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STATE GEOLOGICAL SURVEY

FRANK W. DeWOLF, Chief

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**GAS PURIFICATION IN THE MEDIUM-SIZE
GAS PLANTS OF ILLINOIS**

BY

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and

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ILLINOIS MINING INVESTIGATIONS

Prepared under a cooperative agreement between the Illinois State Geological Survey
Division, the Engineering Experiment Station of the University of Illinois,
and the U. S. Bureau of Mines



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GAS PURIFICATION IN THE MEDIUM-SIZE GAS PLANTS OF ILLINOIS

By W. A. DUNKLEY and C. E. BARNES

PURPOSE OF THE INVESTIGATION

For several years, the Illinois State Geological Survey Division, the Engineering Experiment Station of the University of Illinois, and the U. S. Bureau of Mines have been carrying on a cooperative investigation of coal and coal-mining methods in the central district, which includes the states of Illinois and Indiana, and the western end of Kentucky. One division of the main investigation is the use of coals of this district in gas manufacture. A number of bulletins have been published (see inside rear cover), dealing with various phases of this subject. Gas purification, the topic discussed in the present bulletin, is a phase of the subject which has an important bearing on the use of central district coals in gas manufacture with the existing equipment and operating methods.

One of the chief problems confronting the gas operator in using coals of the central district in place of gas coals from Pennsylvania, West Virginia, and eastern Kentucky, is the increased amount of sulphur which must be removed from the gas before distribution. This increase may be small or large, according to the particular coal used, but even the central district coals of lowest sulphur content usually contain more sulphur and yield more to the unpurified gas, whether coal-gas or water-gas, than do the best low-sulphur gas coals from the regions mentioned, or the cokes made from those coals.

Recognizing this condition, it was decided to make a study of existing purifying conditions in the gas plants in Illinois, to ascertain to what extent the use of low-sulphur central district coals would overload the purifying equipment now installed, and where changes in equipment, operating methods, or purifying materials might be necessary to enable the various plants to purify the gas from central district coals economically, should other conditions make a more extended use of these coals desirable.

INSPECTION OF GAS PLANTS

The problem of studying Illinois gas-purifying conditions was assigned to W. A. Dunkley, gas engineer of the State Geological Survey Division, and an inspection trip was made by him to sixteen gas plants. The plants visited comprised nearly all of the medium-size plants of the State,

including the suburban plants of Chicago. The urban plants of Chicago were not studied at this time, since it was felt that on account of their large size and special conditions, they might have problems which were not typical of individual plants in smaller cities.

NATURE OF DATA COLLECTED

In visiting the various plants an effort was made to secure as detailed information as possible in the time available, regarding load factor, size and arrangement of equipment for cleaning and purifying the gas, gas storage capacity, fuels used, and purifying methods employed. A few simple tests were made in each plant to determine the sulphur content of the unpurified gas and the amount of tar entrained in the gas entering the purifiers. Samples of spent purifying material and unused material were collected wherever possible, in order that information to be gained from chemical analysis of these materials might supplement the information available from inspection of the plants and conversation with the operators. At all stages of the inspection, hearty cooperation was given by the gas men interviewed, and much interest was manifested by them.

With the opening of the college year, 1919-1920, at the University of Illinois, C. E. Barnes, research graduate assistant in gas engineering at the University, was assigned to assist Mr. Dunkley in this study. Mr. Barnes devoted most of his time to the analytical work involved in studying the purifying materials collected during the inspection of the various plants.

A summary of the results of these studies and a statement of the conclusions that seem warranted follow:

SUMMARY

To summarize briefly, the following purifying conditions were found to exist in the plants inspected:

1. Low-sulphur eastern gas coals were being used in practically all of the coal-gas plants inspected. These low-sulphur coals, together with the considerable percentages of water-gas made in most of the plants, gave an average H_2S content in the gas entering the purifiers of only 250 grains per 100 cubic feet.

2. Six of the eight straight water-gas plants inspected were using low-sulphur Illinois or Indiana coals for generator fuel. The average H_2S content in the unpurified gas in the water-gas plants was 140 grains per 100 cubic feet.

3. In spite of the generally low sulphur-content of the gas to be purified in all the plants, 75 per cent of the water-gas plants and 50 per

cent of the mixed-gas plants had maximum hourly gas productions in excess of purifier capacities. The computed overloads varied from 11.5 to 177 per cent.

4. Only two water-gas plants and one mixed-gas plant had average hourly productions in excess of purifying capacity.

5. Overload in most cases was due to lack of uniformity of load on the purifiers. This in turn was due to the sharp peak load and insufficient holder capacity. In some cases the load could probably have been materially reduced by a little more attention to the rate of pumping gas through the purifiers.

6. Tar in appreciable amounts was found in the gas entering the purifiers in nearly all the plants inspected. The spent oxide from all the plants contained some tar. The average tar content of spent oxides from water-gas plants was 6.9 per cent and from mixed-gas plants 3.6 per cent. Tar seemed to be chiefly responsible for low sulphur absorption in some cases.

7. The spent oxides from mixed-gas plants had an average sulphur content of 37.4 per cent, and those from straight water-gas plants had an average sulphur content of 21.7 per cent. Overload and tar seemed to be mainly responsible for these conditions in some cases. In other cases, operating methods seemed to be the cause of these low absorptions.

8. Revivification in place was practiced by most water-gas plants but by few mixed-gas plants at the time of inspection. Only one plant revived oxide in the off-box. Little trouble was reported in that plant as a result of the practice, and the operating costs were low.

9. Though several purifying installations are arranged for reversible gas flow, there seems to be little effort to realize the fullest advantage from this arrangement. The same is true of rotation of boxes.

10. Few operators keep purifying records from which actual performance of a particular batch of oxide or method of operation can be definitely determined.

11. Few operators make any systematic quantitative tests on their purifiers to determine performance of the individual oxide batches. In several plants where the necessary testing apparatus is available, it is seldom used.

12. It seems that the greatest opportunity for immediate improvement in purifying conditions rests in the establishment of a simple but regular testing routine, together with better purification records. The analysis of fouled oxides for sulphur and tar, even if done by an outside laboratory, would, it is believed, be worth while.

13. Total purification costs for the year 1919 varied in the plants inspected from 0.5 cents to 2.25 cents per 1,000 cubic feet of gas purified. Careful operation and good facilities for the handling of oxide were apparently responsible for low costs in several cases where the equipment was overloaded. Different conditions prevailing in different plants preclude the possibility of drawing comparisons as to the effects of load, etc., on costs.

14. Few different oxides are used in the plants of the State. It is believed that more experimentation on the part of gas companies, to find materials best suited to particular conditions, would be advantageous.

15. The use of low-sulphur Illinois and Indiana coals as water-gas generator fuels is general in the water-gas plants of the State. Though the sulphur content of the resulting unpurified gas is in some cases double that of gas from low-sulphur eastern cokes, the computed capacities of the purifiers is but slightly less in the former case.

16. Low-sulphur Illinois coals in coal-gas manufacture might decrease computed purifier capacities by 25 per cent in some cases, as compared with the gas coals in use at the time of inspection. This decrease might be offset in a measure by more attention to selection of oxides, by making the load on the purifiers as uniform as possible, and by more attention to tar removal and purifying operation.

17. In several cases it appears that coals of higher sulphur content could be handled if existing equipment were rearranged and made more flexible in operation. In a few cases additional purifying apparatus is badly needed.

THE PURIFYING PROCESS

The purification of gas, by which in the narrower sense is meant the removal of the sulphur present in the form of hydrogen sulphide (H_2S), is accomplished by the same process in nearly all the gas plants of the United States. It was discovered about 35 years ago that hydrated oxide of iron was a much more economical absorbent for this sulphur compound than slaked lime which had been in use since the beginning of the gas industry.

Oxide of iron does not remove sulphur compounds other than H_2S present in the gas, but since the gas from most American coals does not usually contain any excessive amount of these other sulphur compounds, it followed that purification with hydrated oxide of iron was adopted almost universally within a few years after its initial use for this purpose. Hydrated oxide of iron, when of good quality, not only absorbs a large amount of hydrogen sulphides, but also, after sulphiding, if exposed to the action of the oxygen of the air, undergoes a process of regeneration whereby iron oxide is again formed by oxidation of a considerable portion of the iron sulphides present, free sulphur being liberated. This process is usually called revivification by gas operators. After revivification the material is again in condition to be used for purifying gas. Alternate sulphiding and revivification may be carried on until, with favorable conditions, the material may contain 50 to 60 per cent of sulphide. It is then usually incapable of absorbing more hydrogen sulphide on account of the clogging action of the free sulphur and the formation of more or less inert iron compounds and is replaced by new material.

The chemical reactions involved in the sulphiding and regenerating, or revivifying, processes are not known with absolute certainty. Various chemical equations have been written expressing the probable final reactions, but it is likely that many secondary reactions really take place which are decidedly more complex than those given in the text books. Since it is the intention to confine this bulletin to the practical working phases of the purifying process, no attempt will be made here to repeat these equations or to go deeply into the theory of the reactions. The reader is referred to the literature of gas manufacture and chemistry for existing information on this subject.

FACTORS AFFECTING PURIFICATION

Efficiency and economy in gas purification depend upon three main factors—equipment, operating methods, and purifying material. The effect of each of these factors is more or less determined by existing plant conditions. Perhaps the most important condition affecting plant conditions is the load factor. Load factor as applied to purification will here

be designated as the relation between the volume of gas passing through the purifying equipment during the hour of maximum production and the rated hourly capacity of that equipment, as determined from its dimensions and from practical and theoretical considerations pertaining to operation with the usual purifying materials.

FORMULAS FOR GAS PURIFIERS

Since the advent of the gas industry, nearly 20 formulas have been propounded for the dimensioning of gas purifiers. Many of these were based upon the use of slaked lime, the predecessor of hydrated oxide of iron for purification. Many are indefinite in their terms and include an insufficient number of factors to make them really applicable to present conditions. The formula of the Steere Engineering Company¹ of Detroit, which appeared about a year ago, is perhaps the most complete of all, and while there are still factors which will probably have to be introduced or changed in it when our knowledge of these factors becomes more complete, the formula is very useful and has been used in the computations of this bulletin. For the convenience of readers, the Steere formula and some information regarding its use are given in Appendix A.

DESIGN OF EQUIPMENT

In designing purifying equipment for a given plant, a number of things must be considered. One of the most important is the output of the plant, both present and prospective. In spite of electric competition, the output of most gas plants is growing rapidly; in fact, many companies are experiencing difficulty in keeping up with the demand for gas. It is important, therefore, to make the purifying equipment of ample size, but at the same time the investment is heavy and the interest on a greatly oversized equipment may offset to a considerable extent the operating advantages which might be derived from extra large capacity.

