given application. This has been done for a two-ton-per-acre application for the various size grades and the results are shown in figure 30. It is significant from a practical point of view that all sizes up to and including the 8-mesh (0.093 inch) are comparatively high in efficiency, as each particle is required to neutralize less than one cubic inch of soil, while the 4-mesh size is highly inefficient. A two-ton application of 4-mesh limestone (0.186 inch) provides so few particles that there is only one particle to each 6½ cubic inches of soil, and with ¼-inch particles there would be one to each 15½ cubic inches of soil.

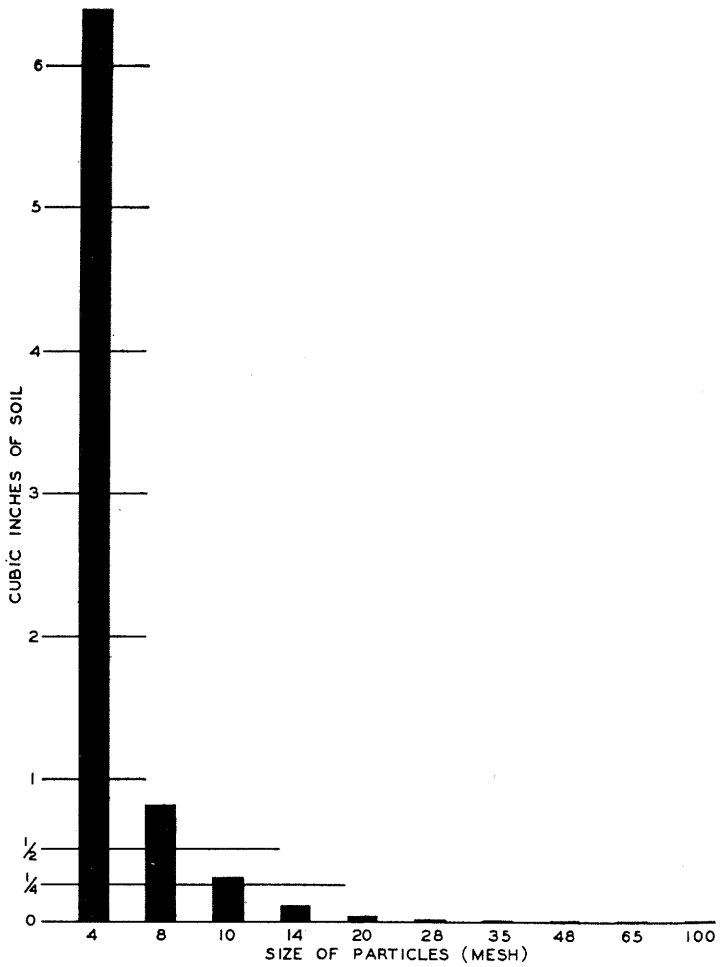

FIGURE 30.—Relation of particle size to space distribution of limestone particles in an application of two tons to an acre.

LIMESTONE SCORE CARD FOR FINENESS RATING

The preceding discussion has emphasized the fact that from the standpoint of actual value to the farmer the evaluation of limestone as to fineness should consist of a method of dockage for very coarse material rather than a method for drawing fine distinctions between different sizes toward the fine end of the scale. Such a score card should also provide for expressing the fineness rating of a limestone by means of one figure rather than by a series of percentages of the different sizes present in the sample. The score card which has been in use in Illinois for some years was devised with the above aims in view. It appeared desirable, in working out the details, to take into account certain other matters as well.

Screen test data were available on some 200 carloads of commercial limestone that had been sold to Illinois farmers, so that it was possible to prepare, by accurately combining different size fractions, a limestone which was similar to the average commercial limestone in use in the State. This was done with five different limestones representing the different geological formations which were furnishing the bulk of Illinois agricultural limestone. These were studied over a period of five years in soil cultures in which sweet clover and grain crops were grown. At the same time they were compared with some of the different size grades used separately. Not only was the growth of crops, particularly sweet clover, determined, but also the rate at which the limestone disappeared and at which the soil acidity was neutralized. As a result of these studies it was found that the limestone of the average fineness then in use rated approximately 75 per cent as effective as finely ground limestone (100-mesh). This information furnished a basis for a score card calibrated in terms of the actual value of the limestone on the farm, since the starting point in the construction of the score card was the assignment of a value of 75 to limestone of the average grinding. The score card is as follows:

Percentage of sample	Multiply by	Product
Thru 100-mesh[a]	1.15	.....
Thru 48, over 100-mesh	1.05	.....
Thru 28, over 48-mesh	1.00	.....
Thru 14, over 28-mesh	.95	.....
Thru 8, over 14-mesh	.80	.....
Thru 4, over 8-mesh	.33	.....
Over 4-mesh	0	.....
Sum of products	.....	.....

a In the Tyler standard screen scale used, the opening of the 100-mesh is 0.0058 inch on a side. In each succeeding screen of the series the size of the opening is twice that of the preceding one.

The sum of the products obtained is the fineness rating of the limestone. It will be noted that this is not a severe score card. Everything finer than 8-mesh receives a high rating, and the very coarse particles are severely discounted. The chief criticism is that the finest fractions are overrated. This was necessary in order to offset the dockage on the coarsest faction and bring the rating on the entire sample up to its true value as demonstrated by crop response. The use of this score card for several years has brought added conviction that the method gives an accurate evaluation of agricultural limestone for use under Illinois farm conditions. Its use also may have been partly responsible for the improvement in fineness of agricultural limestone during recent years. Illinois producers have raised the average fineness rating of commercial agricultural limestone from 75 to 84 during the past 7 years. Some further improvement is still needed, but it is debatable whether Illinois agriculture would profit by increasing the average rating above 90.

CHEMICAL QUALITY OF LIMESTONE

The matter of chemical quality scarcely needs discussion. Limestone is of value only in so far as it will correct acid soils and no amount of preparation can raise this value. Its value in this respect depends on its content of calcium carbonate, or the equivalent in magnesium carbonate, and is expressed as calcium carbonate equivalent (C.C.E.). The cost of quarrying and grinding precludes the practicability of working low-testing deposits.

AMOUNTS OF LIMESTONE NEEDED

The amount of limestone needed in any given case is conditioned upon the acidity of the soil. The final effect should be to saturate the base exchange clay (base-capacity) to the extent of approximately 80 per cent with calcium, since this degree of saturation is sufficient to assure a neutral soil reaction in practically any soil. It is entirely unnecessary to have an excess of free limestone (calcium carbonate) in the soil, and such an excess, if present, is much less resistant to loss by leaching than is the calcium contained in the calcium clay of a neutral soil. For satisfactory growth of acid-sensitive crops during the first year or two after liming, it is essential that neutral centers about the limestone particles be numerous enough that plant roots come in contact with them. Experience has indicated that applications which are sufficient for final neutralization of the plowed depth of the soil usually bring good stands of clovers or alfalfa within less than a year after application.

LIGHT LIMING

Light liming consists of drilling limestone in the row with clover seed. The limestone is applied through the seed hopper of the grain drill (or through the fertilizer attachments where drills have such equipment), while

the clover is seeded through the grass seed attachment. The tubes of the grass seed attachment are run into the grain tubes, thus carrying the clover seed into the drill row in contact with the limestone. A careful setting of the drill is necessary to prevent covering the seed too deeply. This method of liming requires only 500 pounds of limestone an acre. The limestone should all pass an 8-mesh screen, including fines but no additional advantage has been found by using finely pulverized material. Light liming owes its success to the fact that the neutral soil zone around the applied limestone is near the seeds so that the roots of the seedlings are fairly certain to find neutral soil. In cases where the soil mass away from the neutralized zones is highly acid the method has not been successful. The chief advantages of light liming are in getting quick results and in getting a crop of clover or alfalfa with a very small amount of limestone. Its chief disadvantage is that it does not correct the acidity of the whole soil mass and is good for only one crop, whereas an adequate application of limestone is good for 10 to 15 or more years.

KINDS OF LIMESTONE

There are many kinds of limestone. They differ not only in chemical composition, but also in hardness, porosity, character of fracture on crushing, rate of solubility and other properties. These variations have resulted from the conditions under which they were formed and one would expect that the principal differences might be found by comparing material from various geological formations. The five sources previously referred to are believed to include most of the limestone used in Illinois. They are the Ste. Genevieve, Burlington, St. Louis, Niagaran and Coal Measures. Of these, only the Niagaran contains enough magnesium to be considered dolomitic.

Since limestone which has not dissolved has performed no function in the soil, the rate of solubility would be expected to be an important property having to do with its rate of becoming active in the soil. The chemical approach to this problem would be to determine the rate of solubility under controlled laboratory conditions with other variables eliminated. This has been done, using 20-40 mesh limestone and 0.4 normal acetic acid with the results shown in figure 31. Similar results were obtained with the other sizes. The rate of solubility of the dolomitic stone is shown to be very much slower than that of the others. These results are presented to show how completely erroneous may be the interpretation of legitimate results of a carefully controlled experiment if the experiment is not so designed as to answer the real question at issue. The real question at issue here is the behavior of limestone in the soil. When limestone particles are placed in undisturbed soil, as is done in practice, instead of in an acid which is being stirred, the rate at which it dissolves and neutralizes the soil is almost completely dominated by the rate of migration of dissolved calcium through the

soil away from the limestone particle. The actual rate of solubility becomes a very minor affair. Moreover, both the dolomitic and high-calcium limestone particles in the acid soil become surrounded very soon by a layer of neutralized soil so that the rates of solubility of both limestones in this neutral environment are so greatly retarded that differences of rate become insignificant.

The relative solubility rate in soil was determined for the Niagaran dolomitic limestone and the four high-calcium limestones by measuring the amount of undecomposed carbonate remaining in the soil five years after the applications were made. Since the high-calcium limestones were essentially alike in their behavior, the results from only one are given in table 2 along with those for the dolomitic limestone. The soil used was an acid surface soil from Cisne silt loam having a lime requirement of 7,000 pounds calcium carbonate an acre. The "average commercial" limestone addition was made by screening the limestone into a series of size grades and then recombining them in separately weighed portions of each size for each individual jar so that all jars contained not only the stated amount of limestone but also exactly the same proportions of all the different sizes.

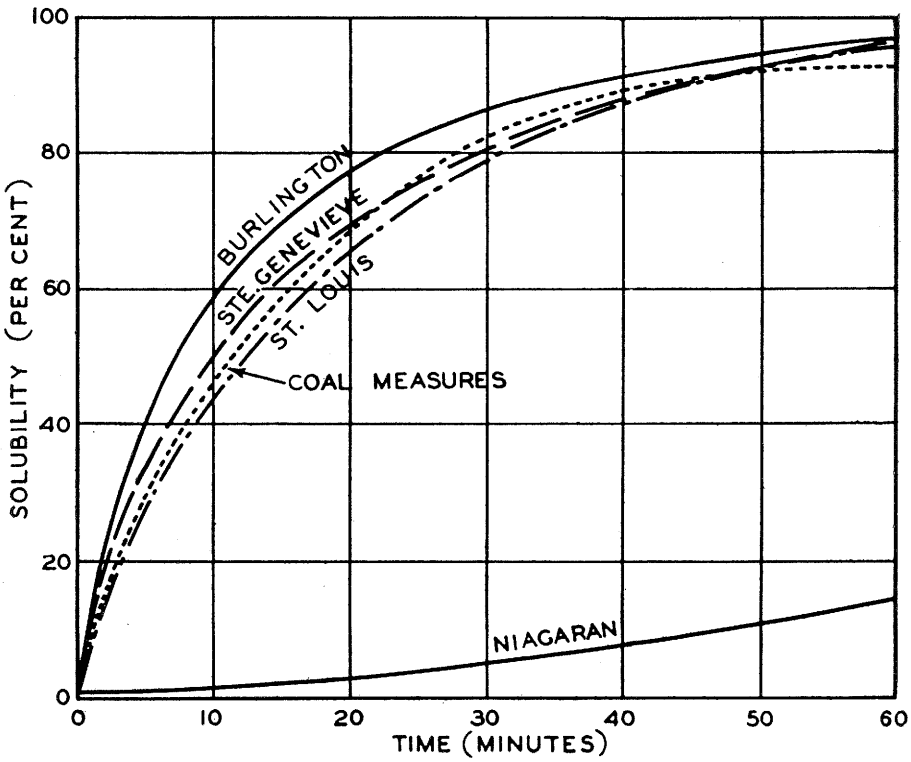

FIGURE 31.—Relative rates of solution in acid of limestones of different geological formations. (20-40 mesh limestone in 0.4 N acetic acid, with stirring.)

TABLE 2—UNDECOMPOSED LIMESTONE REMAINING AS CARBONATE AFTER FIVE YEARS IN THE SOIL, WITH DIFFERENT APPLICATIONS

Kind of limestone	Amount of original application remaining from an acre-application					
	3,000 lbs.[a] 4-5 mesh (Per cent)	3,000 lbs.[a] 8-10 mesh (Per cent)	3,000 lbs.[b] 8-10 mesh (Per cent)	10,000 lbs. average commercial (Per cent)	5,000 lbs. average commercial (Per cent)	7,000 lbs. 100 mesh (Per cent)
Dolomitic	97	81	53	40	20	7
High calcium	81	67	39	24	19	6
Difference	16	14	14	16	1	1

a Accompanied by 7,000 lbs. an acre of 100-mesh limestone.
b Used alone.

FIGURE 32.—Sweet clover growth with 5 tons (above) and 2½ tons (below) of limestone. Kinds of limestone, left to right: Ste. Genevieve, Burlington, St. Louis, Niagaran, Coal Measures (no limestone).

Two facts brought out by these results are worthy of comment. One is that in the coarser size-range high-calcium limestone dissolves in the soil approximately 15 per cent faster than dolomitic limestone, but this difference does not occur in the finer size range. The other is that with commercial limestone (4 mesh down) a similar difference (16 per cent) in favor of high-calcium limestone occurs where the application exceeds the lime requirement of the soil so that the soil is approximately neutral at the end of the five-year period, but the two types of limestone become equal in rate of solution (20 and 19 per cent, respectively, remaining) where the application is less than the lime requirement of the soil so that the latter remains acid throughout the five years. In comparing acid solubility with soil solubility it will be noted that whereas in acid the high calcium limestone dissolves more than six times as fast as the dolomitic type, this difference is reduced to an advantage of only 15 per cent for high calcium stone in the coarse size range and no advantage in the fine range. The practical interpretation of this study would appear to be that for equal results in the field, if just the amount to meet the lime requirement is used, the dolomitic limestone should contain a somewhat smaller proportion of material at the coarsest end of the scale. As a matter of fact, in actual practice farmers generally use an excess above the minimum requirement so that either type of stone produces the results desired in the growth of sweet clover, alfalfa, or other acid-sensitive crops.

The interpretation stated above is supported by the growth of sweet clover in these experiments. Figure 32 shows the adequacy of all five limestones when used at the rate of 5 tons an acre and the inadequacy of all of them at the 2½-ton rate, the sweet clover having been seeded immediately after applying the limestone. The growth of sweet clover in the same soils three years later is shown in figure 33.

USE OF LIMESTONE IN ILLINOIS

So far as is known the first carload of limestone delivered to an Illinois farmer was shipped in September, 1906. The tonnage has increased steadily, except for a decline during the recent depression, to more than a million tons in 1936. No other state uses so much agricultural limestone. It owes its popularity in considerable measure to the success of the limestone-sweet clover combination in soil improvement, and the sweet clover acreage has kept pace with limestone tonnage. But the limestone used in Illinois up to the present time has not kept pace with removals from the soil in the farm products sold and in drainage waters. Of our 20-odd million acres of cropped land, probably 15 million acres need liming, and to supply this need would require a minimum of 30 million tons of limestone. If our farmers were to apply it at the rate of 2 million tons a year, evidence now at hand indicates

that the time would be ripe at the end of the 15 elapsed years to start liming the first limed areas a second time. It appears that natural forces and man's farming the land are combining to provide a continuing demand for agricultural limestone for many years to come, and the evidence of field experiments as well as of farmers' experience leaves no doubt that the crop increases and better balanced farming systems, which its use permits, will make it profitable.

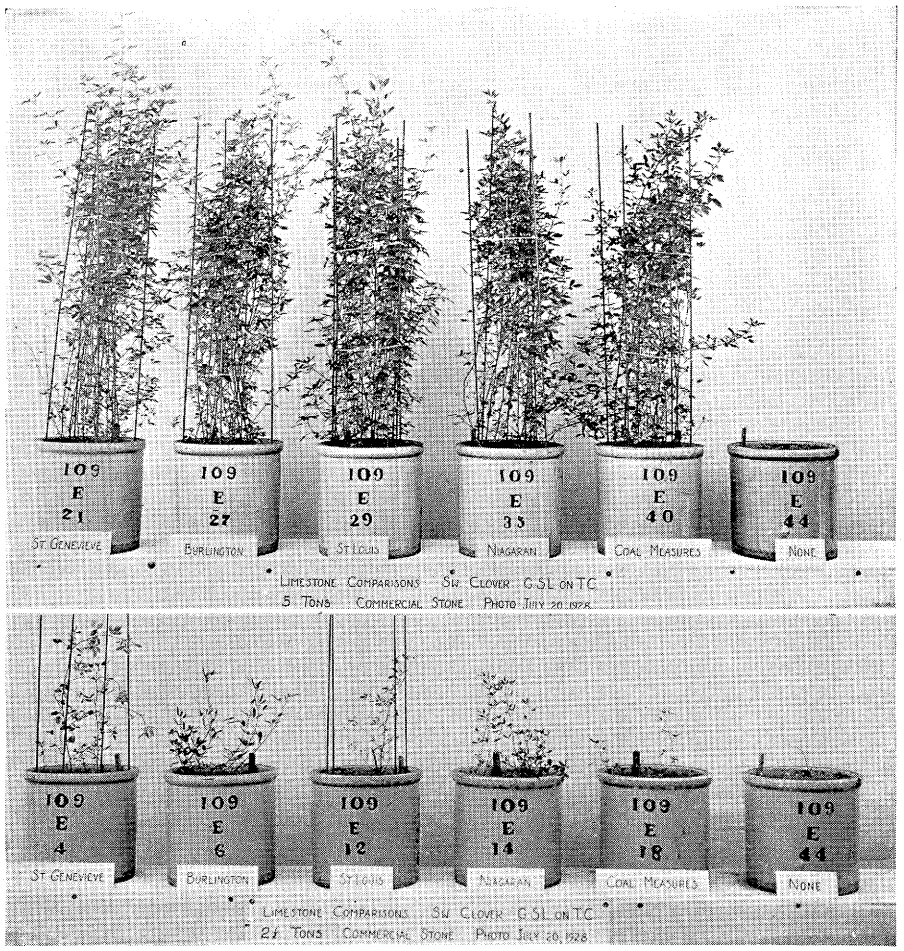

FIGURE 33.—Sweet clover growth with 5-ton and 2½-ton applications of different limestones. This clover grew three years after liming.

CURRENT DEVELOPMENTS IN STABILIZED GRAVEL AND CRUSHED STONE ROADS

By

Ernst Lieberman

Chief Highway Engineer, Illinois State Highway Division

The present day acceptation of the word "stabilization" may refer to the natural subgrade or to a surfacing material placed upon that subgrade, but in this paper I shall deal exclusively with the so-called stabilized base or surface course of crushed stone or gravel.

The stabilized road as designed and built actually involves nothing essentially new in materials or construction except the application of some sound basic characteristics and theories affecting the blending of the materials and then proper construction methods and maintenance to obtain a resulting product in which the voids have been reduced to a minimum, in which enough clay has been introduced to give satisfactory binding qualities, and which will have a density to the highest degree possible to prevent the entrance of capillary water. We find ordinarily a compacted weight of 4,000 pounds per cubic yard.

A study of the theory of design and nearly four years construction experience have proved that the idea is based on sound and accurate theories of proportioning and that we have secured a type of surfacing most satisfactory for moderate traffic from the standpoint of rigidity, strength and surface smoothness.

Experience has proved that certain features in the original specifications may be eliminated or altered in order to get the cost of this type of pavement within the economic principles for a road of this character without seriously affecting the resulting product. An ability to vary the gradation of aggregates to a limited extent affords an exceptional opportunity to utilize materials from the ordinary commercial pits and to develop local gravel and stone deposits at a very reasonable cost.

The theoretical stabilized mix is one in which there is just enough of the sand and clay or soil mortar to fill the voids in the coarse material, with a slight excess. The introduction of the clay is not a new idea; in fact it has been rather common for many years, but a study as to the proper quality and amount is entirely unique in the case of the stabilized road and there is a very definite theory governing its use. Stability in any wearing surface may be defined as resistance to lateral flow under load. It depends upon shear strength, which in turn depends on the combined effect of internal friction and cohesion. Sand, when dry, is unstable but when a small amount of water is added it attains a high degree of stability. Clay, on the other

hand, with a small percentage of moisture, will carry almost an unlimited load but it entirely loses its carrying capacity when wet. The problem then is to combine them in the correct proportions to eliminate the undesirable characteristics and to utilize the desirable ones to produce the best all-year stability. In doing this, certain basic soil properties must be given consideration in the design of any mix; namely, internal friction, capillarity, cohesion, and compressibility, and of these basic points, internal friction, cohesion and retarded capillarity are essential for stability. It is essential that the soil mortar; that is, the combination of clay and sand shall not expand excessively when wetted, otherwise the internal friction will be destroyed. Since internal friction is a function of the sand and gravel grains but cohesion is not, the clay lends the necessary cohesion. Capillarity is harmful to the mass in that it tends to break up cohesion and reduce internal friction. Therefore clay, with its low rate of water flow, tends to reduce the amount of capillary water entering the mixture. On the other hand, clay is expanding material and the amount must be strictly limited in order to prevent undue expansion and breaking up when wet.

Our own experience has proved that it is generally better to use a little less clay than too much, and whereas ten to twenty per cent was accepted at first, ten to twelve per cent is now generally regarded as more desirable. A high percentage of clay often results in a dangerously sloppy surface in wet weather.

The function of the calcium chloride is to attract moisture, particularly to the clay. This preserves its cohesion, thus preventing raveling and surface dust.

A question is often raised as to relative values of broken stone and gravel, and local and commercial products. We have had experience with all. Another question is whether or not the soil mortar or fines represented by the screenings and dust in a broken stone mix can be considered of equal value to the mixture of sand and clay in a gravel mix. There is a divided opinion on the theory; nevertheless from the standpoint of construction results, a mix of broken stone, screenings and stone dust meeting the gradation as shown in the stabilization chart (the stone dust taking the place of clay) has proved satisfactory (see fig. 34).

The chart shows the original stabilization band (ruled down to left) and the other band (ruled to right) indicates our present common practice. It has not been considered particularly detrimental to the mix to allow slight variations even from the latter band, particularly when it is desirable to permit the use of local material—either commercial or roadside products—where economics justify. It is a fact well proved during the past few years that an analysis of many samples of our own local deposits throughout the State indicates that they fall close within the band, the

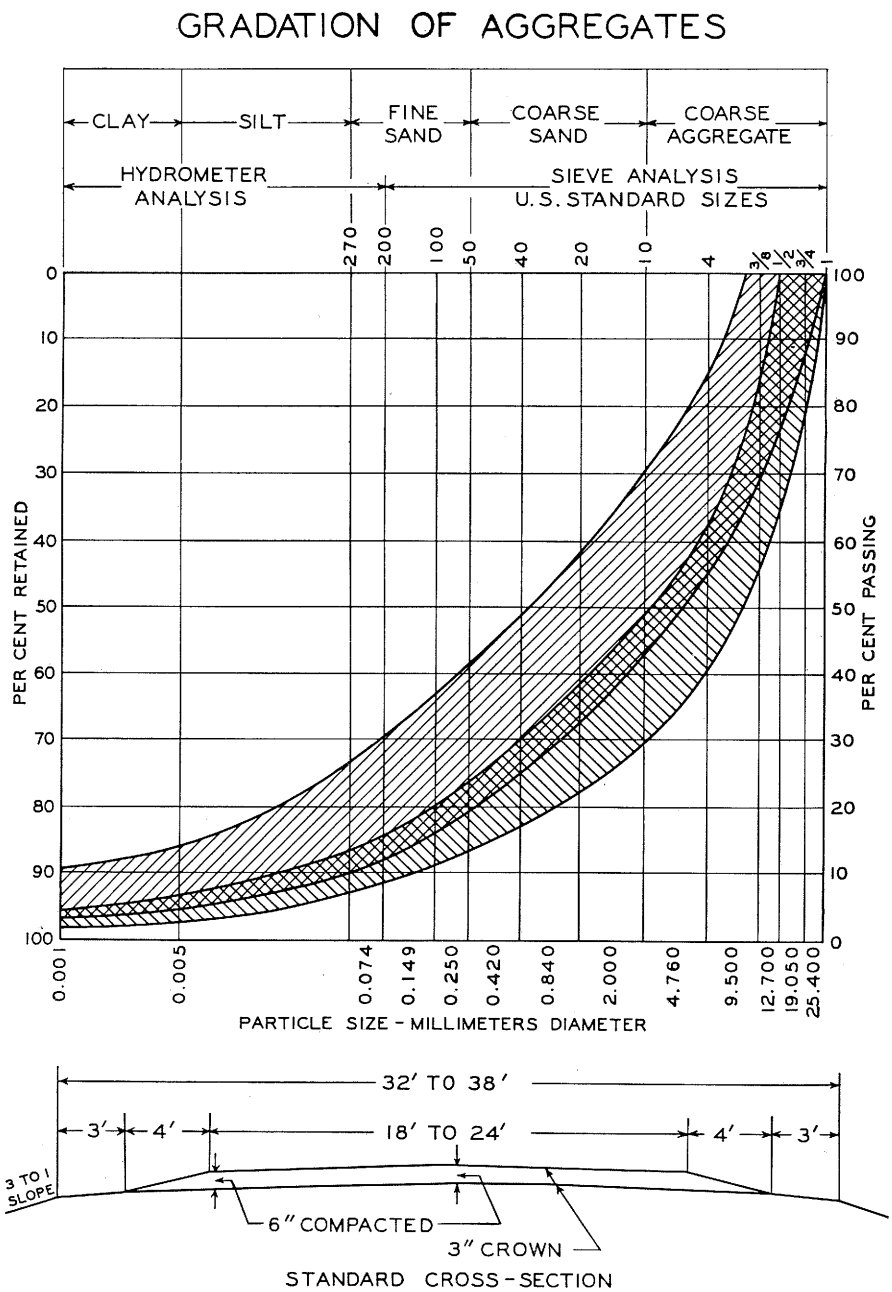
GRADATION OF AGGREGATES
CLAY
SILT
FINE SAND
COARSE SAND
COARSE AGGREGATE
HYDROMETER ANALYSIS
SIEVE ANALYSIS U.S. STANDARD SIZES
270
200
100
50
40
20
10
4
3/8
1/2
3/4
1
PER CENT RETAINED
PER CENT PASSING
0.001
0.005
0.074
0.149
0.250
0.420
0.840
2.000
4.760
9.500
12.700
19.050
25.400
PARTICLE SIZE - MILLIMETERS DIAMETER
32′ TO 38′
3′
4′
18′ TO 24′
4′
3′
3 TO 1 SLOPE
6″ COMPACTED
3″ CROWN
STANDARD CROSS-SECTION

FIGURE 34.

usual tendency being an excess of fines, which can be removed by screenings or by adding coarse material.