LOAD FACTOR

Another factor to be considered is the distribution of load during the day. The rate of output of most plants is far from uniform. Indeed, it is not unusual for some plants to put out 10 per cent of their daily production during the hour of maximum load. And since storage capacity has not usually grown apace with output, it is frequently necessary to generate and purify the gas practically as fast as it is sent out. From the figures

¹Gas Age, Vol. 43, p. 227, 1919.

MAXIMUM HOURLY PURIFIER CAPACITY—M CU. FT.

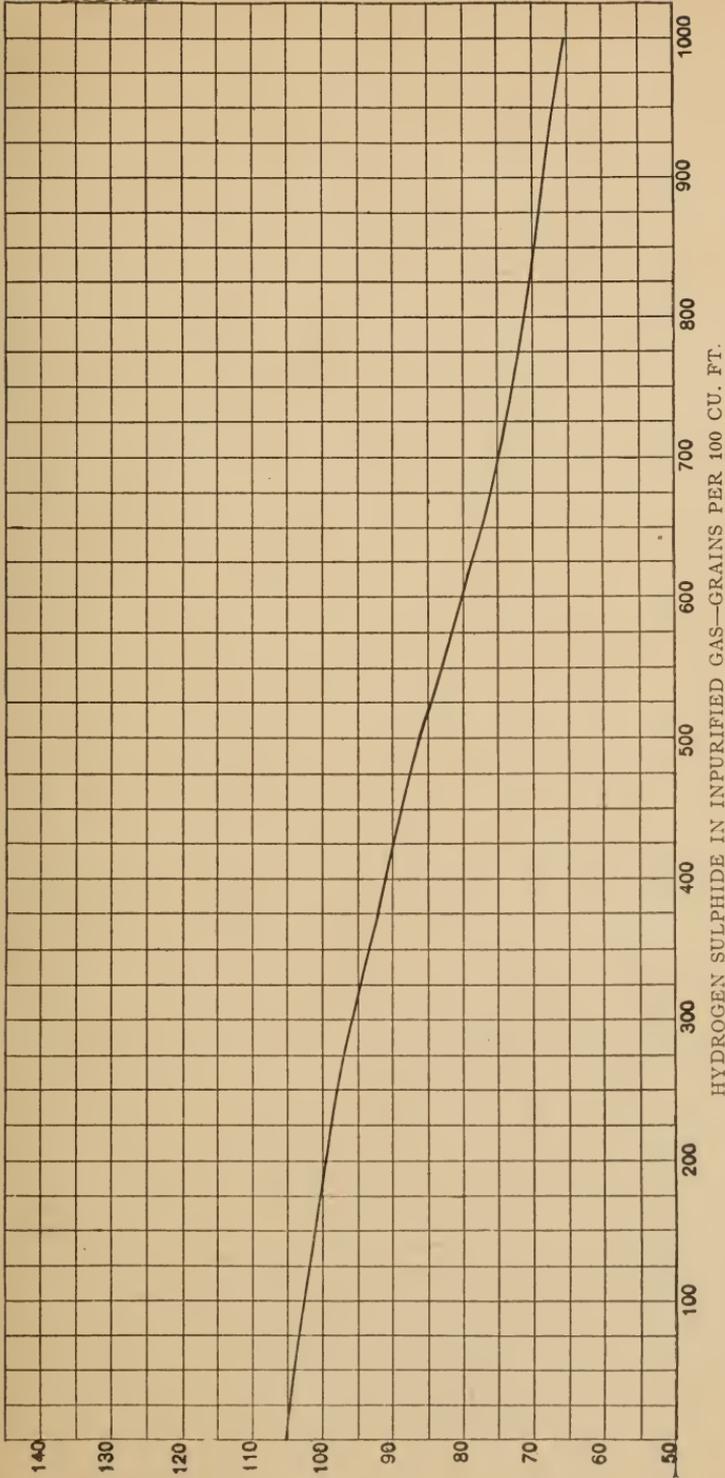


FIGURE 1—Effect of hydrogen sulphide content of unpurified gas on purifier capacity, in a plant having purifiers rated at 100,000 cu. ft. hourly capacity with gas containing 200 grains of hydrogen sulphide per 100 cu. ft.

obtained from the inspection of 16 gas plants of Illinois, of which 8 made straight water-gas and 8 mixed coal- and water-gas, it was found that the maximum volume of gas purified per hour in water-gas plants varied from 4.5 per cent to 11.2 per cent of the maximum daily output, with an average of 7 per cent; and in mixed-gas plants from 3.6 per cent to 9.3 per cent, with an average of about 6 per cent. Since the complete absorption of hydrogen sulphide from the gas by iron oxide takes a measurable time, the purifiers must be so designed that even at maximum rate of flow there will be ample time of contact between gas and oxide, even when the oxide is partially sulphided and inactive. As the laws of nearly every state require that the gas leaving the gas plant must at all times be free from any appreciable amount of hydrogen sulphide, the gas manufacturer must comply with this requirement by whatever means he may. Oftentimes when the purifying equipment is heavily overloaded or fuels run considerably higher in sulphur content than usual, compliance with the law is difficult and costly.

As an economic matter, the purifiers must be so designed that they will hold enough oxide to completely purify the gas at the maximum rate of flow for a sufficient time so that it will not be necessary to handle the oxide too frequently. It is desirable that the oxide be allowed to remain in the purifiers long enough between revivifications so that it will absorb a reasonable amount of sulphur. The labor cost of handling oxide is one of the heaviest items of purification cost, and it is therefore desirable that an oxide take up a maximum amount of sulphur with the least cost of handling. This can be done by making the purifiers large enough, due consideration being given to investment charges.

SULPHUR CONTENT OF GAS

The sulphur content of the gas to be purified is another factor to be considered. The gas industry has always been a particular customer in the purchase of coal, and the sulphur content has always been an important specification where there was otherwise little choice between coals. Good gas coals heretofore have contained not exceeding one per cent of total sulphur, and frequently the content of sulphur has been only .5 or .6 of one per cent. The decrease in supply of such superfine coals has caused gas operators to look about for possible new supplies, but while the industry will probably have to be reasonably particular so long as present purifying methods are in use, it will probably be necessary to use coals of higher sulphur content than would heretofore have been considered expedient. In water-gas not only the sulphur content of the generator fuel, but also the

sulphur in the enriching oil must be considered. Purifying equipment consequently will have to be designed with these matters in mind.

The maximum permissible rate of gas flow through a system of purifiers does not vary inversely as the hydrogen sulphide content of the gas to be purified. Figure 1, which is plotted from the Steere formula, shows the relation existing between maximum hourly rate of gas flow through the purifiers and the hydrogen sulphide content of the gas. The curve represents the maximum hourly purifying capacity with various contents of hydrogen sulphide of a plant which would have a capacity of 100,000 cubic feet of gas per hour, if the gas to be purified contained 200 grains of hydrogen sulphide per 100 cubic feet.¹ It will be noted that if the sulphur content is multiplied by 5, giving 1,000 grains per 100 cubic feet, the capacity is reduced from 100,000 cubic feet to 66,500 cubic feet. Capacity in this sense pertains, of course, to the hourly rate of gas flow permissible, not to the capacity of the oxide for absorbing H_2S . If the oxide in the purifiers could be completely fouled in either case, it is evident that five times as much gas containing 200 grains of H_2S could be purified. It is evident, therefore, that the permissible rate of gas flow through the purifiers is not directly proportional to the absorption capacity of the oxide nor inversely proportional to the sulphur content of the gas. The rate of the chemical reaction has an important bearing, but this is not taken directly into consideration in any existing formula for the design of purifiers, though it is indirectly allowed for in the Steere formula.

CAPACITY OF AUXILIARY EQUIPMENT

While the capacity of the oxide purifiers must be designed to handle the maximum hourly load, a properly designed system may fail to accomplish the complete purification of the gas because of conditions existing in other units of the gas-cleaning apparatus. Under favorable operating conditions, the purifiers are not usually called upon to handle all of the hydrogen sulphide that is originally present in the gas when generated. Water and tar vapor condensing from the gas in the condensers, and wash water in the scrubbers all remove a certain amount of H_2S from the gas. In coal-gas plants the ammonia present in the gas has a very important part in sulphur removal, since it combines directly with H_2S . There is not enough ammonia present to remove all the sulphur, but this incidental purification may remove as much as 20 per cent to 40 per cent of the H_2S present in the gas. If the condensing and scrubbing apparatus is under-

¹It may be objected by some that when the gas contains no H_2S at all the capacity of the purifiers would be infinite and that there should be consequently a sharp rise in the curve. Practically, however, as soon as there is any appreciable amount of H_2S present in the gas, the time factor of the reaction between H_2S and hydrated oxide of iron comes into play, necessitating a very a perceptible time of contact to purify the gas. It is often observed in practice that it is more difficult to remove the last 10 per cent of H_2S from the gas than the first 90 per cent, emphasizing the fact that the permissible rate of purification is not inversely proportional to the H_2S content of the gas.

GAS PURIFIED PER HOUR—M. CU. FT.