Experience has also proved the undesirability for an excess of the fine sand combined with a low percentage of coarse aggregate, and it is generally believed that the upper limits may well be avoided and that for a specific mix, a uniform curve is more effective.

The comparison between local roadside pits or quarries and commercial plants is largely a study of economics. Oftentimes a local gravel pit can produce a correct mix with enough overburden to eliminate the necessity for the separate introduction of the clay; likewise many quarries control their screenings and dust content to a proper mix. On the other hand, the production cost of the established commercial plant is always a factor, and a shorter haul from the railroad siding compared with a long deadhaul from the local plant may offset the railroad rates. The demand for a large volume of aggregate for stabilized roads may prove the logic of the producer adding the proper amount of fines and clay before shipping to the job, and it is my opinion that as soon as he realizes the field which is now open for him to furnish materials for bases and surface courses of this character, he will meet this problem. However, in this connection permit me to sound a note of warning; we are dealing with the secondary road, which must be low in price. The producer must not introduce intricate equipment and expect to get an advanced price for material. To my mind, any increase in price naturally discourages the development of this particular type of road. I urge an intensive study of a proper means of introducing and blending the aggregate in the proper porportions at the production plant. Whether this can be done economically is still a question. If it can, expensive construction operations can be markedly reduced; if not, the more costly road or plant mix must be developed to the lowest economy.

The theory of construction is a thorough mix on the road if a perfect mixture cannot be obtained at the plant; spreading in layers to permit proper compaction; application of water to obtain proper moisture cohesion and aid compaction; a kneading or compacting of each layer to completely interlock the essential ingredients and reduce the voids to a minimum (thus bringing in the three soil properties—internal friction, cohesion, and compressibility); and finally, the application of the chloride to create a moisture attracting agency to prevent raveling and dust.

If it is possible to get a natural mixture, including the clay, the material may be dumped directly on the grade in piles correctly spaced to secure proper thickness, but if an artificial mix is necessary, the mixing is generally done on the grade.

Since most producers can furnish a correct mix of coarse and fine aggregate, the usual procedure is to spread the first layer of aggregate over about half of the subgrade and then add the proper amount of clay. It is always

best to pulverize the clay at the pit, if possible, as it saves time and secures a more uniform mix. The entire mass is then mixed together by blading back and forth across the grade, and finally leveled down to proper width and cross-section. Wetting and rolling follow. The successive layers are built up in the same manner as the first. Care must always be taken to keep the subgrade from being incorporated during the mixing.

Layers of approximately two inches seem to give best results, which is an axiom for the compaction of any material, earth, gravel or stone. A minimum thickness permits complete and thorough interlocking of the particles which may not be obtained with thicker layers because the effect of the roller will not be transmitted through the entire mass, thus causing voids at the bottom.

The roller best adapted is the truck-tire type recently developed on the same principle as the dual truck wheel; that is, six or eight wheels with pneumatic tires strung on an axle which supports a body, this machine propelled by truck or tractor. It produces the effect of a series of truck tires which I believe secures better compaction than the ordinary roller; the very nature of a tire secures an excellent interlocking of the materials.

Traffic, if not too heavy, and if not concentrated in one rut serves much the same purpose as the roller.

One of the uncertainties to the contractor in figuring a job is the hauling, spreading, and intermixing on the grade of the various aggregates, particularly the clay, and to eliminate delays and standardize production, several machine mix methods have been developed. In several instances a 27-E concrete mixer has been used successfully but production is limited. One machine mixer which picks up the windrowed material from the subgrade and runs it through a pugmill has proved very satisfactory. The best piece of equipment used in this State to date is the Pioneer plant mix unit. The advantage of this particular machine is that it combines the sand and coarse aggregate, runs the clay through a shredder and then mixes the entire mass with water and calcium chloride in a pugmill, delivering the finished mixed product into a storage bin, from which it is dumped into trucks and hauled to the subgrade. The only road operation necessary is the spreading in layers and rolling. One such outfit in 1936 laid 27 miles of 18-foot road and this year has a program of 38 miles. The resulting mix is more satisfactory and the cost markedly lower than a road mix. Economics of construction must be given still further study and let me repeat: A correct gradation of all component materials by the producer would eliminate all the expensive job mixing.

Whereas the flake calcium was originally applied to the finished surface, it has been found more desirable now to mix it in the top layer. The use of salt in place of calcium chloride has proved economical and the action is satisfactory.

It has been definitely demonstrated that the stabilized road will not compact thoroughly or "make" except under continued traffic and at least 30 days maintenance should be provided to work out soft spots and insure proper interlocking of the aggregate. Continual blading, the application of water, and some rolling may be necessary. As a matter of fact, I have come quite firmly to the conclusion that any stabilized road should go through a winter's traffic before we can safely say that it is thoroughly compacted with the reduction of the voids to a minimum.

Blading or dragging at the proper time is essential for the maintenance of any stabilized road and a firm smooth surface quite free from loose material results. Three applications of calcium—¾ pounds per square yard are recommended in May, July and September.

The chart also shows our latest cross-section. The featheredge shoulder of gravel is believed to be of advantage in keeping free water from damaging the pavement: that is, surface water cannot be trapped on the subgrade by a more or less impervious earth shoulder. This is especially important during the early spring thaws when all gravel or broken stone roads are proverbially soft.

The earth shoulder has a particular disadvantage under maintenance where the drag or blade is bound to deposit a certain amount of earth on the edges of the road metal, resulting in a slippery surface which is invariably avoided by traffic, thus restricting the traveled roadway.

The cross-section as shown gives a very wide and ample road, tending to distribute traffic; this tends to compact uniformly the entire surface width and is of distinct advantage when a bituminous surface is contemplated—an otherwise soft edge tends to a raveling of the "blacktop".

Naturally the one interesting question to all of us is the place, the scope, and finally the future of this particular type of construction. Without reservation I refer to the secondary road system, which seems to be well established now in our highway program. It has been recognized emphatically not only by our Governor, but also by the Federal Government through the fact that each of the Federal relief grants for highway purposes, the 1934 and 1935 N.R.A. and the 1936 W.P.A. specified that a definite percentage of the grant must be spent for secondary highways.

In line with such a program and realizing the necessity for an economic study of the entire highway system of the country in order to properly classify roads according to present traffic and future importance, the Federal Government in 1935 appropriated a definite sum of money to be expended on a national planning survey of the highway system of each state. In our State practically all of the field work has been completed and the great mass of information is now being correlated—so as to be utilized at once in the economic design of highways capable of handling their present day traffic, yet still looking ahead to their future development—not wasting funds

on roads which must always be only feeders, and likewise not building something which may be a total loss when in a few years increased traffic demands a more modern construction.

The secondary system fits well into the picture as the logical place for the stabilized road because of its moderate cost and reasonable maintenance under moderate traffic. It will handle satisfactorily the present traffic, and as time goes on and a higher type of surfacing is required, it can be utilized in practically its entirety as a base course for some type of bituminous surfacing or even as a stable base or subgrade for Portland cement concrete.

As to the farm-to-market or small feeder roads of very light traffic, the stabilized type may well have a place in their construction, dependent entirely upon the economy of the materials and construction. Roads of this character justify some sort of gravel or broken stone surfacing, and if the stabilized road can meet competition with the so-called traffic-bound, it is distinctly as satisfactory.

The 1937 session of the State Legislature, to meet Federal legislation, authorized the Department of Public Works and Buildings, Division of Highways, to lay out a ten thousand-mile system of Federal secondary roads, which henceforth will serve as a basis for future construction.

Federal appropriations for the years 1937 and 1938 specify approximately one million dollars each year to be spent on the secondary system, with the understanding that the State will contribute a similar amount. What the future will bring is yet a problem, but it is thought that the establishment of a definite system and the policy of a specific appropriation presupposes its definite place in our future Federal and State program.

While the stabilized gravel or broken stone road has not been adopted by all counties, nevertheless the work which has been done under State supervision has served in a large measure as an object lesson with the result that many of the counties have begun to appreciate the advantages of this particular type of construction; yet I may say without fear of contradiction that the one thing which has held back its adoption is economics. Certain refinements in materials and construction practices have a tendency to add slightly to the price, which is an important factor with a county limited in funds. Bear in mind, too, that on many of the county roads traffic does not, and probably will never, justify the necessity for anything more than two or three inches of gravel to give adequate service 365 days in the year.

A few figures may be of interest to the material producers. The State under its own supervision has constructed in the past four years (1934, and including 1937 estimated), 587 miles of gravel and crushed stone roads, of which 444 miles have been stabilized. For the cross-section shown on the chart we estimate 2,347 cubic yards, compacted measurement, of aggregate for

a 20-foot width, including the gravel shoulders, and 2,151 cubic yards for an 18-foot width.

Gravel or broken stone road construction by the counties and cities, with the motor fuels tax (M.F.T.) funds, is even more significant as the figures for the past four years will show:

1934—313 miles	1936—659 miles
1935—389 miles	1937—600 miles (estimated)

On county and city work quantities vary between rather wide limits, but a safe average would be 1,500 cubic yards, loose measurement, per mile.

Our own program on the new Federal secondary system from the 1937 appropriation contemplates 139 miles of gravel or broken stone road, and 1938 should be closely the same. The future on the county and city M.F.T. work, judged by the past, may easily average 500 miles per year. These rather approximate estimates should show the aggregate producers the present trend.

In conclusion:

A. An analysis of the traffic on our highway system indicates that we have many, many miles of secondary roads which will carry only moderate traffic—say less than 500 vehicles per day.

B. On roads of this character, a road of broken stone or gravel seems the economical type, for its first cost, reasonable maintenance, and its adaptation as a base for future improvements when required.

C. Thus far, our own experience justifies the stabilized aggregate, but its economic development calls for a thorough cooperative study between the engineers of the highway department, the material producers, the equipment manufacturers, and the contractor.

D. Economy in construction of this type of road involves a more or less elastic specification to utilize such local resources as we have available, the development of equipment which can reduce construction costs, and the realization by contractors that this type of construction is permanent and that they are economically justified in equipping themselves with proper machinery to handle a reasonable program.

E. If we all enter into the problem with the idea of getting a road in terms of cost equal to its value, such a type will be justifiable. On the other hand, if the price figures a little beyond the logical value, the utilization of this particular type will not prove successful.

F. We have before us a definite secondary road program utilizing Federal and State funds; likewise a continued yearly expenditure by the counties and cities of their M.F.T. allotments which approximate $7,500,000 to each.

G. Judging the future by the past few years, it does not seem an irrational assumption—rather a low conservative estimate—to state that the material producers and the contractors alike have a definite outlook in the stabilized gravel or broken stone road during the next decade.

SYMPOSIUM ON INDUSTRIAL MINERALS

UNEXPLOITED OR LITTLE KNOWN INDUSTRIAL MINERALS OF ILLINOIS

By

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INTRODUCTION

Throughout the State of Illinois are scattered a variety of minor industrial minerals, most of which are unexploited and many of them not generally known. None of these resources as now understood are conceived to be the basis for an extensive mineral industry. However, some of them may be sources of additional revenue for certain of the State's mineral industries, which by reason of technical knowledge, geographic location, or business relations, are able to profitably exploit one or more of these resources.

The data presented are an accumulation of thoughts and observations rather than the results of an intensive study of the resources described. Probably some of the resources to be described and their utilization might well be made subjects of research by the Survey were not other projects of greater general significance and more widespread application occupying attention. Despite the fact that the data at hand are limited, it does seem worth while to point out these resources for the information and possible benefit of the Illinois mineral industry.

For many of the resources, those uses which have thus far come to mind will be suggested, likewise any significant test data at hand will be given. The field is, however, wide open to the ingenuity and resourcefulness of the Illinois mineral industry.

Due to the length and scope of this paper, details regarding many items have of necessity been omitted. Upon request the Survey will gladly furnish any specific data available, and will further be glad to cooperate in any way possible within its legitimate field with those of the Illinois mineral industries seeking to develop uses for these resources.

POTASH

The potash-bearing rocks of Illinois of possible commercial significance are of two major kinds, shales and greensands. In the latter the potash is probably present mainly as a part of the mineral glauconite, which is essentially a hydrous silicate of ferrous iron and potassium. The mineral is green in color, hence the name greensand for sands rich in glauconite.

Several articles have been published regarding potash in Illinois,[1] one of which deals with potash as a by-product from the shale used in cement manufacture. It is not proposed to consider this particular angle here, but rather to discuss potash-bearing rocks, with reference to their possible use as fertilizer, reviewing briefly the published data and adding recently obtained unpublished information.

SHALE

A potash-bearing shale, the Mountain Glen formation, 35–45 feet thick, outcrops at a number of places in Union County (fig. 35). Several deposits favorable with respect to quarrying conditions and railroad transportation have been described. This shale has an average K_2O content of 5½ per cent and appears to be quite uniform with respect to potash content. Sixty-two per cent of the potash in a sample studied in detail was removable by extraction with sulfuric acid and pot culture tests indicate that the acid extractable material is largely responsible for the fertilizing value of the shale. A series of greenhouse pot culture tests were made in which various combinations of lime with kainit, alunit, leucite, and Mountain Glen shale were employed. The results of this work led to the following conclusions: "The pot culture work in the greenhouse indicates marked benefit to crops resulting from application of shale. The results are so striking and of such possible economic development as to warrant more extended investigations, particularly in the field. It is quite evident that the potassium in this shale can be directly used by crops in pot cultures under greenhouse conditions."[2] No commercial exploitation of this shale has occurred to date.

GREENSAND

Deposits of greensand have been observed in the vicinity of Olmsted[3] (fig. 35) in southern Illinois. The exact thickness of the deposits is not known, but a 4-foot greensand bed separated from another 3½-foot bed of greensand by 1 foot of conglomerate has been reported to outcrop in Sec. 13, T. 15 S.,

[1] Parr, S. W., Austin, M., Krey, F., and Stewart, R., Univ. Illinois Agr. Expt. Sta. Bull. 232, 1921.
Schroyer, C. R., Notes on potash possibilities in Illinois: Illinois Geol. Survey Bull. 38, pp. 434-436, 1922.
Schroyer, C. R., Potash as a by-product in cement manufacture: Illinois Geol. Survey Bull. 38, pp. 437-440, 1922.
[2] Parr, S. W., et al., Univ. Illinois Agr. Expt. Sta. Bull. 232, 1921.
[3] Schroyer, C. R., Notes on potash possibilities in Illinois: Illinois Geol. Survey Bull. 38, pp. 434-436, 1922.

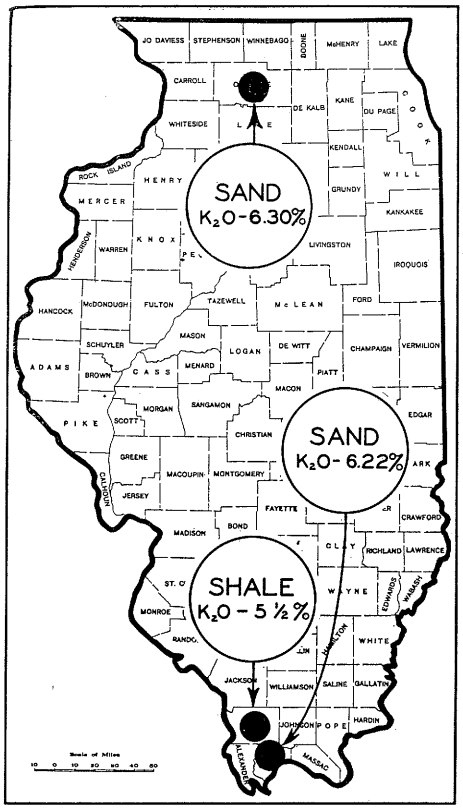

FIGURE 35.—Potash shale and greensand deposits in Illinois.

R. 1 E. This deposit analyzed 6.22 per cent K_2O, most of which probably was present as a constituent of the mineral glauconite. Detailed search may reveal other deposits of greensand in southern Illinois of sufficient size and having thin enough overburden to be workable on a moderate scale, but in general a thick, unconsolidated overburden is likely to be found on most deposits.

About one-half mile northeast of Oregon, Illinois (fig. 35), in the S. ½ N. ½ E. ½ sec. 3, T. 23 N., R. 10 E., there is exposed in what appears to be an old quarry a glauconite sandstone known as the Mazomanie formation. This is the only outcrop of this formation in Illinois, and it appears to have resulted from sharp folding or faulting of the bedrock or possibly both. Ten feet of the sandstone is exposed, but its total thickness is probably much greater than this. It is a fine-grained, brown, thin-bedded sandstone that is easily reduced to a sand. A count of 1,000 grains of the sand after washing to remove clay, showed 12 per cent of glauconite grains. A chemical

analysis of the raw sandstone reported 6.30 per cent K_2O. The amount of sandstone which could be quarried by open pit methods is probably small, but as the sandstone is overlain by a dolomite formation, a good roof probably would be available for underground mining. The possible effects of structural conditions on such a procedure would require thorough investigation.

The Glenwood sandstone, which also outcrops at many places near Oregon and lies above the thick St. Peter sandstone formation of that region, is likewise glauconite in places. No deposits have been reported which have a glauconite content comparable to that of the other greensands described, but careful search might reveal such deposits.

Probably the best known greensand deposits in the United States are those occurring in New Jersey. The K_2O content of these sands varies between 5 and 7 per cent.[4] Attempts have been made to extract the potash from the New Jersey deposits, but so far as is known were unsuccessful commercially. However, the possible use of raw greensand as a potash fertilizer material[5] should not be overlooked. It is reported[6] that New Jersey greensand is spread on the soil in its raw state as a fertilizer and that Virginia greensand is dried and ground for use in commercial fertilizers.

COARSE-GRAINED AND FINE-GRAINED SANDS

Sands of various types are widespread throughout Illinois. In the northern part of the State glacial or related sands, most of them calcareous, are abundant and in this area likewise occur the unexcelled silica sands of the St. Peter formation. Sand is also abundant along Mississippi, Illinois and Wabash rivers and adjacent areas; some of it is calcareous, most of it is not high silica sand. In Alexander, Pulaski and Massac counties of extreme southern Illinois, sands of an entirely different age than those mentioned are to be found in deposits of considerable thickness and extent. Mostly the sands are medium or fine grained but in Alexander County coarse sand is also present. In view of the possible commercial significance of these coarse sands and very fine sands, a brief discussion of the Alexander County sands is given.

DESCRIPTION OF DEPOSITS

Near the center of the south line, SW. ¼ sec. 22, T. 15 S., R. 3 W., near Thedes, 16 feet of coarse sand is exposed in a hillside behind a farmhouse. Below the sand lies 16 feet of interbedded fine sand and clay and above it a variable thickness of brown clayey silt. There is a thin layer of chert gravel about 12 feet from the top of the sand deposit. The sand is red in color due to a coating of red clay on the grains. When washed free

[4] Schroyer, C. R., Idem, p. 436.
[5] Ladoo, R. B., Non-metallic Minerals, p. 444, 1925.
[6] Ries, H., Economic Geology, p. 279, 1930.

of the clay about 5 per cent of the sand grains are seen to be chert and the remaining 95 per cent are almost entirely quartz. Some of the quartz grains are clear and transparent, others are of the milky variety. The shapes of the grains vary from angular to rounded and all grains exhibit more or less polished surfaces. Sample 61, table 1, was taken from this deposit, which is about 1½ miles by road from two railroads and the Mississippi River.

Another deposit of a roughly similar nature occurs on the top of a ridge in SE. ¼ sec. 27, T. 15 S., R. 3 W. near Fayville. Seventeen feet of coarse red sand is exposed in an old gravel pit. Overburden is chert gravel and clayey silt but the nature of the exposure did not permit worth-while estimates of overburden thickness. Sample 42 was taken from the upper 6 feet of the exposure and sample 42A represents the entire 17 feet of sand (table 1).

Fine-grained, high silica sand is exposed at a number of places near Fayville, one of the best of which occurs in an abandoned man-made roadway cut between two valleys in the NW. cor. NE. ¼ NW. ¼ sec. 34, T. 15 S., R. 3 W., where 35 feet of white micaceous sand locally containing thin beds of clay is exposed beneath about 25 feet of brown clayey silt. The deposit is about ½ mile from two railroads and Mississippi River. Sample 300 was taken from the sand.

Twenty feet of similar white sand is exposed along the wagon road in the cen. SE. ¼ of the same section and sample 41 represents this deposit. The deposit is located along a railroad and is only a short distance from Mississippi River.

TABLE 1—RESULTS OF SIEVE TESTS ON ALEXANDER COUNTY SANDS
(The sieve test of St. Peter sand from the Ottawa district is included for comparison.)

Sieves	Coarse sands			St. Peter sand	Fine sands	
	No. 42A	No. 42	No. 61		No. 41	No. 300
—4 + 6 mesh.....	1.1	0.5	0.0	.....	.....	.....
—6 + 10 mesh.....	3.1	3.0	2.3	0.0	.....	.....
—10 + 20 mesh.....	19.8	27.0	32.3	0.4	.....	.....
—20 + 28 mesh.....	29.9	26.0	31.3	18.3	0.0	.....
—28 + 35 mesh.....	19.9	16.4	15.7	52.5	0.1	.....
—35 + 48 mesh.....	8.7	12.1	4.3	19.2	0.5	0.0
—48 + 65 mesh.....	4.1	4.0	2.6	4.9	3.9	2.0
—65 + 100 mesh.....	2.2	1.9	1.5	2.7	57.1	17.6
—100 + 150 mesh.....	0.3	0.2	0.2	1.2	21.7	20.4
—150 + 200 mesh.....	.....	.....	.....	0.5	8.8	34.4
—200 + 270 mesh.....	.....	.....	.....	0.1	1.9	11.6
Pan.....	0.2	0.2	0.3	0.1	0.6	9.8
Clay.....	10.5	8.5	9.6	0.6	4.7	4.2

USES OF SAND

Laboratory washing tests on the coarse sand shows that most of the clay associated with it is removable without difficulty giving rise to a light pinkish-colored sand. It would seem likely, therefore, that a commercial washing process, such as that used in the Ottawa district, would yield a product suitable for some of the physical uses of silica sand. However, it is doubtful if simple washing would yield a product suitable for most chemical uses of silica sand. The outstanding character of the sand is its coarseness, its non-calcareous nature and high silica content. So far as is known, the sands described are the coarsest quartz sands in Illinois. Compared with a sample of silica sand from Ottawa it is seen that whereas the Ottawa sand contains 0.4 per cent material coarser than a 20-mesh sieve, the southern Illinois sands have 24, 30, and 35 per cent plus 20-mesh material. Likewise, a figure of 19 per cent coarser than 28 mesh for the Ottawa sand is to be compared with figures of 54, 57 and 66 per cent for the southern Illinois sands. Figure 36 presents some of these data graphically.

While further testing is necessary before specific uses can be recommended, it is suggested that the sand is worthy of consideration for sand blast sand, filter sand, and probably other uses. Whether the deposits are of suitable character and of sufficient size to warrant commercial exploitation cannot be stated on the basis of the data available from the natural outcrops; however, it is believed the chances are good that detailed exploration will reveal commercial deposits.

The fine-grained sands are composed, exclusive of their clay content, of about 96 per cent quartz, 3 per cent white mica, and 1 per cent other minerals. Laboratory washing gives rise to a white sand except for small amounts of yellow iron-cemented clay grains. Probably scalping over a 65-mesh sieve would remove most of the clay pellets and one-third of the mica. Washing also offers an opportunity to eliminate clay and a considerable portion of the mica. The latter may be marketable.

Sieve tests on two samples of the fine-grained sand are given in table 1, which shows, excluding clay, 33 per cent finer than 100 mesh for one sample and 76 per cent for the other.

The fine-grained sands may have a number of uses but the only one which has been investigated thus far is molding sand. Results of a molding sand test made in the Foundry Laboratory, University of Illinois, are as follows:

Am. Foundry Men's Assn. Grain fineness No. — 20
Cohesive strength—100
Permeability—38

This sand is very good in fineness, permeability and refractory qualities, but the bond or cohesive strength is low. The bonding material is also short lived. As found in nature the sand would have a small use in core sand mixtures; if the cohesive strength were raised by adding about 2 per cent of plastic clay, it could be used for heavy brass castings.

> If the sand were treated to remove mica and clay and then were used with an artificial bond, it would be a good molding sand for brass, aluminum and small cast iron castings and also a good core sand for general purposes.

The statement previously made regarding commercial deposits of coarse sand applies as well to the fine-grained sands.