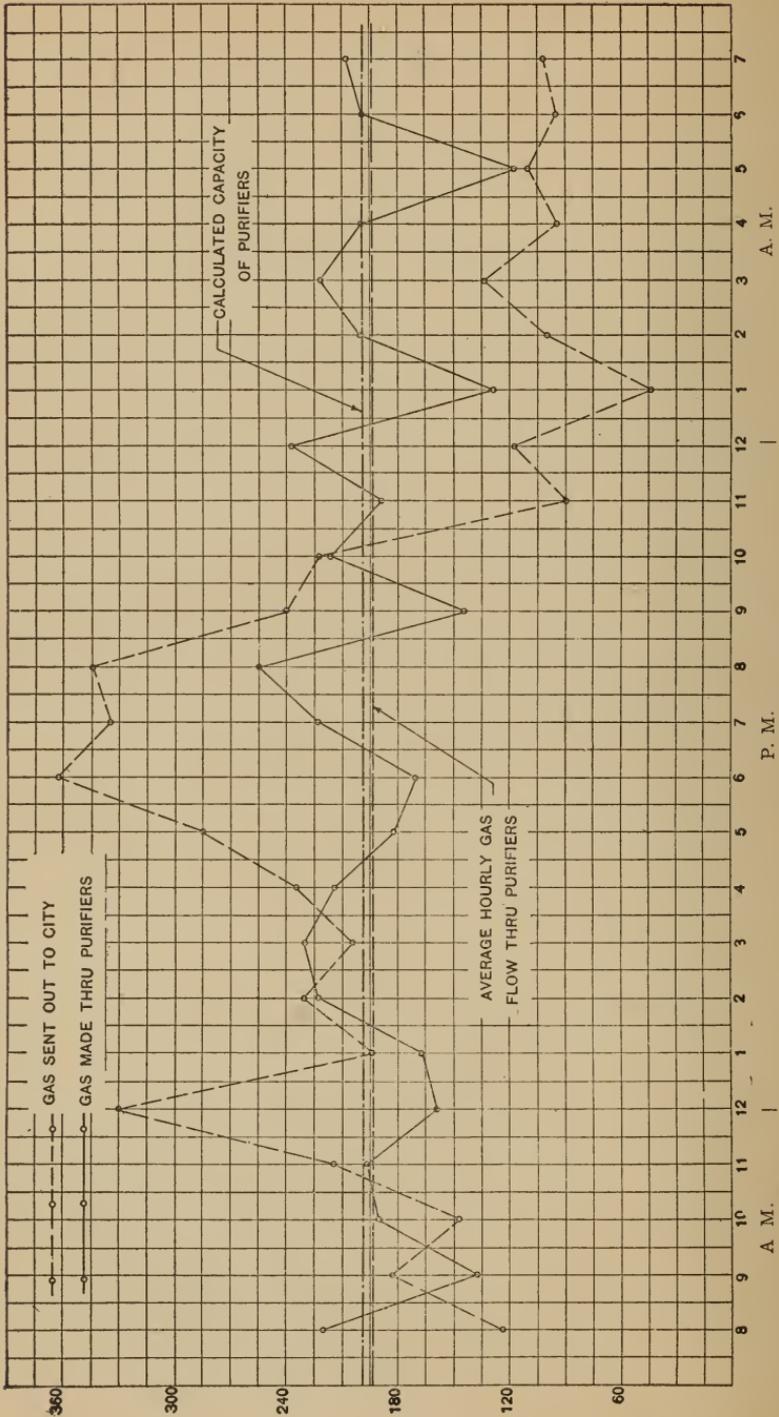


Figure 2.—Distribution of load in a typical water-gas plant

sized, not only is this incidental purification diminished, but the oxide purifiers are forced to do part of the work, namely, tar extraction, which should be confined to the first-mentioned equipment. Tar and oil vapors undoubtedly have a detrimental effect on the operation of the purifiers, since they coat the purifying material and render it partly inactive. Despite the recognized harmful effect of these vapors, there are few plants in which the gas entering the purifiers is entirely free from them. In some plants well equipped as to purifier capacity this condition is responsible for poor purifying results. Tar removal before purification is very important both as a matter of equipment design and of operation, and deserves more attention than it usually gets. Some kind of test by which the tar content of the gas entering the purifiers can be determined, should be made regularly where purifying results indicate the possibility of this trouble. Frequently a plant which seems to need additional purifying capacity is really in far greater need of more efficient tar-extracting apparatus.

PURIFIER OPERATION

UNIFORMITY OF LOAD

Granted adequate purifying equipment, the purifying efficiencies realized will depend much upon how the equipment is operated. First, the handling of the load may well be considered. The hourly rate of gas output from a plant is, of course, out of the control of the gas manufacturer. He must supply the demand as needed. For the sake of safety to tide over any accident to the gas-producing equipment, it is usually considered necessary to keep the gas storage holders as nearly full as possible at all times. If the storage capacity is much undersize, in order to make good the output, it may be necessary to purify the gas almost at the rate of output during certain hours of the day. This may necessitate purifying the gas at a rate much in excess of the rated purifying capacity during such times. Even so, it may be possible by attention to smooth out the production curve somewhat. Figure 2 shows the output and production rates in a typical water-gas plant operating 24 hours per day. The rated capacity of the purifiers and the average hourly make are shown by horizontal lines. It will be noted that the hours of large production do not always coincide with the hours of large output. The production curve crosses and recrosses the line of average production not only when the production is near the average for a considerable time, but also when it is averaging considerably above or below the general average for some time. By careful attention to the rate of pumping gas these wide fluctuations could probably be prevented to a considerable extent with benefit to purifying operation.

TEMPERATURE CONTROL

Temperature control is another important consideration in purifier operation. Both excessively high and excessively low temperatures at the purifiers should be avoided. The statement is often made that at low temperatures (below about 60°F.) the sulphiding reaction becomes sluggish. That there is some difference of opinion relative to the effect of temperature on the purifying process, is indicated by the fact that this matter is now being studied by the Purification Committee of the American Gas Association. A temperature of about 100°F. is usually thought to give the best results, and often it is considered important that the temperature be kept up in winter by artificial means if necessary. Formerly it was the practice to have the purifiers installed indoors, but the high cost of building construction as well as successful experiments with outdoor purifiers have resulted in a rapidly increasing number of outdoor installations. Practically all of the new installations are of the latter type. Where the temperature of the gas has a tendency to fall in winter much below the temperatures above stated, it can usually be kept up by the installation of steam coils in the purifiers or by injection of steam into the gas ahead of the purifiers. The latter practice may be questioned by some operators on account of the amount of moisture which is deposited in the purifying material, while the former may be open to objection on the ground that it dries out the oxide too much. Some outdoor installations are insulated to diminish the drop in temperature during cold weather, but this is not common practice, at least in Illinois.

While a fairly high temperature is usually considered advantageous in its effect on the sulphiding reaction, the temperature of the gas throughout the condensing and purifying system should not be maintained too high, lest difficulty be experienced in extracting the tar. A temperature much above 100° at the inlet to the purifiers, if maintained by the original heat in the gas as generated, would usually necessitate a temperature considerably in excess of this back at the tar-extracting equipment. It is usually considered that 100° to 110°F. is about the highest temperature at which tar can be extracted efficiently by most forms of tar extractors, though opinion may vary on this point. During the inspection trip to various Illinois plants by the writer, several cases were observed where the temperature at the inlet of the purifiers was around 120° to 130°, but in practically every such instance there was an excessive amount of tar being carried into the purifiers. Probably the best results will be obtained by maintaining a temperature of 90° to 100°F. at the boxes and keeping the gas saturated with water by the admission of steam to the gas, or otherwise.

REVIVIFICATION

OUTDOOR REVIVIFICATION

As previously mentioned, the greatest advantage of hydrated oxide of iron as an absorbent for hydrogen sulphide lies in its ability to revivify or regenerate when after sulphiding it is exposed to the oxygen of the air. Naturally the first method of revivification adopted was to remove the sulphided material from the purifying box and expose it to the air. The appearance of the material as it changes from the black iron sulphide to red or brown iron oxide, is of course a guide to the operator by which he can determine with more or less certainty when the material is reoxidized and ready for use in the purifiers again. The usual procedure in revivifying out of doors is to put the material in piles or windrows, perhaps two or three feet high. When the material begins to heat as a result of the oxidation process, it is raked down into a layer a foot or so in thickness, and as the surface reddens, the whole mass is turned over by shovel, this operation being repeated until the mass is of uniform color and no longer heats. This process, simple as it seems, requires considerable attention. The material frequently oxidizes very rapidly upon removal from the purifiers, and when it contains a considerable percentage of iron sulphide it is likely to ignite, especially if in a deep mass from which heat cannot escape readily. Overheating is detrimental to the further value of the material, rendering it inactive. At the same time, a moderate degree of heat promotes the oxidizing reaction without injuring the material. The operator therefore usually cools hot spots in the material by shoveling them out and exposing the hot material to the open air, which rapidly cools it, rather than by application of water, which cools the material to such an extent as to unduly retard the revivification.

This method of revivification involves much handling of the material. Indeed, since it is not possible to leave material in the boxes until it is completely sulphided, it is usually necessary to handle it a dozen times or more to get a very good sulphide content. But since the sulphiding and revivifying reactions slow down greatly after a time, the cost of handling the material may soon offset the value of the work it is doing. Consequently, material is frequently discarded long before it contains 50 to 60 per cent sulphur, which is considered good operation.

REVIVIFICATION IN PLACE

Naturally gas operators looked for a method of revivifying which involved less handling of oxide, and revivification in place was the outcome. Two methods are in use at the present time, namely, (1) introduc-

tion of a small percentage of air (1 to 2 per cent) into the gas ahead of the purifiers; (2) blowing or drawing air through a box of material which has been shut off from the remainder of the purifying system. Each of these methods of revivification has its advantages and disadvantages, and there are some details of operation in both cases on which operators disagree.

SMALL PERCENTAGE OF AIR WITH THE GAS

One advantage of the first method is that it involves no danger and requires little attention. The air pump is connected to the exhauster and pumps more or less air as the exhauster runs faster or slower. One obvious disadvantage of the first method is the amount of inert nitrogen which is introduced into the gas, if an attempt is made to introduce enough air to secure complete revivification in place. Although less than 0.5 per cent of air would theoretically be required to accomplish the revivification of an oxide which was being fouled with gas containing, say, 100 grains of H_2S per 100 cubic feet, as a matter of fact, even 2 per cent does not completely accomplish revivification. Excessive nitrogen of course dilutes the gas and requires additional enrichment, especially if the gas is made to conform to a candle-power standard. With the heating-value standard which is fortunately rapidly replacing the candle-power standard, this effect is not so serious. The differences in operation found in different plants with this method of revivification relate chiefly to the reversal of direction of gas flow and order of the purifiers with respect to the condition of the contained materials. These will be discussed in the next section.

AIR BLOWN THROUGH OXIDE IN AN OFF-BOX

Revivification by forcing air through a box of oxide after shutting off the gas has been employed in various plants for a number of years and is heartily approved by many operators, and as heartily condemned by others. Its advantage lies in the fact that no nitrogen is admitted to the gas. On the other hand, careful attention has to be given to it while in progress, and under some circumstances it may be dangerous. O. B. Evans¹ of Philadelphia presented a paper before the American Gas Association recently, in which the experiences of several companies in the use of this method are given. From these experiences he concludes that revivification by this method is a simple operation when purifying capacity is ample and revivifications are frequent, but with overloaded purifiers extreme care must be used to prevent firing of the oxide. He believes that the best method is to recirculate air (which soon becomes chiefly nitrogen,

¹O. B. Evans, Revivification in place, presented at a meeting of the Amer. Gas Assn., October, 1919.

since the oxygen is soon removed by the purifying material) continuously through the box and through a cooler of the contact type, in which it comes in contact with water. The water keeps the recirculated mixture saturated, and the water vapor helps to keep down the temperature in the oxide. Arrangement of valves is made whereby a small amount of fresh air can be admitted to the circulation and a similar amount of inert gas expelled from it as desired. The blower should be of sufficient capacity to reduce channeling effect and to circulate the mixture faster than the rate at which gas is passed through the box during operation. He states that shallow boxes aid considerably in successful revivification in place on account of their greater radiating capacity per bushel of oxide. With these methods Mr. Evans believes that revivification can be carried out without danger, channeling and excessive local heating being largely avoided. The successful experiences of many operators over a number of years confirm this.

REVERSAL OF GAS FLOW AND ROTATION OF BOXES

Reversal of direction of gas flow through the purifiers and the order of the various purifiers with respect to the condition of the contained oxide, are matters of considerable importance in connection with revivification in place. In both of these matters the operator may be limited by the arrangement of his equipment. Not all plants are so arranged that the direction of gas flow in a given box can be reversed; and while a certain amount of latitude is usually allowed as to the order of purifying boxes, one finds a number of cases where the connections are so arranged that the possible number of combinations is small. Obviously, any group of purifiers must be so connected that any box can be shut off for refilling. In most of the older installations, when one box is off, the order of the other boxes is predetermined, only one arrangement being possible. Reversal and rotation, as applied to revivification in place, depend upon the principle pointed out several years ago by B. E. Chollar, that iron sulphide will not revivify to the oxide in the presence of hydrogen sulphide. Let us assume, as is frequently the case in new purifier installations, that the gas enters at the middle of the box and passes downward and upward through the two layers of oxide and comes out at the top and bottom of the box. The lower layer will sulphide downward and the upper layer upward. If when the sulphiding has extended say half-way through each layer, the direction of flow be reversed so that the gas enters at the top and bottom of the box and leaves at the middle, then the comparatively fresh oxide in the top of the upper layer and the bottom of the lower layer will remove the H_2S from the gas, and any oxygen present will go on and revivify the foul upper part of the lower layer and the lower part of the upper layer. The

frequency of reversals will depend upon the degree of loading of the purifiers. Where the purifiers are being operated at normal capacity, reversal once a week is often advised. With an overload, it might be advisable to reverse oftener.

Box rotation is another means to accomplish the same end. Where there are three or more boxes in series, it would seem logical to have the clean box first to remove the H_2S and the fouler boxes after, to be revived by the oxygen which had been admitted to the gas. The following are suggested orders of rotation of a 4-box set, the changes being made when H_2S appears at the outlet of the third box:

1 — 2 — 3 — 4
 4 — 1 — 2 — 3
 3 — 4 — 1 — 2
 2 — 3 — 4 — 1

In this way the most revived batch is placed first and the next cleanest batch is always last to take up any traces of H_2S which may get by the previous batches at any time.

Where there are only two boxes in series, especially those of the non-reversing type, it would hardly seem advisable to have the clean box first, since failure of the second box to revive for any reason would leave no active material to intercept traces of hydrogen sulphide.

As stated earlier in this section, there is no method of procedure in the matter of revivification in place, which is accepted as best practice by all operators. The only way by which any operator may arrive at a satisfactory conclusion is to try various methods and arrangements and satisfy himself which method is most applicable to his particular plant.

CHEMICAL CONTROL AND RECORDS

In order to secure and maintain good purifying efficiencies, it is important that the operator know at all times the status of the material in each one of his purifiers. Knowing this, he will not only be able to judge whether his method of operation is satisfactory, but he will be able to detect differences in purifying material which might otherwise be obscured by other conditions. The extent of the system of tests and records maintained will of course depend, among other things, upon size of the plant and the force available. Practically every plant makes the simple lead acetate paper test, but this is merely qualitative. It tells of the presence or absence of hydrogen sulphide, but gives little information relative to the amount present. The total-sulphur test carried on under the requirements of the Public Utilities Commission, at least in the State of Illinois, gives informa-

tion only with respect to the amount of sulphur in all forms present in the finished gas, but gives no information in regard to the performance of the individual purifiers.

The introduction several years ago of the Tutwiler hydrogen sulphide burette marked a distinct advance in the matter of checking up purifier operation because it gave the gas operator a simple, easy method of studying his purifier performance without the aid of a trained chemist. Unfortunately, the apparatus has to be made of glass, and is so shaped and proportioned that it is easily broken; and, further, unless care is taken to remove the plugs of the glass stop-cocks and insert pieces of paper around them after using, they are very liable to become hopelessly stuck in a short time. Nevertheless, with reasonable care the apparatus can be kept in good order, and the information obtained with it is very useful. One advantage of the instrument is the short time required to make a series of determinations. Probably after a very little practice any operator, even with no chemical training whatsoever, could make a test of the gas entering the first box and leaving each box of a four-box series, in fifteen or twenty minutes. By simple subtraction of the number of grains of hydrogen sulphide found at the outlet of each box from the amount present at the inlet the amount of sulphur being removed by each box would be immediately known. The results of a test on a certain day might be as follows:

Grains H_2S before boxes		H_2S Removed
.....	100	
“ “ after 1st box.....	25	75 by 1st box
“ “ “ 2d “.....	10	15 “ 2d “
“ “ “ 3d “.....	5	5 “ 3d “
“ “ “ 4th “.....	0	5 “ 4th “

Now 5 grains of H_2S after the third box could probably be detected by lead acetate paper as ordinarily used and would perhaps ordinarily be taken as a sign to change the order or empty a box, but if this same distribution of the work continued for several days and the last box handled the remaining few grains of H_2S were absorbed in the last box all right it might be well to retain this order for a time, since a larger absorption in the first box would be accumulating. A considerably greater sulphur absorption might be realized in the first box than would be obtained if it were emptied or reversed as soon as a trace, as shown by lead acetate paper, was visible at the outlet of the third box. Steere¹ states that 20 to 50 grains of H_2S may be safely passed to the last box if tests are made regularly, and the boxes are properly proportioned. He would allow 20 additional grains to pass to the last regular box, where a catch box is provided. On the other hand, let us assume that the following results were shown by the tests:

¹Bull 37, Steere Engineering Co., 1919.

Grains H ₂ S before boxes	100	H ₂ S Removed
“ “ “ 1st box	80	20 by 1st box
“ “ “ 2d “	20	60 “ 2d “
“ “ “ 3d “	5	15 “ 3d “
“ “ “ 4th “	0	5 “ 4th “

It would at once be evident that box No. 1 was not doing its share of the work, since if it were in good condition it could usually be expected to do at least 60 per cent of the total absorption. It would be evident that box No. 2 was bearing the chief burden and it would be high time to empty No. 1 or reverse so that it would clear up.

If such tests as the above were made faithfully day after day and carefully recorded in a book (not on loose scraps of paper) it is evident that a running record could be maintained from which, knowing the amount of gas metered per day, the actual number of grains of H₂S absorbed by each box from change to change would be known. Knowing the number of bushels of oxide in each box, the volume of gas passing in a given time, and the number of grains of H₂S absorbed by each box per 100 cubic feet of gas passing through, it would be very simple to calculate with a reasonable degree of accuracy the number of pounds of sulphur absorbed per bushel. A sample record and computation is given in Appendix B. Such results would be of far greater value in determining relative merits of various operating methods or of various oxides than would the usual record of gas purified per bushel between changes, because unless tests are made there is no way of knowing what proportion of the purification should be credited to each box. Usually the first box is credited with all of the purification on the theory that in the long run each box will be similarly credited, and will average up, but during this same time the sulphur content of the gas may change, or more or less tar may be carried forward, affecting sulphur absorption so that the actual performance may be entirely obscured by other conditions.

As a final check on operation, analysis of the oxide for sulphur and tar after each removal from the box and especially before discard would be very helpful. Often a batch of oxide is discarded when it is still capable of doing much useful work, and perhaps even more often a batch is returned to the box at considerable expense of handling when it might better have been discarded. Even the trained eye may sometimes be deceived in judging oxide, especially if it contains some tar. In a paper by Fulweiler and Kunberger¹ a method for determining mathematically

¹Some of the Physical Characteristics of Ferric Oxide, Proc., Amer. Gas Institute, 1913, Vol. 8, Pt. 1, p. 476.

whether a given batch of oxide is worth using again has been developed. The formula used is given in Appendix C. It will be observed that no knowledge of higher mathematics is required, though one does need to know what the batch has done in the past and what it is capable of doing as judged by a simple laboratory test. If the operator were in possession of the facts derived from the running record of tests above described, together with certain costs which he should know for intelligent operation of his plant, it would not be difficult to use the formula provided he could make or have made an analysis of his oxide and a laboratory hydrogen sulphide absorption test.

The writers of this paper do not advise every gas company large and small, to maintain a chemical laboratory and a trained chemist. The small companies probably could not afford these refinements. The large companies already have them and know their value. We will not attempt to prescribe the minimum size of plant that can afford a laboratory. However, many of the smaller plants in this and other states are links in a chain of plants. It would seem feasible for a chain of several plants to maintain a laboratory and a chemist, to whom samples of oxide, ammonia, and other materials could be sent for examination. The results reported by him from testing oxides, together with the Tutwiler test made by the plant superintendent or other person, and adequate record of purifier changes and batch performance, all taken together, would suffice to put purifying operation on a much higher plane than it now is in the average plant. It is believed that it would also effect a real economy in dollars and cents within a reasonable time.

Purification costs heretofore have usually been but a small item in the total cost of making and distributing gas, but with the greatly increased cost of labor, it is becoming especially desirable to get the greatest absorption of sulphur with the least amount of handling. Revivification in place, with its obvious advantages where properly conducted, should become much more general. If difficulties are encountered, careful inquiries should be made as to why they are encountered. Only by intelligent study, aided by tests and good records, can the best results be obtained.

QUALITY OF OXIDE FOR GAS PURIFICATION

The quality of oxide used for purifying gas is another factor affecting efficiency and economy of purification, but this has not as yet been worked out so that it can be expressed mathematically in computing performance of a given equipment. Some research work, having as its object the determination of the effects of the peculiar properties of various oxides is now

in progress, and it is hoped to throw some light on the subject in a later publication. At the present time it is recognized that oxides produced by different processes, and indeed even oxides made by the same process, show variations in performance, but just what are the causes of these variations and how they can be controlled is not now known.

TYPES OF HYDRATED IRON OXIDES

Three main types of hydrated oxide of iron are in use for purification. These include:

(1) Oxides made by rusting cast iron borings in the air with water only, or with accelerating agents such as sulphate of iron, salt, etc.

(2) Natural oxides, which include certain ores having the proper chemical and physical condition.

(3) Precipitated oxides, made by the chemical precipitation of hydrated oxides of iron from the salts of iron produced as by-products in certain industries or from the iron-bearing water of some mines.