PEAT

The peat deposits of Illinois occur mainly in the north half of the State and in Tazewell and Mason counties in the central part. Although the peat resources of Illinois have not been studied in detail, it has been estimated that in the 6 counties thought to contain the largest deposit of peat —DuPage, Kane, Kankakee, Lake, Tazewell and Winnebago—over 42,000 acres of peat are present which would yield about 10,000,000 short tons of air dried peat.[7] In general most of the deposits are comparatively small but a deposit in Cattail Slough near Sollers in Whiteside County is estimated to contain nearly 4 million tons of air dried peat, a deposit near Manito in Tazewell County, 120,000 tons, and a deposit near Antioch in Lake County over 400,000 tons.[7]

The thickness of the peat deposits usually ranges between 5 and 20 feet but deposits as thick as 35 feet are reported. Most of the peats are the result of the decay of grass, sedge or cattail vegetation. No sphagnum moss peat of consequence is known.

Analyses of Illinois peat[8] indicate that in general they contain too much ash to be used as fuel, though they may be used in making fertilizer and packing material. The Illinois peats are in the main relatively impure, however, the average nitrogen content of 18 samples of Illinois peat is 2.65 per cent which is above the general average. Five Illinois samples contained over 3 per cent nitrogen and one from Lake County 3.84 per cent, an unusually high figure for raw peat.

Comparatively small amounts of peat or muck are now being produced in the Chicago district. One of their important uses is lawn dressing. At Manito peat was once produced in considerable amounts as a filler or packing material and for other purposes.

The effectiveness of raw Illinois peat in general as a fertilizer has not been definitely determined but due to its water holding capacity, the peat can be used advantageously for reducing cracking and improving the texture of heavy clay soils. Packing material, filler, litter, lawn dressing and for addition to the soil on greenhouse benches are other possible uses of Illinois peats.

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[7] Soper, E. K., and Osbon, C. C., The occurrence and uses of peat in the United States, U. S. Geol. Survey Bull. 728, pp. 104, 107, 109, 110, 1922.
[8] Ibid., pp. 27 and 58.

MARL

The term marl is popularly used in Illinois to describe any incoherent deposits consisting principally of $CaCO_3$. Shell marl is one general type of material to which the term is applied and it is likewise used to describe spring deposits. Materials of the latter type have been observed at several places in Calhoun County, in Bureau County, in Fairies Park at Elgin and other places north of the park on the east side of Fox River valley, and near Danville. In general these deposits are small and solely of local significance as sources of material mostly used as agricultural limestone.

The shell marl deposits on the contrary in places may reach considerable size. They are composed of the shells of small fresh water animals together with variable amounts of clay and sand. In general the shell marl deposits lie below peat deposits, although in some deposits the peat is thin. Discovery of the deposits is mainly a matter of chance or of prospecting peat deposits or swampy depressions. In general the marl accumulated in ancient lakes which existed in depressions which are usually still reflected in the present topography and topographic conditions favoring relatively clear quiet lakes might be expected to favor the formation of marl. It is believed that the northern third of the State is more favorable for marl deposits than the southern two-thirds, and that in general marl deposits will be found most commonly in Lake, McHenry, Cook, DuPage and Kane counties.[9]

A brief description of some of the larger known deposits may be of interest. Southwest of Chatsworth in Livingston County a marl deposit is reported[10] to be 40 feet deep and to cover 40 acres. Another deposit near DesPlaines on the Elmhurst Road just north of McDonald Road is said[11] to be 19 feet deep and some 16 acres in extent. A deposit in Phillips Park in Aurora was shown by borings to have a maximum thickness of 30 feet; other borings recorded thicknesses of 13, 16 and 18 feet.[12] A few miles west of Antioch in a bog between channel Lake and Lake Marie in the flood plain of Fox River 6 to 8 feet of marl was encountered in the center N. ½ sec. 3, T. 43 N., R. 9 E.; about 6 miles north of Barrington, 6 to 8 feet of very pure marl overlain by roughly 1 foot of less pure marl is reported; and Lilly Lake south of the town of the same name contains about 20 feet of peaty marl.[13] Further and more specific information regarding marl in Lake and McHenry counties is expected to result from a study of the geology and mineral resources now in progress.

The composition of Illinois shell marls is not known in detail but it seems likely the marls containing over 85 or 90 per cent carbonates may be reasonably common.

[9] Ekblaw, G. E., Personal communication.
[10] Pontiac, Ill., "Leader," July 16, 1937.
[11] DesPlaines, Ill., "Times," Aug. 6, 1937.
[12] Powers, Wm. E., Geological setting of the Aurora mastodon remains: Trans. Illinois Acad. Sci., vol. 28, no. 2, p. 194, December, 1935.
[13] Ekblaw, G. E., Personal communication.

Because shell marl is usually easy to dig and requires little if any crushing, it is attractive for the production of agricultural limestone.

SLATE

There are no true slates in Illinois, but there are several types of material to which this term is sometimes popularly applied and it is these which will be discussed briefly. The first and most widespread "slate" is the variety associated with the coal beds of the State, and sometimes called "roof slate." These "slates" in places lie immediately above a coal bed or several feet of other strata may intervene between the top of the coal and the "slate". They are usually black due to a comparatively high carbon content, fine grained, well bedded and break into brittle, thin sheets sometimes of considerable size. They resemble true slate somewhat in appearance and cleavage, but do not have the hardness or weather resistance of true slates. None of the "slates" tested thus far have been calcareous, but many of them contain pyrite, though this is not necessarily a general characteristic.

As has been intimated, the Illinois black "slates" are of Coal Measures age and as many Illinois coals have some "slate" above them, it is evident that the "slates" are widespread. It is impossible to describe all the known Coal Measures "slate" outcrops in Illinois, but a few data will serve to give an idea of their occurrence and thickness. In northern Illinois, the LaSalle No. 2 coal has 2 to 3 feet of black "slate" above it in that part of the area lying west of Starved Rock State Park; east of this place the "slate" is lacking, or inconsequential. Also, in northern Illinois the Springfield No. 5 coal is overlain generally by 2 to 3 feet of "slate." A similar thickness of "slate" lies below the LaSalle limestone in the same general area and likewise 2 to 3 feet of "slate" occurs below the No. 6 coal of the Streator area and is the floor of coal mines.

Four feet of black "slate" is found in places over No. 1 coal north of Monmouth in western Illinois. "Slate" also occurs above the No. 2 coal of western Illinois. In the vicinity of Peoria and Galesburg the No. 5 coal has a "slate" which reaches 4 feet thick.

In Williamson County of southern Illinois the No. 5 coal also has a black "slate" above it in places. The "slate" has a maximum thickness of about 3 feet. Many mines in No. 6 coal in southwestern Illinois locally have 2 to 3 feet of "slate" above the coal.[14]

No special study has been made of Coal Measures "slate" deposits capable of being worked solely as a source of slate. Some such deposits probably exist, but an easier and probably cheaper procedure would be to produce "slate" in conjunction with coal mining.

[14] Cady, G. H., Personal communication.

Two other types of slaty shales occur in southern Illinois a few miles southwest of Jonesboro in Union County. One of these is a black or dark brown well bedded shale which splits into thin sheets and the other is a highly silicified, hard shale. Both occur in accessible deposits up to 35 feet thick. The black shale owes its color to carbonaceous matter and is usually not calcareous. The silicified shale is hard, brittle and slaty in appearance, gray to greenish gray in color, and in places is slightly calcareous, but considerable thicknesses of noncalcareous shale are present.

So far as is known no use has been made of the Coal Measures "slates" except as a road material. The black southern Illinois shale is not known to have been used for any purpose, but the silicified shale was at one time quarried and crushed for roofing granules. Its weather resistance is reported to have been unsatisfactory, however, and production was abandoned.

No comprehensive investigation of the above mentioned materials as mineral fillers, particularly as a substitute for slate flour, has been attempted but it appears that such a study might have possibilities. Also worthy of consideration is the possibility that the southern Illinois silicified shale might provide a suitable granule for use in preparing coated roofing chips.

BRINES

At the present time salt (NaCl) is being produced in the Middle West from rock salt mines in Kansas, mines and brines in Michigan and from brines in Ohio. It is not generally known, however, that during the nineteenth century Illinois was an important salt producing state; in fact, for a time the major producer in the Middle West. Salt works existed at Equality, Central City, Murphysboro, St. John, Danville, and probably at other places. The eventual cessation of salt production in Illinois was due to the discovery of stronger brines elsewhere in the Middle West.

The fact that salt making from the relatively weak brines used in Illinois in the nineteenth century could not compete with the production of salt from stronger brines elsewhere should not be interpreted to mean that Illinois does not have brines worthy of consideration. As a matter of fact, it has been only in recent years that any even moderately detailed data regarding Illinois brines have been available. There are now in the Survey files about 300 analyses of Illinois brines, most of which were obtained from oil wells or wells drilled for oil. So far as is known no special search for strong brines has been made in Illinois, so that our knowledge of Illinois brines is really a by-product of information obtained for purposes of the oil industry. Nevertheless, an examination of these data shows much of interest.

TABLE 2—ANALYSES OF BRINES FROM ILLINOIS AND OTHER STATES
(Hypothetical combinations in parts per million

	1	2	3	4	5	6	7	8	9	10	11	12	13
KNO_2	.....	5	2	1	2	3	.....	.....	.....	.....	.....	.....	.....
KCl	5,525	1,302	6,520	1,493	9,322	709	.....	.....	.....	114	713	.....	.....
$NaNO_3$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
NaCl	115,200	97,680	68,950	10,770	91,980	30,150	91,595	42,582	87,889	84,300	310,977	234,050	141,000
NH_4Cl	.....	854	123	35	138	.....	27	9	4	.....	.....	.....	.....
$MgCl_2$	10,070	4,789	8,468	20,360	5,055	.....	3,695	3,900	4,414	5,590	462	21,200	31,000
$CaCl_2$	35,620	4,643	11,995	400	8,166	.....	3,024	125,382	9,400	14,340	1,033	32,900	83,000
$CaSO_4$	1,212	7,752	.....	393	3,288	2,375	796	886	280	.....	4,857	800	.....
$CaCO_3$	64	52	33	467	236	227	71	146	103	.....	.....	.....	.....
SiO_2	132	7	12	19	18	19	160	220	120	12	0	.....	.....
Fe_2O_3	11	11	.....	.....	.....	17	17	143	324	83	0	.....	Trace
Al_2O_3	16	14	40	24	22	9	140	1,380	240	.....	0	50	Trace
MnO	1	1	.....	.....	.....	1	5	15	5	.....	.....	.....	.....
Na_2SO_4	.....	.....	.....	.....	.....	6,649	.....	.....	.....	.....	.....	.....	.....
$(NH_4)_2SO_4$	.....	.....	.....	.....	.....	43	.....	.....	.....	.....	.....	.....	.....
$MgSO_4$	.....	.....	.....	.....	.....	1,069	.....	.....	.....	.....	.....	.....	.....
Non-vol	67	1	.....	35	.....	29	100	180	80	.....	.....	.....	.....
Total	167,918	117,111	96,143	33,997	118,227	41,300	a99,641	b174,869	c102,869	d105,198	e318,163	289,000	f256,000

a Includes $Ca(NO_3)_2$-11 parts per million.
b Includes $Ca(NO_3)_2$-26 parts per million.
c Includes $Ca(NO_3)_2$-10 parts per million.
d Includes $MgBr_2$-155 parts per million; $SrCl_2$-257 parts per million; $BaCl_2$-343 parts per million; NaI-4 parts per million and LiO_2-trace.
e Includes $MgBr_2$-12 parts per million; $SrCl_2$-89 parts per million and LiO_2-trace.
f Includes bromine-1000+ parts per million.

1. St. Peter sandstone; J. R. Middagh well, near Lawrenceville, Lawrence County, Illinois; depth 5,185 feet. No oil associated with this brine.
2. Carper sandstone, Lower Mississippian; S. McClelland well No. 1, near Martinsville, Clark County, Illinois; depth 1,400; oil well.
3. Carlyle sand, Devonian; M. Smith; near Carlyle, Clinton County, Illinois; depth 2,620; oil well.
4. Biehl sand, Lower Pennsylvanian; Price No. 2, near Allendale, Wabash County, Illinois; depth 1,480; oil well.
5. Carper sandstone, Lower Mississippian; S. McClelland well No. 2, near Martinsville, Clark County, Illinois; depth about 1,400 feet; oil well.
6. Biehl sand, Lower Pennsylvanian; Widmer Oil Company, well No. 4, near Allendale, Wabash County, Illinois; depth 1,210; dry hole.
7. "McClosky sand," Ste. Genevieve formation, Lower Mississippian; D. Smith, well No. 7, near Clay City, Clay County, Illinois; depth 2,633 to 2,648 feet; oil well.
8. "McClosky sand," Ste. Genevieve formation, Lower Mississippian; Arbuthnot No. 3 well, near Noble, Richland County, Illinois; depth about 2,950 feet; oil well.
9. Benoist sand, Bethel formation, Upper Mississippian; Merryman No. 1 well; depth 1,391 to 1,418 feet; oil well.
10. Coal Ridge Salt Works, Pomeroy, Ohio; Conemaugh formation (Pennsylvanian). Ohio Geol. Survey Bull. 8, p. 27, 1906.
11. Artificial brine, Cleveland, Ohio, H. Ries, "Economic Geology," 1930, p. 222.
12. North American Chemical Co., Bay City, Michigan. Depth 970 feet; upper Marshall sandstone (Mississippian). Michigan Geol. and Biol. Survey Pub. 15, Ser. 12, p. 59, 1914.
13. Midland Chemical Co., Midland, Michigan. Depth about 1,300 feet; upper Marshall sandstone (Mississippian). Michigan Geol. and Biol. Survey Pub. 15, Ser. 12, p. 59, 1914.