Each of these oxides has properties peculiar to itself, the reasons for which are not yet clear. While ferric oxide (Fe_2O_3) is included in the composition of each and is the reacting material, the presence of other materials in combination with it and the physical structure of the material are of the greatest importance in determining performance. Ferric oxide by itself without water of hydration is almost or entirely non-reactive with hydrogen sulphide.

Formerly the iron content of a commercial material was considered as an index to its value for purifying gas. While this may be true to a limited degree when applied to oxides of one type, it does not hold in comparing oxides of different types.

TESTS OF OXIDES

Since the absorption of hydrogen sulphide is the main thing desired from the oxide, it follows that tests which will indicate the absorbing value of a particular oxide are the most logical ones to apply in valuing a material. Such tests have been devised but no test which has yet been suggested is sufficiently definite in its provisions and indicative of the results to be obtained in actual practice to thoroughly meet the requirements of a standard test. This is evidenced by the fact that the Purification Committee of the American Gas Association is now endeavoring to devise such a standard test, which will meet the requirements of the gas industry generally.

One of the simplest and best-known laboratory tests worked out thus far is that of A. F. Kunberger¹ (see Appendix C). In the Kunberger

¹Some of the Physical Characteristics of Ferric Oxide: Proc., Amer. Gas Institute, 1913,

method a small weighed sample of oxide is fouled by dry hydrogen sulphide for one hour, the water liberated by the reaction being retained in a tube containing granulated fused calcium chloride, which is weighed with the tube containing the oxide before and after fouling. The gain in weight of the two tubes (or one tube containing both oxide and calcium chloride may be used) is equal to the weight of H_2S absorbed.

Such a test is very useful in determining the relative capacities of various materials under the conditions of the test. The test is also said by some operators to check practical operations quite closely. Other operators, however, place less reliance in it, and in purchasing an oxide of unknown quality are not satisfied with anything less than a semi-commercial test. Such a test usually consists in fouling two oxides, one of known practical performance, the other the unknown material, with unpurified gas, in a pair of small purifiers. These purifiers may contain from a few quarts to a few bushels of the materials in one or more layers. Sometimes two sets of two or more purifiers each are used. The purifiers are followed by gas meters to measure the gas passing through each oxide. The test usually consists in passing gas through both materials at the same rate and noting the volume of gas purified by each until the time when some hydrogen sulphide passes one material as shown by a test with lead acetate paper at the outlet. The rate of gas flow at the beginning of the test is generally at least twice that usual in practice. Sometimes when one material begins to pass hydrogen sulphide the rate of flow is reduced until absorption is complete and the test continued at the new rate until H_2S again passes the material. The test may be continued until both materials are entirely fouled and in some cases the materials after revivification are tested again. Such a test would seem to possess advantages over a strictly laboratory test, since the same kind of gas is used that has to be purified in the works purifiers and the rate of fouling is nearer to that obtaining in practice. On the other hand, in small test installations where the surface of contact between the oxide and the box is usually relatively much greater than in practice, there is danger of the gas passing up the sides of the box to a considerable extent and the excessive rates of purification are likely to cause channelling. Another disadvantage of tests of this kind is the time required to complete them. With rates of fouling approaching those in practice, weeks or even months may be required to foul the materials.

In all tests of oxides, the great difficulty is to interpret the results fairly and with certainty. At present those gas companies who make extensive tests on oxides interpret the tests as best they can in accordance

with their own particular conditions and the opinions of their own engineers, and until a standard test with carefully specified equipment and testing procedure is worked out, it will be very difficult properly to evaluate commercial purifying materials.

ACTIVITY AND CAPACITY OF OXIDES

The existing overloaded condition of the purifying apparatus in many gas plants necessitates more attention to the activity or speed of oxides than has hitherto been given to the subject. A satisfactory test must indicate the relative activity of the materials under test. At the same time capacity of oxides will remain an important consideration. The Steere formula allows about 6 minutes time of contact of gas with oxide, assuming all the space occupied by the oxide to be free space. The actual free space in a layer of oxide will of course be considerably less than the total volume, depending upon the coarseness of the material, a factor which is continually changing as the material is used and becomes more and more clogged with sulphur. A new oxide sponge might have 60 to 70 per cent free space, and therefore the actual item of contact would be considerably less than 6 minutes as mentioned above. If, as is sometimes the case, the time of contact in a heavily loaded purifying system is reduced to 2 minutes or less, it is evident that the rapidity of the material may have a very important bearing on its value for such a plant. It is quite likely that various factors could be worked out applying to various types of purifying oxides, which introduced into formulas for purifying capacities would materially alter the hourly capacities permissible with an equipment of a given size and arrangement. This subject needs further study. For the present the differences in oxides will not be considered in studying the purifying conditions in Illinois plants. Computations will be made, assuming that all oxides are the same. In drawing conclusions and suggesting remedies for certain cases, the possibility of using more rapid oxides must be borne in mind.

CONDITIONS FOUND IN ILLINOIS PLANTS

Having considered the conditions affecting purifying efficiencies, let us see what the actual conditions are in Illinois plants, so far as can be determined from the information collected.

As was mentioned earlier in this bulletin, sixteen of the medium-size plants of the State were visited. Information was gathered relative to load conditions, size and kind of equipment, operating methods, and to a

certain extent, the results obtained. This latter information was supplemented by the results of analyses of spent oxide samples collected in the various plants.

Upon returning to headquarters the information obtained was tabulated, purifier capacities were computed, oxide samples were analyzed, and the results tabulated. Half of the plants visited were mixed-gas plants. Their problems were somewhat different from those of straight water-gas plants, so the data and results have been tabulated separately. In accordance with an oral agreement under which results were obtained, the tabulations contain no plant names. The writers will be glad to inform any operator as to the designation of his own plant, in order that explanations may be made in case of misunderstanding or difference of opinion as to results obtained.

EQUIPMENT CONDITIONS

The purifying equipment conditions in Illinois plants are probably the same as those existing in similar plants elsewhere. There is the usual combination of old and new equipment which results from piecemeal construction. The old equipment has often been outgrown, but in many cases is still serviceable, and the usual policy has been to increase capacity by adding another purifier, usually of the outdoor type, to the older indoor equipment, retaining the latter in service. Such a condition exists in about half of the plants inspected.

While it is of course advantageous to get as much economical service as possible from a given unit of equipment, it appears in some cases that the old equipment is a drag on the new. In making additions in some cases, the minimum cost of the addition has been looked after, rather than operating economy. The connections are so arranged as to permit both the old and new equipment to be used at the same time, but with little regard to the flexibility of the system. The arrangement is often so fixed as to permit only one order of the boxes in series. In some cases there is a certain latitude for arrangement among the old units, but usually the new equipment either precedes or follows the old in a fixed position relative to it. Most of the new purifiers are equipped for deep layers of oxide and valved for reversible flow, whereas most of the old boxes have shallow oxide layers and straight flow. In no case which we recall is there a combination of old and new equipment in use, provided with arrangements for perfect flexibility as to rotation of boxes and reversibility of flow. In about half the plants are the boxes uniform as to size and type and completely flexible as to arrangement.

The computation of purifier capacity for many of the plants is a rather complicated matter. The Steere formula is applicable primarily to boxes arranged for reversible flow, though the formula can be applied to straight-flow boxes by the use of an appropriate factor. In some plants where there is a combination of reversible and straight-flow boxes, it is necessary to use one's judgment in the selection of the proper factor, and opinions of two engineers might differ as to the proper value of the factor to be taken.

PURIFYING EQUIPMENT OF INDIVIDUAL PLANTS

The following is a brief description of the purifying equipment of the various plants inspected, together with remarks relative to special conditions which seem noteworthy and pertinent.

Plant No. 1. The purifying equipment of this straight water-gas plant consists of three cylindrical steel outdoor boxes, each 35 feet in diameter and 13 feet high. Each box contains two layers of oxide 4 feet deep. The arrangement is entirely flexible, permitting the boxes to be used in any desired order. The direction of gas flow in each box is reversible, the gas entering between the layers and leaving at the top and bottom or vice versa. Southern Illinois coal is used as generator fuel in this plant and the gas at the purifier inlet contained 180 grains of H_2S per 100 cubic feet at time of inspection. The computed hourly capacity of the purifiers is 240,000 cubic feet, or nearly 2.2 times the maximum hourly make reported. The installation is therefore oversize and with good oxide would permit the use of coal of considerably higher sulphide content, if other conditions made it desirable. The cost of purification per thousand cubic feet in this plant should be very low, unless the capital charges on an equipment so considerably oversize are excessive. No figures relative to capital charges are available. Analyses of spent oxide from this plant indicate that best results are not being realized from this equipment, the sulphur absorption per bushel not being nearly so high as in several other water-gas plants that are much more heavily loaded.

Plant No. 2. The purifying equipment in this plant consists of two cylindrical dry-seal straight-flow indoor boxes, 18 feet in diameter and 9 feet deep. Each box contains two 4-foot 3-inch layers of oxide. The generator fuel used at time of inspection was eastern coke and the H_2S content of the unpurified gas was 100 grains per 100 cubic feet. The computed hourly capacity of the boxes was 39,800 cubic feet of gas, which could theoretically be increased to about 52,000 cubic feet per hour by arranging for reversible flow, while the maximum hourly make was reported as 110,000 cubic feet. The sulphur absorption per bushel in this

plant was low, as would be expected in a plant so overloaded. The situation was complicated by insufficient condensing apparatus and by a relief holder having but one connection, giving but slight opportunity for any cooling of gas in the holder. At the time of inspection the gas was entering the boxes at a temperature of about 120°F. and was carrying much tar fog. Analyses of spent oxide, however, indicate that this is not a year-around condition. The purifying condition in this plant were the most unfavorable observed in the State, and it is greatly to the credit of the operators that they succeeded so well in supplying clean gas to the public. The shortcomings of the present cleaning and purifying systems are realized by the management, and extensive improvements are projected.

Plant No. 3. The equipment of this water-gas plant consists of three dry-seal, oblong, indoor boxes 16 feet by 12 feet horizontal section, and 12 feet deep. Each box contains two 5-foot layers of oxide. These boxes were originally designed for reversible flow. The superintendent conceived the idea that the capacity would be increased by making straight-flow boxes of them. The computed capacity was thereby reduced from 55,200 to 40,800 cubic feet per hour with gas containing 190 grains per 100 cubic feet. Whether decrease in efficiency has resulted from the change would be extremely difficult to determine, since recent improvements in the tar-extracting apparatus have probably increased efficiencies to a far greater degree than the change referred to decreased them. Since the purifiers are now overloaded nearly 100 per cent, a return to the former arrangement which would involve very little expense, is suggested.