Table 2, analyses 1 to 9, shows the composition of some of the stronger Illinois brines. Analysis 1 is the highest on record in NaCl and second highest in $CaCl_2$; No. 2 is the highest in $CaSO_4$; No. 3 is the third highest in $CaCl_2$; No. 4 is the highest in $MgCl_2$; No. 5 is the highest in KCl and also quite high in $CaCl_2$; No. 6 is the highest in $NaSO_4$; No. 7 from the new Clay City oil field is quite high in NaCl; No. 8 from the new Noble oil field has the highest recorded $CaCl_2$ content; and No. 9 from the new Patoka oil field is moderately high in NaCl. Samples 10 and 11 are brines from Ohio and 12 and 13 are from Michigan.

In general, it is believed that the most important constituents of the brines under discussion are NaCl, $CaCl_2$, $MgCl_2$ and bromine. The Michigan and Ohio brines contain bromine; in general, most of the Illinois brines thus far examined contain very little, if any, bromine,[15] though one analysis showed 78 p.p.m. of NaBr according to hypothetical calculations. No intensive search for bromine-bearing brines has been made in this State, however, so that the data at hand are not conclusive.

Disregarding bromine content, it is interesting to compare some of the Illinois brines with the out-of-state brines reported in table 2. Sample No. 8 which is an artificial brine presumably produced by pumping water into and then out of a salt bed, is not fairly included in the comparison. As figure 37 shows, Illinois brines compare fairly well with the other brines. The outstanding brine is No. 1 which comes from the St. Peter formation in Lawrence County at a depth almost 5200 feet. Unfortunately no data regarding the quantity of brines available from Illinois wells is available but there is reason to believe that an adequate quantity may be expected at least from certain formations.

Illinois is at present experiencing a new oil boom which is accompanied by the drilling of numerous wells in regions where no wells or only a few wells previously existed. Unexplored water-bearing strata will be tapped, probably the St. Peter formation mentioned above will be penetrated at a number of places. Insofar as it is possible, the Survey will continue its brine sampling and analysis, with the hope that even stronger brines than any thus far known will be discovered. In the meantime the data at hand is worthy of thought and attention, particularly in its relation to the possible success of a special search for stronger brines in Illinois.

GYPSUM AND ANHYDRITE

Gypsum and anhydrite are two minerals which are closely akin in chemical composition, the difference being that gypsum is calcium sulphate plus two molecules of water, whereas anhydrite is calcium sulphate without chemically combined water. The water which the gypsum contains can be

[15] Rees, O. W., Personal communication.

driven off by proper heating and the burned material when wetted again takes up water to give a compound having the original gypsum composition. This last is the familiar action which occurs in the setting of plaster of paris.

Anhydrite, since it contains no moisture, does not possess the properties of gypsum just described. Consequently it has not been a widely used mineral. Due, however, to the fact that it is often found in large amounts associated with gypsum, a considerable amount of research has been devoted to a search for major uses for this material, particularly in the field of building materials. Successful research in England resulting in the commercial manufacture of a finish coat plaster, partition tile and "fine aggregate walling" has been reported recently.[16] Further research may soon broaden considerably the field of usefulness of anhydrite.

The existence of deposits of gypsum and anhydrite in Illinois is not generally known; however, considerable thicknesses of these materials are present in places in the area shown in figure 39. The minerals occur in the upper part of the St. Louis formation at depths of 700 to 1,200 feet or less. Unfortunately most of the data regarding gypsum and anhydrite comes from churn drill records which do not permit accurate evaluation of thicknesses. However, several diamond drill cores are available which give a clew as to the probable nature of the gypsum and anhydrite deposits. The results of a study of one of these cores are given in figure 40. The commingling of gypsum, anhydrite and limestone in various proportions which characterize all the cores available is well illustrated. It is to be noted that 4 mineralized zones were encountered between 943 and 1,015 feet in depth and that 28 feet of core contained gypsum and/or anhydrite.

Iowa, Kansas, Michigan and Ohio are all important Middle Western gypsum-producing states and the deposits from which the gypsum is obtained are generally at the surface or not much more than 100 feet below the surface. Whether or not it would be possible to produce gypsum and anhydrite from Illinois deposits on a commercially competitive basis cannot be determined from the data at hand. However, it does appear worth while to indicate the existence of the Illinois deposits and the possibility that the gypsum and anhydrite horizon in the St. Louis formation may be found by careful prospecting at a relatively shallow depth in the southwest part of the area shown in figure 39.

WAX- OR RESIN-BEARING LIMESTONE

In Calhoun County (fig. 38) there outcrops a stratum of wax-or resin-bearing limestone which so far as is known is not duplicated elsewhere in the State. The deposit is probably a part of the Decorah formation and under-

[16] MacTaggart, E. F., Gypsum anhydrite as a base for plaster products: Rock Products, vol. 40, no. 7, pp. 46-48, July, 1937.

lies the Kimmswick formation which is a high calcium limestone. It may be the stratigraphic equivalent of the "oil rock" of the Illinois-Wisconsin lead and zinc area.[17] The extent of the wax- or resin-bearing limestone bed has not been determined but it appears likely that it underlies a considerable area. An exposure in the NE. ¼ SE. ¼ NE. ¼ sec. 6, T. 12 S., R. 2 W., shows 7 feet of the limestone and this represents only a part of the total thickness of the bed as the bottom of the stratum was covered by stream deposits.

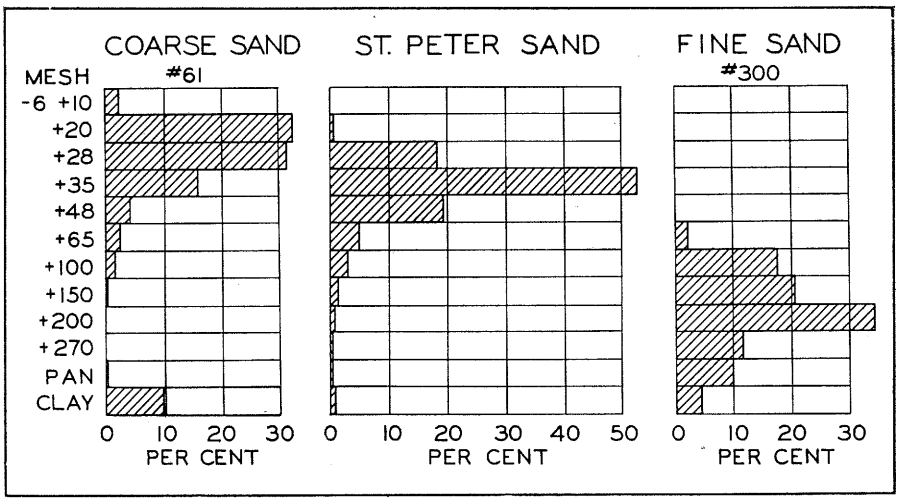

FIGURE 36.—Mechanical composition of a coarse sand and a fine sand from southern Illinois in contrast with a sample of St. Peter sand from the Ottawa district.

The limestone is a chocolate brown but weathers a light gray or almost white. It occurs in beds 3 to 6 inches thick and thin partings of shale are present between some of the limestone beds. This shale will burn when ignited with a match. A chemical analysis of a sample of the limestone is shown in figure 38. These data indicate that the limestone is somewhat impure, the chief impurity being silica, and that it is low in Fe_2O_3. The combustible carbon figure results from the wax or resin present.

The wax or resin occurs mostly as irregular, brownish-yellow masses disseminated through the limestone. A few brownish colored particles having definite outlines are also present and may be plant remains.

It is estimated that the combustible carbon figure shown in the chemical analysis is equivalent to a value of about 500 B. t. u. per pound of limestone.

[17] Bain, H. F., Zinc and lead deposits of the upper Mississippi Valley: U. S. Geol. Survey Bull. 294, pp. 25-27, 1906.
Trowbridge, A. C., and Shaw, E. W., Geology and geography of the Galena and Elizabeth quadrangles: Illinois Geol. Survey Bull. 26, p. 47, 1916.

A ton of the limestone would, therefore, contain about 1,000,000 B. t. u. which is equivalent to the B. t. u. in about 80 pounds of good Illinois coal.

The chemical composition of this limestone compares favorably with some natural cement rocks which have been used for making natural cement, though many of the limestones so used are higher in silica and alumina. Whether the rock can be used for making natural cement or some other similar product has not been investigated but the unique combination of low iron content and the wax or resin fuel is of interest. Probably the presence of wax or resin alone is sufficient to justify description of the limestone; the possibilities for the recovery of this wax or resin may bear study.

The deposit is located about 1½ miles from Mississippi River and about the same distance from a power transmission line. No rail transportation is available. Conditions for underground mining appear to be good.

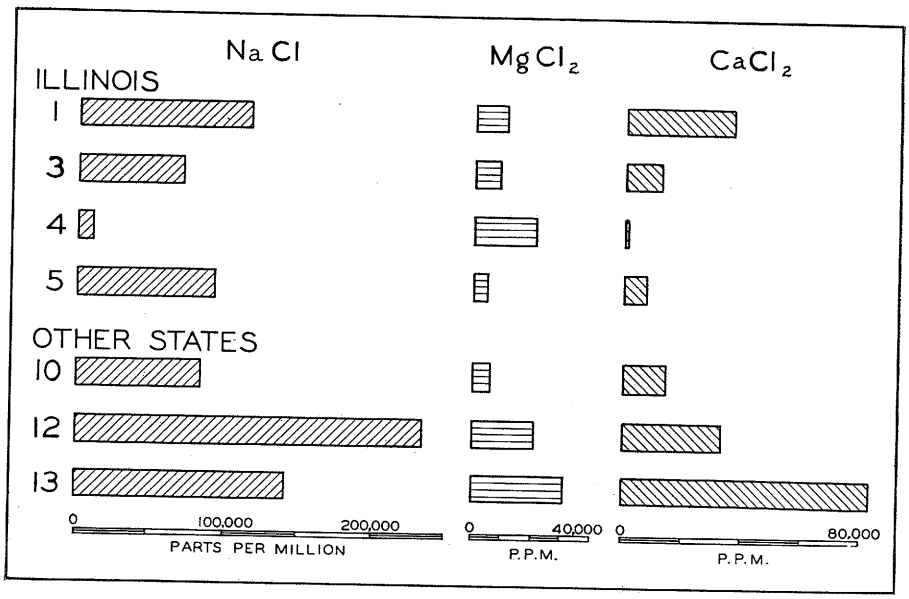

FIGURE 37.—Comparison of Illinois brines with those from other states. Data in parts per million (see table 1).

QUARTZITIC SANDSTONE

In two localities of extreme southern Illinois, there occur deposits of sandstone whose grains are firmly cemented by quartz. In a sense they are quartzites but since the degree of cementation is not as firm as that of the Minnesota and Wisconsin quartzites familiar in the Middle West, the term quartzitic sandstone is used.

About 6 miles below Golconda in the bluffs of Ohio River in the NW. ¼ NW. ¼ sec. 13, T. 14 S., R. 6 E., Pope County, there is exposed 30 feet of sandstone, most of it quartzitic, which is a part of the Bethel formation. The total thickness of the quartzitic sandstone may be considerably more than 30 feet. The sandstone layers vary from an inch to 8 inches or more thick and many of them are separated by shale partings. These partings facilitate the quarrying of blocks or slabs. The sandstone is light brown or gray in color and contains small brown iron-stained spots. Some layers of clayey sandstone are present. The deposit is located on Ohio River but is not near any railroad. Quarrying conditions are favorable for the production of large amounts of sandstone.

Another quartzitic sandstone outcrops in Rineking Hill cut along the Southern Illinois and Kentucky Railroad near the village of Round Knob,

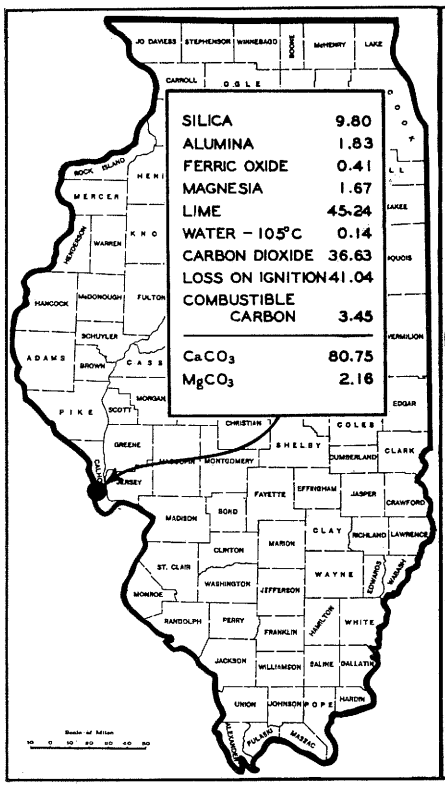

FIGURE 38.