Plant No. 4. This is an up-to-date small water-gas plant. The purifying equipment consists of two cylindrical reversible flow outdoor boxes 14 feet in diameter and 10 feet high, each containing two layers of oxide $4\frac{1}{2}$ feet deep. The computed maximum hourly capacity is 25,000 cubic feet of gas, containing 175 grains H_2S per 100 cubic feet, and the reported maximum hourly make is 22,000. Since no air is admitted for revivification the reversibility of these boxes is a matter of less consequence than would otherwise be the case and the actual capacity is probably less than the computed. The plant is seldom operated more than 12 hours per day. In addition to these working boxes there are four square indoor water-seal, straight-flow boxes, 10 feet in diameter and 4 feet deep, designed to hold one 3-foot 6-inch layer of oxide each. These boxes are relics from a former coal-gas plant. They are connected by a center seal, so that only three of them can be in service at one time. The feasibility of putting these boxes into service so as to permit the use of generator fuel (bituminous) of higher sulphur content has been considered. Inasmuch as the coal suggested for use gives about 400 grains of H_2S in the gas, and

the two boxes now in use would have a computed maximum hourly capacity of 22,600 cubic feet of gas of that sulphur content, it hardly seems that the slightly increased hourly capacity to be obtained from the small old-type boxes would warrant the expense of putting them into service and the inconveniences attending their use.

Plant No. 5. The purifying equipment of this plant was originally designed for coal gas. Extensive necessary repairs to the coal-gas equipment, difficulty of securing efficient retort-house labor, and the economies realized from making water gas from bituminous coal have resulted in at least temporary abandonment of the coal-gas equipment except in so far as it could be utilized in handling the water gas. The purifiers include two oblong dry-seal indoor boxes 15 by 10 by 8 feet deep, each containing two layers of oxide $3\frac{1}{2}$ feet deep, and one square dry-seal box 20 by 20 by 5 feet deep, containing one layer of oxide $4\frac{1}{2}$ feet deep. The boxes are all of the straight-flow type. The large shallow box can be used only as a catch box, being necessarily last in the series. The computed capacity of the purifiers is 32,700 cubic feet of gas per hour, and the overload during hour of maximum make is about 22 per cent. The present arrangement of the boxes fulfills present needs quite well. By arranging the two deep boxes for divided and reversible flow, the capacity could be increased to about 36,500 cubic feet per hour. The purifying costs reported are quite low.

Plant No. 6. The purifying equipment of this water-gas plant consists of two rectangular indoor boxes 16 by 12 by $11\frac{1}{2}$ feet, each containing two 5-foot layers of oxide, in parallel with two boxes 20 by 20 by 5 feet containing one 4-foot layer of oxide each. The deeper boxes are arranged for reversible flow, but the shallow boxes have straight flow only. The computed capacity of the system as now arranged is about 60,000 cubic feet per hour. The overload at the time of maximum make is about 67 per cent. It is understood that a rearrangement of the boxes whereby all the boxes would be in series, has been considered. If such a change were practicable from other considerations, the capacity would be increased slightly but probably not sufficiently to pay. On the other hand, if plenty of overhead room is available, and it were practicable to double the depth of the two shallow boxes, making two layers in each box, and to arrange the whole system for reversible flow throughout, the capacity would be increased to over 100,000 per hour or to about the present maximum hourly production of the plant.

Plant No. 7. This large suburban water-gas plant is equipped with four rectangular water-sealed indoor boxes each containing two 5-foot layers of oxide. The gas flow in each box is reversible, gas entering at the

middle and leaving at the top and the bottom of the box or vice versa. Rotation of the boxes can be accomplished in only one direction, as: 1 — 2 — 3 — 4, 2 — 3 — 4 — 1, etc., but not 4 — 3 — 2 — 1, etc. The computed hourly capacity of the system is about 206,000 cubic feet. It is about 40 per cent overloaded at time of maximum production. The purifying costs in this plant are the lowest reported by any plant inspected. The spent oxide from this plant showed a sulphur content rather above the average. The tar content was higher than the average found in all the plants and indicated that an excessive amount of tar had been allowed to enter the boxes at some time during the life of the oxide. At the time of inspection, the gas entering the boxes was reasonably clean. The indications are that purifying results could be improved somewhat if the load curve, shown in Figure 2, could be smoothed out, making the production through the boxes more uniform.

Plant No. 8. This suburban water-gas plant has two sets of purifying boxes in parallel. One set consists of four rectangular indoor boxes connected by a center seal which permits the use of only three boxes at a time. Each box is 24 by 24 by 7 feet deep and contains two layers of oxide 3 feet deep. The other set of boxes consists of four boxes, each 16 by 16 by 4½ feet deep. Each box contains a single layer of oxide 2½ feet deep. Three of the boxes are interchangeable, viz., any one of them can be made first box, but the position of one box fixes the order of the set. The fourth box of the set is a catch box and is always at the end of the series. All the boxes in both sets are arranged for straight upward flow. The computed maximum capacity of the two sets of boxes, as now arranged, is about 100,000 cubic feet of gas per hour. The capacities of the two sets are so different (about 4 to 1) that any rearrangement by placing in series would probably not be feasible. The set of larger boxes has a present capacity of about 80,000 cubic feet of gas per hour. If a new valving system could be installed, putting the fourth box into use and permitting reversal of flow, the capacity of the set would be approximately doubled, giving the entire system a total capacity of 180,000 cubic feet, more or less, per hour, which is about equal to the present maximum flow through the purifiers.

Plant No. 9. This plant produces about 60 per cent water-gas and 40 per cent coal-gas. Each kind of gas has an independent condensing system and the gases are mixed at the inlet of the purifiers. The purifying equipment consists of six boxes. Of these, four indoor boxes are arranged in two pairs, the members of each pair being connected in parallel and each pair acting as one divided-flow but non-reversible box. The paired boxes are 16 feet square in horizontal section and contain one layer

of oxide each, three feet deep. The remaining boxes include an outdoor cylindrical steel box 25 feet in diameter and 10 feet high, containing two 4-foot layers of oxide, and an indoor catch box 16 by 16 by 4 feet deep, containing one 4-foot layer of oxide. The paired units and the cylindrical box can be arranged in various orders as 1 — 2 — 3, 3 — 1 — 2, and 2 — 3 — 1. The direction of flow except in the cylindrical box is non-reversible. The history of the development of this installation is not known. It seems likely that the original installation consisted of a four-box set arranged with a center seal as is common in old installations. In adding to the original equipment, an arrangement was made which is more flexible than is found in many plants. The computed hourly capacity is about 70,000 cubic feet per hour, which is ample for present needs.

Plant No. 10. This mixed-gas plant puts out about 90 per cent coal gas on the average. The peak load on the purifiers is rather sharp, the maximum hourly production being about 9.5 per cent of the maximum daily production. The purifiers include two cylindrical outdoor boxes 15 feet in diameter and 12 feet high arranged for reversible flow. Each box contains two 5-foot layers of oxide. The computed maximum capacity is about 30,000 cubic feet per hour and since the maximum hourly production through the boxes is said to be 75,000 cubic feet, there is a large load factor. The storage capacity in this plant is about 65 per cent of the maximum day. Water-gas and coal-gas are cleaned separately and mixed at the inlet of the boxes. The coal-gas production will probably average around 540,000 cubic feet per day, with an hourly production of about 20,000 cubic feet. The maximum daily gas output from the plant is reported to be about 800,000 cubic feet, which indicates that the maximum water-gas production may be about 32.5 per cent. The overload on the purifiers then is evidently due to the pumping of water-gas through the purifiers at an exceptionally high rate during peak load. It would seem, however, that if the maximum hourly output of the plant for a peak lasting say four hours at a time averaged no greater than the reported maximum make through the boxes, namely, 75,000 cubic feet per hour, and if the holders were full at the beginning of the peak, there would be no necessity of pumping gas through the purifiers so fast, even were it necessary to retain the city holder two-thirds full at all times. Even were the load curve smoothed out as much as possible, with the existing storage capacity it is likely that there would be a considerable overload during maximum hours. The logical extension of the purifying system would seem to be the installation of another box similar to those now in place. Another such box would bring the hourly capacity up to about 50,000 cubic feet per hour.

Plant No. 11. This small mixed-gas plant has an average output of about 200,000 cubic feet of gas per day, of which about one-fourth is water-gas. The maximum hourly purification is about 12,000 cubic feet. The purifying equipment consists of two cylindrical outdoor purifiers, 15 feet in diameter and 12 feet high, containing two 5-foot layers of oxide each. The flow is divided and reversible. The computed capacity of these purifiers is about 30,000 cubic feet per hour; therefore the system is much underloaded. It would be interesting to know the capital charges on an oversize system of this kind, but no figures are available. The size of the purifiers is ample to care for the growth in output for some years to come.

Plant No. 12. The purifying equipment of this plant which produces only 10 to 15 per cent water-gas, consists of four water-sealed indoor boxes 16 by 16 by 7.5 feet deep, each containing two layers of oxide 2.75 feet deep. Three of the boxes are arranged for rotation, the possible arrangements being 1 — 2 — 3, 2 — 3 — 1, 3 — 1 — 2, but not the reverse. The fourth box acts as a catch box and is always in last position. The computed capacity of this installation is about 44,800 cubic feet. If the boxes were valved for divided reversible flow, and 2 per cent of air used for revivification in place, the computed capacity would become about 61,000 cubic feet per hour. At present the installation is about 25 per cent overloaded at time of maximum hourly production, but since the load is being handled well and the cost of purification is low, there is little reason for making a change. The use of higher sulphur coals, if desirable or necessary for other reasons, might make the suggested change advisable.

Plant No. 13. The original purifying equipment of this plant, which makes about 40 per cent water-gas, consisted of two rectangular, water-sealed, indoor boxes, each 16 by 24 by 5 feet deep and containing one layer of oxide, 4 feet 4 inches thick. A cylindrical outdoor box, 15 feet in diameter and 12 feet high, containing two 5-foot layers of oxide was subsequently installed. The new box is of the divided-flow reversible type. On account of tar trouble, the first rectangular purifier was emptied and refilled with shavings to act as a shavings scrubber. The remaining rectangular box and the new outdoor box have a combined capacity of about 26,000 cubic feet of gas per hour. As is common in piece-meal installations of this kind, there is little opportunity for rotation of boxes; indeed in this plant there is only one arrangement possible. The rectangular box is always first in series, and the only change possible is reversal of flow in the second box. The overload during maximum hour is only about 15 per cent and there seems little reason for making a change on that account. Greater flexibility with respect to rotation of boxes would be desirable and would probably permit a more nearly complete fouling of the oxide and a

reduction in purification labor. If a regular shavings scrubber were installed and the box now used for tar extraction were put into service again as a purifier, the capacity of the installation would be increased to about 35,000 cubic feet of gas per hour.

Plant No. 14. This plant makes about 95 per cent coal-gas and the purifying results obtained are considerably above the average. Seven boxes are in use, of which three boxes handle coal-gas exclusively, while the remaining four handle a smaller part of the coal-gas and all the water-gas. The purifiers are arranged in two parallel groups. One group consists of two 24 by 24 by 5 foot boxes, each box containing one layer of oxide 4 feet 6 inches in depth, and one 24 by 24 by 12 feet box containing two oxide layers, each 4 feet 6 inches in depth. These boxes are straight flow, but the sequence can be changed. The other group of boxes consists of four rectangular boxes, each 20 feet in diameter and containing one 2 foot 6 inch layer of oxide. These boxes are connected by a center seal and one box is always off. The computed hourly capacity of the first group is about 72,000 cubic feet of gas per hour, and that of the second group about 23,000 cubic feet per hour. Since the maximum hourly production is reported to be 70,000 cubic feet, the system is not overloaded, at least with gas of the present sulphur content. In case an increased capacity were necessary, it might be desirable to build up the two shallow 24-foot boxes to conform with the existing deep box of the same area. Such an enlargement with valves so arranged as to give complete reversibility would increase the hourly capacity of this group from 72,000 cubic feet to 157,000 cubic feet per hour, over 150 per cent of the present total capacity. Similarly, the four shallow boxes of the other group, if built up to double depth and arranged for complete reversibility, would have a capacity of about 100,000 cubic feet per hour.

Plant No. 15. This small mixed-gas plant produces about 40 per cent water-gas. The purifying equipment consists of four old-type, indoor, water-sealed boxes, connected by a center seal which permits the use of only three boxes at one time. The boxes are 10 by 8 by 4 feet and each contains one 3-foot 6-inch layer of oxide. The calculated capacity of the installation as now arranged is only about 6,000 cubic feet per hour, while the maximum load is reported to be 15,000 cubic feet, and the average load 7,000 cubic feet per hour. It is evident, therefore, that the installation is heavily overloaded. If the fourth box could be put into service except for the short interval required to change a box, the capacity would be increased to about 7,500 cubic feet per hour, which would still leave 100 per cent overload. A new purifying system, or the addition of one up-to-date box with proper valving, would perhaps be the best solution. The present

single boxes, if built up to double height and arranged for complete reversibility of flow, would have a computed hourly capacity of about 22,600 cubic feet. Such conditions as head room available, strength of supports of the present system, condition of present boxes, and cost of the improvements would of course determine the best way to increase capacity. The fact that the purifying labor cost per 1,000 cubic feet in this plant is about double that of any other plant inspected (other small plants included) indicates that there is sufficient economy to be realized in labor charges to offset a considerable capital charge.

Plant No. 16. This plant makes about 93 per cent coal-gas. The purifying equipment is rather unique among the installations inspected. The system includes two outdoor concrete boxes, each 40 by 26 by 14 feet $4\frac{1}{2}$ inches deep, each containing one 53-inch layer and one 62-inch layer, two indoor boxes each 30 by 20 by 5 feet deep, containing one $4\frac{1}{2}$ -foot layer, and two indoor boxes 20 by 20 by $4\frac{1}{2}$ feet deep containing one 3-foot 9-inch layer each. The greater part of the purification is done in the two concrete boxes. These are placed first in the series and the order cannot be changed, nor is there any rotation of the two boxes though they are valved for divided reversible flow. Coal-gas only is purified in the concrete boxes. The old type indoor boxes follow the concrete boxes and the water-gas enters the inlet of the former. The old purifiers are all single-layer straight-flow boxes and are all arranged in series. The computed capacity of the whole system is about 190,000 cubic feet of gas per hour while the maximum hourly purification is reported to be only 40,000 cubic feet. It is evident, therefore, that the capacity is ample for some time to come. This plant was the only one inspected in which the oxide was revived in the box by an air blast. Only the oxide in the large concrete boxes could be revived in this manner. The way in which revivification is conducted in this plant will be discussed later.

SUMMARY OF CAPACITIES AND LOAD CONDITIONS

Tables 1 and 2 give the summarized data relative to load conditions, storage capacity, purifier capacity, etc., of the plants visited.

TABLE 1.—Purifier load conditions in medium-size water-gas plants of Illinois.

Plant.	Aver. daily output— M cu. ft.	Maximum daily output— M cu. ft.	Aver. hourly make thru purifiers— M cu. ft.	Max. hourly make thru purifiers— M cu. ft.	Holder capacity— M cu. ft. ¹	Holder capacity—per cent, max. day	H ₂ S in gas—grs. per 100 cu. ft.	Bushels oxide in actual use	Bushels oxide per million cu. ft., max. day	Calculated max. hourly capacity of purifiers— M cu. ft.	Max. hourly make— per cent of max. purifier capacity	Aver. hourly make— per cent of maximum purifier capacity
1	1650	1800	69	110	C - 1800 R - 60	103	180	18463	10250	241	45.6	28.6
2	1400	2000	58	110	C - 500 R - 112	30	100	4420	2210	40	277.0	145.5
3	617	712	26	80	C - 300 R - 75	53	190	4625	6500	41	196.0	63.7
4	170	227	7	22	C - 100 R - 50	66	175	2225	9810	25	88.0	28.0
5	360	430	15	40	C - 290 R - 30	72	130	3127	7280	34	119.2	44.8
6	1450	1600	60	100	C - 973 R - 80	66	125	6285	3920	54	186.0	111.6
7	3880	6000	161	280	C - 5000 R - 100	85	100	17125	2865	206	136.0	78.1
8	3200	4100	133	175	C - 500 R - 100	15	125	10900	2660	104	168.8	79.0
Averages.....						61	141	.....	5686	.....	145.8	72.4

¹In holder capacity column, the abbreviations "C" and "R" stand for City Holder and Relief Holder, respectively.

TABLE 2.—Purifier load conditions in medium-size mixed-gas plants of Illinois.

Plant	Per cent water-gas	Aver. daily output— M cu. ft.	Max. daily output— M cu. ft.	Aver. hourly make thru purifiers—M cu. ft.	Max. hourly make thru purifiers—M cu. ft.	Holder capacity— M. cu. ft. ¹	Holder capacity— per cent of max. day	H ₂ S in gas—grs. per 100 cu. ft.	Bushels of oxide in actual use	Bushels of oxide per million cu. ft., max. day	Calculated max. hourly capacity of purifiers— M cu. ft.	Max. hourly make—per cent of purifying capacity	Aver. hourly make— per cent of purifying capacity	
9	60	850	1200	35	60	C - 1280 R - 60	107	90	6450	5360	65	91.8	53.5	
10	10	600	800	20	75	C - 300 R - 200	62	230	840	3560	30	45.0	65.8	
11	25	200	230	8	12	C - 100 R - 50	65	340	2840	12300	29	39.4	28.4	
12	12	550	780	23	50	C - 663 R - 112	99	220	3560	4690	45	111.5	51.1	
13	40	440	500	18	30	C - 525 R - 21	109	150	2755	5500	26	114.5	69.8	
14	5	1500	1800	63	70	C - 902 R - 70	54	165	10735	5960	96	73.0	65.5	
15	40	170	200	7	15	C - 100 R - 75	83	350	675	3370	6	256.0	121.0	
16	7	1400	1800	58	65	C - 1000 R - 390	77	470	22805	12700	191	34.0	32.9	
Averages.....								82	252	6680	120.6	61.0

¹In holder capacity column, the abbreviations "C" and "R" stand for City Holder and Relief Holder, respectively.

In studying Tables 1 and 2 several outstanding facts will be noted. Of the eight water-gas plants, six are loaded at maximum hour beyond the rated capacities of their purifiers, while on the other hand, only two of the eight are overloaded during hours of average production. It is evident then that the lack of uniformity of load is the chief cause of overload. It will be noted that the maximum hourly make is often more than double the average hourly make. (By "make" here, is meant flow through purifiers, *not machine make*.) By referring to the column marked "Calculated max. hrly. capacity of purifiers" and "Bushels of oxide per million cu. ft., max. day", we are able to form some opinion as to the reason for the overloaded or underloaded condition in each case. It is interesting to note that the average number of bushels of oxide per million cubic feet of gas purified on the maximum day, namely 5,686, agrees quite closely with the figure 5,365, which is the average of twenty-three water-gas plants whose results are reported by O. B. Evans in his paper, "Revivification in place", already mentioned. This indicates that Illinois plant conditions conform quite closely to conditions in plants all over the country, as is to be expected.

While, as shown in the tables, the holder capacity bears no direct relation to purifying capacity, it will be noted that in plants where the volume of oxide is small, large holder capacity assists in keeping down the overload. Plants 1 and 2 are interesting as the extreme examples of prevailing conditions. These plants have approximately the same output. Plant 1, however, has a holder capacity greater than its maximum day and an oxide capacity per million cubic feet of gas nearly twice the average. Plant 2, on the other hand, has a holder capacity only 30.6 per cent of its maximum day and an oxide capacity less than half the average. It is surprising to find that despite these great differences, the amount of sulphur absorbed per bushel by both of these oxides is almost the same with a very slight advantage in favor of Plant 1. The probable reasons for this similarity of results under such different conditions will be discussed later in connection with Table 3. Plant No. 8 (see Table 1) presents an apparently anomalous condition. Here the holder capacity is only 14.6 per cent of the maximum day and there is less than half the average amount of oxide per million cubic feet on maximum day found in all the plants, yet the overload is not nearly so great as in some other plants which are apparently more favored. The reason, however, seems to lie in the connection of this plant with a larger system whose holder capacity is to a certain extent available for use by this plant. In this case it is practically impossible to say just what average holder capacity is available for Plant No. 8, though its own individual holder capacity is as given. Probably at least four times the capacity stated is actually available when needed. Formerly many gas engineers considered that a well-designed plant should have a holder capacity at least equal to its maximum day, but the rapid growth of output in most of our plants has resulted in much smaller storage capacity ratios, as shown in Tables 1 and 2. When one considers that in spite of the smaller margin of safety which a small holder capacity gives, practically all of the larger plants operate year after year and give the public uninterrupted service, one is likely to conclude that there is no well-defined lower limit beyond which the gas operator dare not go. While this is true to a certain extent and distribution conditions are likely to be the determining factor in dictating an increase in storage capacity, it is evident that this condition is reflected back upon plant operation and affects purification, tar removal, and indeed any phase of the gas manufacturing process in which rate of gas flow is a factor.