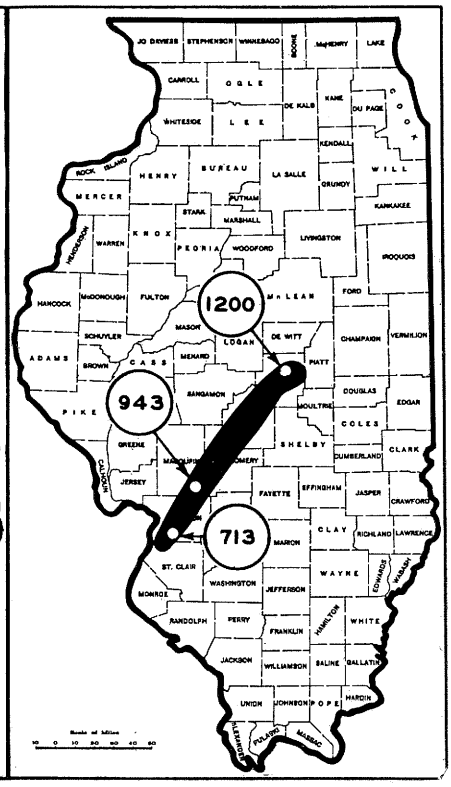

FIGURE 39.

FIGURE 38.—Location and chemical composition of wax or resin-bearing limestone.

FIGURE 39.—Area of Gypsiferous St. Louis formation in central and southern Illinois. The numbers indicate the depth to the gypsum horizon. Data furnished by L. E. Workman.

Massac County in the E. ½ NE. ¼ sec. 23, T. 14 S., R. 4 E. About 15 feet of white to gray quartzitic sandstone is exposed. It occurs in beds 1 to 6 inches or more thick. The deposit shows considerable folding and thorough prospecting is necessary to determine whether sufficient sandstone is available under a reasonable amount of overburden to warrant possible exploitation. Overburden is unconsolidated sand and clay.

No tests have been made on the last mentioned sandstone but the Pope County sandstone gave results in preliminary tests which suggest it may have use in making silica brick although crushing produced a higher per cent of fines than in the case of Minnesota quartzites. The sandstone would probably make a good decorative flagstone and tests indicate that it will withstand temperatures of 3000° F. without fusion. It may, therefore, be useful as firestone for foundry cupolas and for lining pickling vats in the metallurgical industry. Some of the sandstone has been used for riprap along Ohio River. Possibly the Massac County sandstone and likewise a number of other Illinois sandstones may also be suitable for some of the same purposes.

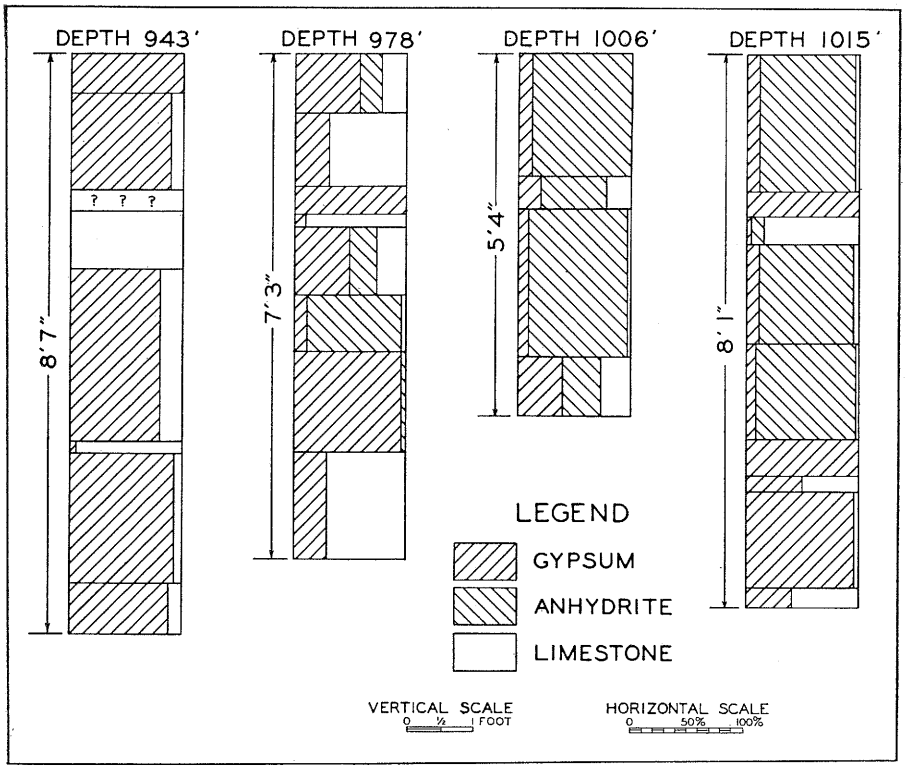

FIGURE 40.—Distribution, depth, thickness, and estimated relative percentages of gypsum, anhydrite, and limestone in core of well located in southeastern Macoupin County.

COLORED CLAYS AND SANDS

Colored sands and shales are quite widespread throughout the State and deposits occur in such number and diversity that no attempt will be made to discuss their distribution. It does seem worthwhile, however, to present a few observations regarding them. Red shales and clays occur at a number of places, maroon clays are known, a deposit of purple shale has been observed and likewise deposits of green clay and shale and brown clay and shale. Some of these clays and shales particularly the reds, are rather strongly colored and consideration is warranted of their possibilities as low grade pigments, particularly for mortars and concrete. Investigation of their value as colored fillers may also be worth while.

Brown and yellow sands, and more rarely orange and red sands occur in many parts of Illinois. Some of them burn red. Most of them are moderately high in clay and their color is due to iron oxides. The question is raised whether they may not have value as a coloring material to be used as a part of the fine aggregate for mortar and concrete. Likewise, the fact that many of them burn an attractive color suggests that they may be of value for sanding or veneering brick.

LIMONITE

Although it is not generally known, Illinois at one time had a flourishing iron-making industry which depended upon deposits of Illinois limonite for ore. Hardin County was the site of this industry and two furnaces were operated there. The limonite deposits resulted from the decay of limestone and other rocks and consisted of small pellets and larger irregular chunks scattered through clay and soil. The deepest accumulations of this kind are likely to be located on the sides of knobs or spurs and some of the old ore pits are said to have been 90 feet deep. "All the known occurrences of iron ore deposits in Hardin County are in areas underlain by the Fredonia or St. Louis limestones and in that particular they are like most of the extensive limonite deposits in eastern United States, as in Pennsylvania and Alabama."[18]

Usually the Hardin County limonite now visible is yellow, brown or red. No recent analyses have been made but an early report on the ore from the bank of one of the early furnaces is as follows:[18]

	Per Cent
Water	10.8
Siliceous earth	5.0
Fe_2O_3	80.0
Alumina	3.7
Loss and alkalies not estimated	0.5
	100.0

[18] Butts, Chas., Geology of Hardin County: Illinois Geol. Survey Bull. 41, p. 305, 1920.

There is probably a considerable quantity of limonite in Hardin County but the nature of the deposits makes estimates impossible without detailed and extensive exploration. The deposits lie about 3 to 3½ miles northwest of Elizabethtown, which is located on Ohio River. No railroad is close at hand.

The limonite deposits of Hardin County are no longer important as sources of iron ore. It may be, however, that they could be used as a source of mineral pigment. The raw ground limonite is yellow brown in color, it can be burned red or maroon.

SIDERITE

The mineral siderite, which is ferrous carbonate, occurs in Illinois mainly as nodules or thin layers in the Coal Measures shales. The nodules are commonly disc shaped, varying in length from about 2 to 12 inches and are usually less than 4 inches thick. The beds are commonly less than 3 inches thick and are generally lenticular. The nodules or beds are mostly gray or dark gray on the inside and where they have been exposed to the weather have an exterior coating of brown or yellow hydrated iron oxide. They contain variable amounts of clay and some also contain calcium carbonate. The latter causes them to effervesce with cold hydrochloric acid. The term "clay ironstone" concretions is often applied to the sideritic nodules.

No extensive investigation has been made of the chemical composition of the sideritic nodules but two samples showed respectively 31.3 per cent and 47.3 per cent Fe_2O_3, which is equivalent roughly to 50 and 75 per cent ferrous carbonate.

The sideritic concretions and beds are comparatively common in a number of the thicker Coal Measures shale formations, especially in the basal 5 to 10 feet. They have been noted in the Canton, Purington, Farmington, and Francis Creek shales, which outcrop extensively in northern and western Illinois. No exact data are available regarding the quantity of these concretions present in the various shales but it is estimated that in places the sideritic materials constitute 5 per cent and possibly as much as 10 per cent of the shales.

It is not known that the Illinois sideritic concretions have any commercial value, however, their possible uses are not known to have been investigated.

SUMMARY

Illinois contains a variety of little used mineral resources which merit consideration. These include potash shale, greensand, coarse and fine sands, peat, marl, "slates" and slaty shales, brines, gypsum and anhydrite, wax or resin bearing limestone, quartzitic sandstone, colored clays and sands, iron ore, and siderite, but little is known in detail about most of these resources and their possible uses. Each of them might merit research as a part of the Survey's program were not other more important problems of wider interest and greater potential returns demanding attention. It seems worth while, however, to call the attention of the Illinois mineral industry to these minor resources so that benefit may accrue to any of the industries which by reason of technical knowledge, geographic location or business relations are able to advantageously exploit one or more of these resources.

MAGNETIC SEPARATORS AND THEIR POSSIBLE APPLICATIONS TO THE BENEFICIATION OF ILLINOIS INDUSTRIAL MINERALS

By

J. J. Ferris

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Before going to the application of magnetic separators to Illinois minerals, I want to outline briefly the art of magnetic separation. In general, magnetic separation can be divided into four classifications.

The first and most common is the removal of tramp iron such as nuts, bolts, coupling pins, etc., from material going to crushers, pulverizers, grinding mills and similar equipment. Tramp iron passing into a grinding circuit causes considerable damage and often fires; and a magnetic separator properly applied prevents this. Some of the materials being so treated in Illinois includes coal, gypsum, fluorspar and many others. The most popular type of magnetic separator used for this application is the magnetic pulley, but where a magnetic pulley cannot be installed, a spout magnet which becomes part of the spout or chute, or a suspended magnet, may be installed with satisfactory results.

The second general classification is the removal of deleterious iron, such as scale, iron of abrasion, and other iron oxides, from materials which are so contaminated. For this application many standard and special type separators are available, and recent improvements in high intensity magnetic separators has widened this field considerably. Typical applications include the purification of glass sand, bauxite, fluorspar, clays and other minerals.

The third classification is the reclamation of materials. Occasionally the iron only is wanted, but more often two or more materials are mechanically combined and the mixture, as such, is practically valueless. After separation, however, the value of each separate material is increased considerably. The separation of ferrous and non-ferrous borings and turnings, the recovery of iron from foundry refuse, and the separation of iron from slag, are but a few examples of this application. The type of separator required is the medium intensity machine, and the size and style depends, of course, upon conditions.

The fourth classification is the concentration of minerals and ores, to raise the grade and eliminate the gangue. A typical application is the concentration of zinc and lead in the Galena, Illinois, district.

The zinc and lead ores there are the sulphides and they are associated with pyrite. Lead separates very readily from the zinc and the pyrite through the specific gravity method, jigs and tables, but the concentrates from the jigs or tables must be roasted so as to make the pyrite magnetic. When roasted the pyrite is readily separated from the zinc.

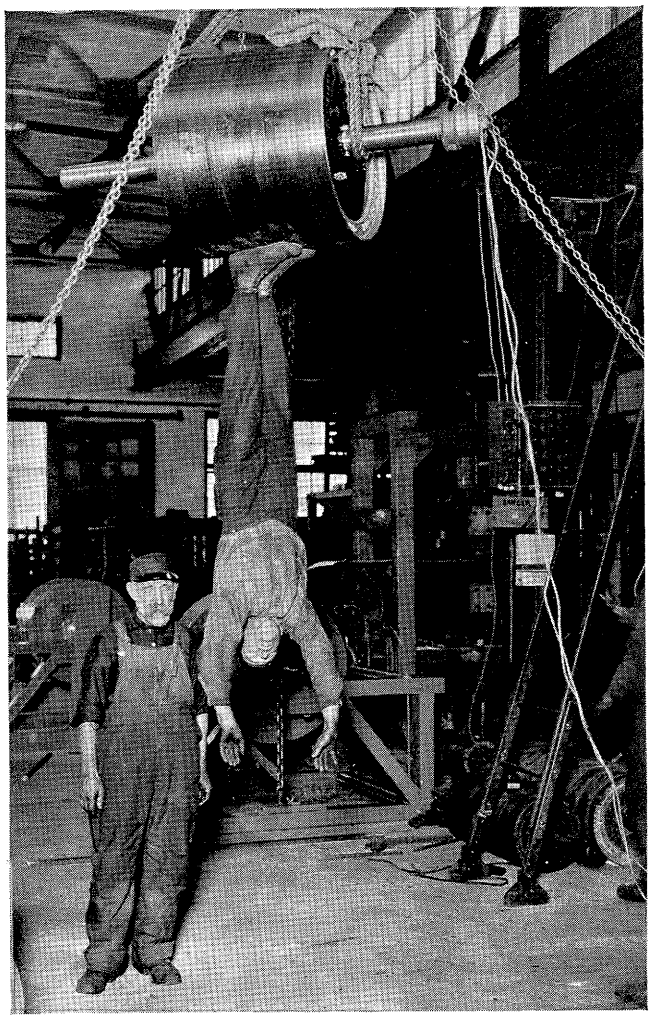

FIGURE 41.—The man being held suspended face downward by the attraction of the magnetism of the magnetic pulley for the iron in his shoes illustrates the tremendous strength of the high intensity magnetic pulley. This is a graphic illustration of the power that can be attained when the design incorporates the proper proportion of copper wire and dynamo steel.

In the early years of magnetic separation in the Galena district, the pyrite was given what is called a sweet roast. The combination of zinc and pyrite was roasted anywhere from two to four hours at a bright red temperature. Such a roast made the pyrite very magnetic and ordinary medium intensity separators and even low intensity separators qualified for the separation. This heavy roast, however, resulted in the loss of the sulphur and it was soon discovered that by subjecting the mixture to a lighter skin roast, merely coating the outside surface with a magnetic iron oxide, that a high intensity separator would produce the desired results. This combination consequently resulted in the saving of the sulphur because very little of it was lost and the skin roasted pyrite was delivered to the sulphuric acid plant and practically all of the sulphur was recovered.

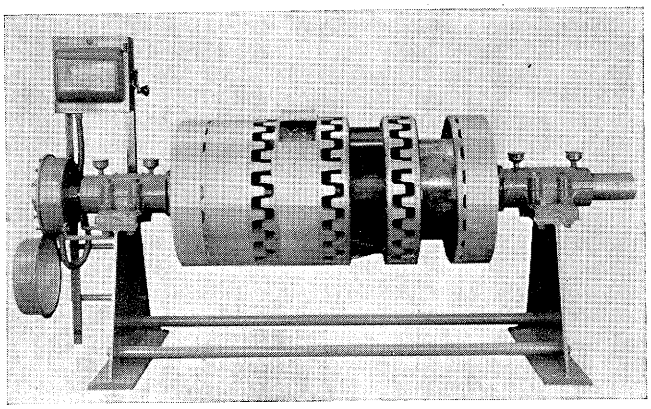

FIGURE 42.—The new air-cooled magnetic pulley has longitudinal and radial air circulating ducts. The surfaces are corrugated and promote a maximum amount of circulating surface. Tests have proved that, with this new design, an increase of strength up to 20 per cent is obtained. The use of bronze spacer rings is further assurance of the highest possible magnetic intensity.

At first high intensity separators had limited capacities as compared to the lower intensity type, but developments in the high intensity separator design has brought about the so-called super high intensity induction type separator, which involves the application of highly magnetized laminated rolls through induction from powerfully energized primary magnetic poles.

Illinois' greatest non-metallic mineral, of course, is coal. When mining much tramp iron finds its way into that coal. Even under ground, coal cutting knives, drill points, chains, railroad spikes, and other railroad iron, tools, etc., are hoisted to the surface with the coal. After the coal leaves the tipples more iron finds its way into it. Bolts, nuts and rivets become detached from the steel railroad cars and where whole carloads of coal are dumped by car dumping equipment, even brake shoes, handwheels and coupling pins fall with the coal.

The wide use of pulverized and stoker coal makes necessary the extraction of that miscellaneous tramp iron from it. Crushers must be protected from it, the pulverizers produce a highly explosive mixture which, when ignited through a spark, causes disastrous results, and even loss of lives.

It is a matter of record that some large consumers of coal recover enough iron to make the sale of it profitable. With handwheels, coupling pins and coal cutting knives worth considerably more than scrap, it has been found to be quite profitable to sort these parts from each other and sell them back to the original owner.

In several cases where coal yards were thoroughly cleaned up for repairs or for other reasons, so much iron had accumulated at the bottom of the coal piles that the crushers and pulverizers would have been fed a very high proportion of tramp iron if the magnetic separator had not been interposed between the coal pile and that machinery.

Illinois coal particularly has a high sulphur content. That sulphur exists in the form of iron pyrite. When taking into account the amount of unburned carbon falling through stoker grates, this type of firing at best is most uneconomical. Ordinary stoker cinders may contain as high as 40% unburned carbon. The balance of those cinders is roasted pyrite and ash. A simple screening process will eliminate the ash and you then have a combination of roasted pyrite, which is magnetic, and unburned carbon. The process of separation is almost identical to that encountered in the zinc district. The separator readily removes the roasted pyrite, not useable, however, for sulphuric acid, because it has been sweet roasted, and the unburnt carbon is easily recovered. That carbon, of course, does not have the B.t.u. value that the original coal had, because the hydrocarbon gases have been burned out.

This process of reclaiming unburned carbon from cinders is extensively used in Germany. Much work has been done on the process in this country, but at this moment it is not considered practical or economical, because coal is still so cheap that it really amounts to spending one dollar to save another.

Another problem involving the reclamation of the iron from powdered fuel flyash has been given some thought and study. The idea is far fetched and will probably never be commercial. The iron pyrite, where powdered coal is used, had been ground up finely and when burning this powdered coal the sulphur is thoroughly burned off. Flyash is a mixture of fine particles of iron and ash. The two are easily separated, but, as stated, the recovered iron costs more than it is worth.

The next largest non-metallic mineral in Illinois is silica. The Ottawa sands are world famous. Most of this silica, existing as St. Peter sandstone, is found in Kendall, LaSalle and Ogle counties. When these deposits were formed very little native iron ore found its way there. To be sure there is considerable animal and vegetable matter associated with this silica, but by

washing, these two are very readily eliminated. Further, much of the small amount of iron encountered exists in the form of oxides or rust. That, too, is quite easily washed off in part, but native magnetite and fine iron of abrasion is extracted by magnetic separators.

Without thorough washing and magnetic separation the average so-called Ottawa sand never ran over 0.04 per cent Fe_2O_3. Washing and separation easily brings that iron content down to 0.025 per cent Fe_2O_3 and much of the sand, when thoroughly processed, will run as low as 0.014 per cent Fe_2O_3.

In many parts much more money is spent to produce silica containing 0.06 per cent Fe_2O_3. As stated, the Ottawa sand is world famous because of its low iron content, its fine structure and its proper alumina content, and other good qualities; and Ottawa could very nicely get along and compete with other sands by merely washing and drying, but in order to excel all other sands offered they do separate magnetically with both medium and high

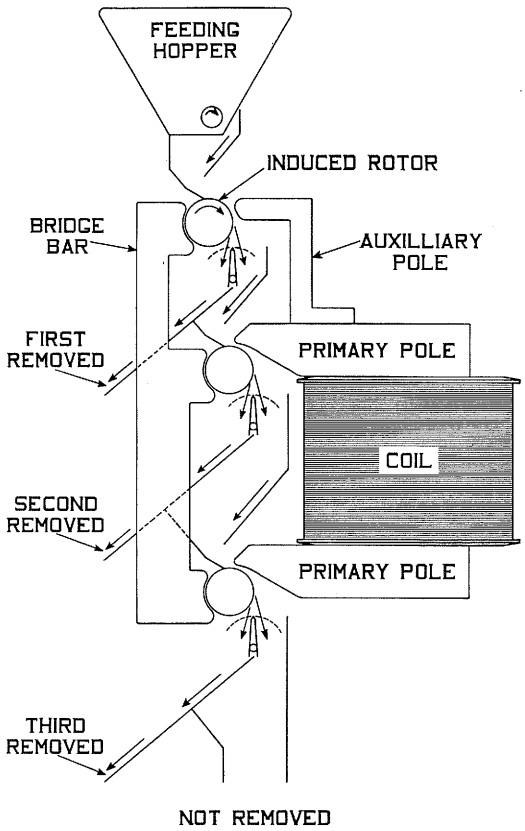

FIGURE 43.—Diagram illustrating the principle of the high intensity magnetic separator.

intensity separators and that brings about the willingness of the discriminating user of sand to pay a premium for the Ottawa sand. That sand is delivered as far east as the Eastern Seaboard, to upper New York and to the southeastern states. Other sand producers who can not produce such high quality have their shipping areas rather limited and they must be content also with a lower price for their commodity.

In Illinois we find clays also. Most of these are suitable for brick making, some for refractories. Magnetic separators find their widest application when used in the process of refining refractory clays. When these clays are weathered the pyrite associated with them becomes feebly magnetic and can be extracted with a high intensity separator. In the reclamation of crucibles, etc., when they are broken up (the resultant product is called grog) the iron which primarily existed as pyrite has been changed to the magnetic oxide and it is readily extractable magnetically. When using grog for producing new crucibles a considerable amount of new clay of course is added to bring about the desired plasticity.

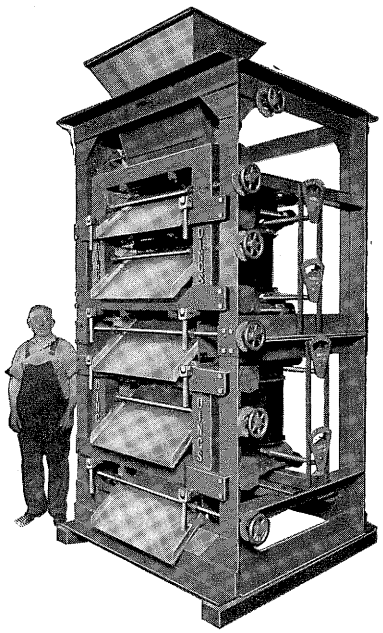

FIGURE 44.—A 30-inch five-role type of magnetic separator used for concentrating ilmenite.

Where iron in any form exists in clay and where the surface is exposed to the elements, oxidation soon takes place with resultant pits, holes and discoloration. In refractory clays, when iron is present, the life of the crucible is shortened because of the difference in the coefficient of expansion

between the iron and the clay. Heat expands the iron and cracks the crucible; or excessive contraction of the iron produces leaky crucibles.

In Illinois there are a considerable number of potteries and glass plants and many of the raw materials used in these plants are separated magnetically. In common with both of these industries we find such products as borax, feldspar, dolomite and bauxite, all separated magnetically to remove the very small amount of iron present. Iron will discolor the product and produce defects on porcelain and china. Many dark specks, pimples and blisters are attributable to iron. Glazes and slip are run through wet type separators to remove this contamination.

In the glass industry, in addition to insuring against iron-contaminted ingredients in the batch, all cullet is separated to remove wires, bottle caps, abrasion iron from machinery and miscellaneous tramp iron. In the wire glass industry trimmings from the wire glass are crushed and separated. Such a reclamation would be utterly impossible if the wires were not removed from the glass before it was remelted.

The foregoing discussion outlines briefly some of the problems encountered in Illinois, but there are many materials susceptible to magnetic separation and to which magnetic separation has not yet been applied. The last five years have seen a considerable improvement in the design and application of magnetic separators and research work in the field is being carried on extensively.

Figure 43 illustrates the principle of the high tensity type of magnetic separator. The machine consists of a large primary magnet with pole pieces properly designed so as to induce a maximum amount of flux on to the laminated roll which is interposed between the primary pole of the magnet and the bridge bar. A minimum of clearance is allowed between the primary pole and the induced roll—just enough to allow the material to pass. The clearance between the bridge bar and the roll is just large enough to allow the roll to revolve freely.

The material is fed at the top of the machine by means of a specially designed feeder for the type of the material to be handled, and passes on to the first induced rotor or laminated roll. The first roll generally is an auxiliary roll designed to remove the very highly magnetic material. The magnetic material is removed at this point, but the nonmagnetic material passes to a second roll where the operation is repeated. Here again the magnetic material is removed and the nonmagnetic material passes to a third roll for a final separation. In practice any number of rolls can be used, and machines have been built with as many as nine induced rolls. Adjustable splitters or dividers are provided beneath each roll to regulate the amount of material removed as magnetic.

The high intensity type of magnetic separator developed by our company is the most efficient commercial machine manufactured today and separations heretofore considered impossible have been accomplished on this machine.

Typical applications are the purification of bauxite, reducing the iron content of chemical ore to a point required by the manufacturers of alum; reduction of iron content of silica sand used in the manufacture of glass; reduction of iron content in nepheline syenite, feldspar, borax and similar materials. In addition, this machine is used for concentrating tungsten, ilmenite, monozite, zircon, and similar feebly magnetic materials.

A laboratory is maintained by our company where complete magnetic analyses can be made on materials which may lend themselves to magnetic treatment. Many of the leading industries have had their problems solved in this laboratory.