In Table 2, the purifier load conditions in eight mixed-gas plants are presented. It is to be noted that the percentage of water-gas varies from 5 to 60 per cent of the total, averaging 25 per cent in all plants. It will be observed that the average holder capacity is larger in proportion to the

maximum daily output than in the straight water-gas plants, as is also, in general, the volume of oxide per million cubic feet output on maximum day. Only one of the mixed-gas plants had an overload on its purifiers, during hours of average production. Since the coal-gas production in a mixed gas plant is usually fairly uniform in rate, the water-gas production taking the peak load, it is evident that in most cases where the purifiers are overloaded, the overload is caused by the production and purification of a large volume of water-gas in a short time. The purifiers are usually designed to handle the coal-gas production, but the water-gas production has often not been provided for. It will be noted that the hydrogen sulphide content of the gas, while about double that found in the eight water-gas plants, is considerably lower than in usual coal-gas practice, even with very low-sulphur coals. Had the sulphur content been higher, then the average purifying capacity would have shown an overload according to the relation shown in Figure 1.

EFFECT ON PURIFIER CAPACITIES OF THE USE OF ILLINOIS COAL

In connection with the influence of sulphur content of the gas on purifying capacity, it is interesting to note the effect of a change from the low-sulphur fuels used in a majority of the plants at the present time to fuels of higher sulphur content. The water-gas plants listed in Table 1, with the exception of Plants 2 and 8, were using Illinois or Indiana coals as generator fuel at the time of inspection. These two plants were using eastern cokes. The coals were in all cases selected low-sulphur coals. It will be noted that in some of the plants using coal, the H_2S content of the gas is no higher than in those using coke. In general, however, the increase in sulphur content with Illinois or Indiana low-sulphur coals as generator fuel would be from 50 to 100 per cent, viz., an H_2S content in the gas of 150 grains to 200 grains per 100 cubic feet might usually be expected. By reference to Figure 1 it will be noted that an increase of 50 to 100 per cent in the H_2S content of the gas does not have nearly the effect on the rated purifier capacity, when the H_2S content is small, that a similar percentage increase would have if the H_2S content were large. Hence a change from a low-sulphur eastern coke as water-gas generator fuel to a low-sulphur central district coal does not have as great an effect as the change from a low-sulphur eastern gas coal to a low-sulphur Illinois coal would have in coal-gas manufacture, it being assumed, as is usually the case, that the best eastern gas coals will average lower in sulphur content than the best Illinois coals. It is interesting to take numerical examples to study the effect of such changes.

Assume that an eastern coke as generator fuel gives gas containing 100 grains of H_2S per 100 cubic feet, and that a central district coal, using the same oil for enrichment gives gas containing 200 grains per 100 cubic feet. A plant which was designed to purify 100,000 cubic feet of gas of the lower sulphur content per hour would have its capacity reduced to 96,000 cubic feet—a decrease of only 4 per cent. On the other hand, if a low-sulphur eastern gas coal gave 300 grains of H_2S at the inlet to the purifier and an Illinois coal gave, as reported in some cases, 600 grains of H_2S , then a plant equipped to handle 100,000 cubic feet of the lower-sulphur gas per hour would have its capacity reduced by the change to about 83,000 cubic feet,—a decrease of about 17 per cent.

All the mixed-gas plants listed in Table 2 except Plants 13 and 15 were using low-sulphur eastern coals at time of inspection. In Plants 13 and 15, mixtures of 50 per cent eastern and 50 per cent Illinois coal were used. In neither of these plants was the sulphur content of the gas exceptionally high, but of course the 40 per cent water-gas made in both cases tended to reduce the sulphur in the mixed gas. It is evident that a decrease of 17 per cent or more in the purifying capacity of some of the mixed-gas plants given would be a serious matter. This difficulty might be met to a considerable extent by more attention to certain details of operation and selection of oxides, as has been previously discussed.

OBSERVED RELATION OF OXIDE VOLUME TO PURIFIER CAPACITY

In Tables 1 and 2 have been given the number of bushels of oxide in use in each plant per million cubic feet of gas output on maximum day. These figures have not been used in computing purifying capacities but are given partly because some engineers have been accustomed to rate purifiers in this manner, and partly to show the effect of oxide volume on purifying capacity in the various cases; especially in connection with storage capacity and load conditions. In Figure 3 is plotted the relation observed between oxide volume and maximum hourly purifying capacity in the various plants. The dotted line represents 1/10 bushel of oxide per cubic foot of gas purified during maximum hour, and is drawn in for convenience of comparison. The water-gas and mixed-gas plants are plotted separately. It is evident that the sulphur content of the gas determines, to a great extent, the position of the curves, and therefore any specification which calls for a certain number of bushels of oxide per 1,000 cubic feet of gas to be purified in a given time can at best be only incomplete. It is interesting to note that the curves for mixed-gas and water-gas plants, while quite close together for the smaller plants, appear to diverge after the 100,000 cubic feet per hour production is passed. Whether this would hold generally for the larger plants cannot be stated on account of insufficient data.

One rather remarkable thing is shown by Tables 1 and 2, namely, that purifiers may be worked far beyond their capacities and still do the work required of them. There does not seem to be any definite point, at least within the range observed, where the purifiers actually break down suddenly in their performance. It is conceivable that gas could be passed

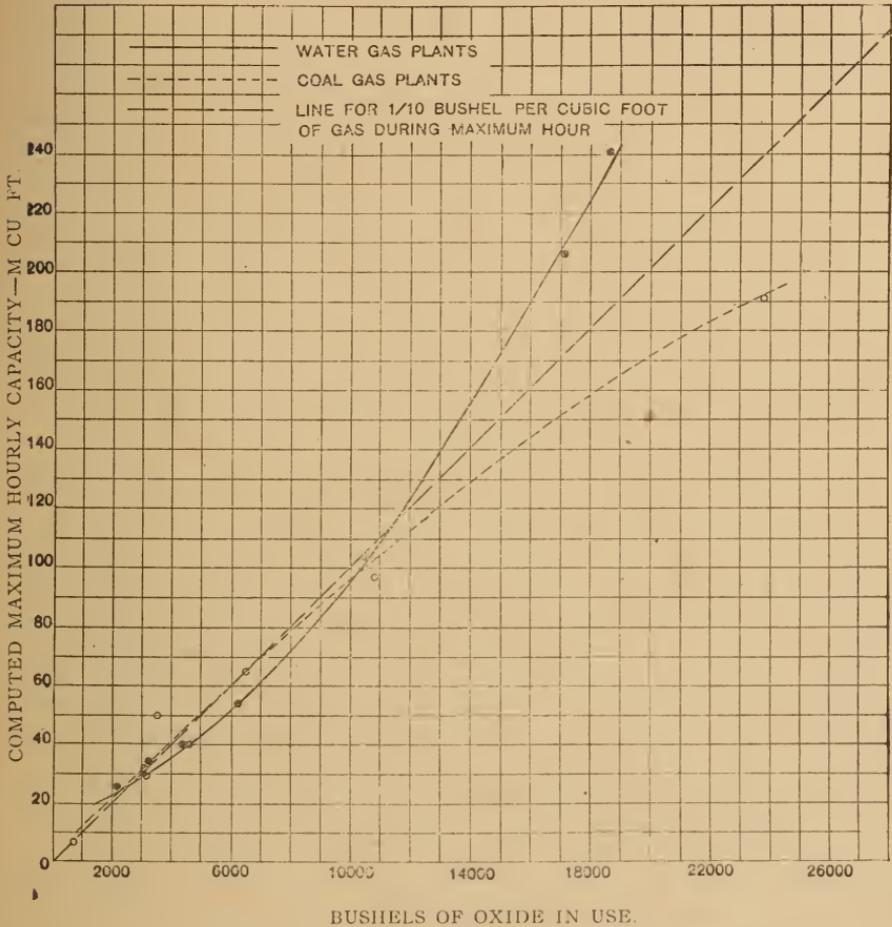


FIGURE 3—Observed relation of oxide volume to hourly purification capacity.

through a series of boxes containing new oxide at such a rate that hydrogen sulphide could be detected almost immediately at the outlet of the system. In testing oxides on a laboratory scale, this condition is found and is made use of to determine the relative rates of reaction of various oxides.

The time of contact called for by the Steere formula is approximately 6 minutes. Many comparatively slow oxides will not give a test for

hydrogen sulphide immediately on a gas containing 100 grains per 100 cubic feet unless the time of contact is reduced to approximately 0.5 minutes. Other more rapid oxides will absorb all of the hydrogen sulphide from gas containing 100 grains of H_2S for several hours with this time of contact. As the oxide becomes fouler, however, the rate of absorption slows down and eventually some hydrogen sulphide will pass by the box. This will happen more quickly, other things being equal, in a purifying system that is overloaded. The result is that in an overloaded plant, other conditions being the same, more frequent changes will be necessary to keep the gas clean. When the frequency of changes becomes excessive the operator usually has one of the following choices; namely, to enlarge the purifying equipment, to rearrange existing equipment, to improve operation by increasing the absorption per bushel through more complete revivification in place, in some of the ways already discussed, or to find a more active oxide. Sometimes in the more extreme cases, only the first alternative will prove a feasible, permanent remedy.

REARRANGEMENT OF EQUIPMENT TO INCREASE CAPACITY

As just mentioned, the capacity of a purifying installation may sometimes be materially increased by minor changes whereby the existing equipment can be used in a more advantageous way, or the existing equipment may be enlarged, without changing its position or increasing the ground space occupied. Again, internal changes are possible whereby the purifiers may be made to accommodate a greater volume of oxide. Frequently, where the existing equipment is in good condition, such changes may be made at a fraction of the cost of an entirely new installation. Where additional capacity is needed it would often pay to consider (1) whether the best possible performance is being obtained from the present equipment, and (2) whether some minor changes would not secure sufficient additional capacity to defer the installation of new equipment to another time. Of course, in this as in any other construction, there is always some uncertainty as to the relative cost of installation now or a few years hence. Some of the rearrangements which may be made have been suggested in the detailed descriptions of the purifying installations inspected.

In the first place, it may be well to consider whether the amount of oxide is the maximum that the boxes will accommodate or whether the layers are of the greatest thickness permissible. In several instances it was found that the available space for oxide in the boxes, even allowing for the trays and a reasonable amount of free space, was considerably greater than

would correspond to the number of bushels said to have been purchased for the boxes.

Again the amount of free space allowed may be excessive. In some cases the trays could be relocated without unduly diminishing the free space and with a distinct increase in capacity. Take, for example, a 4-box set of purifiers arranged for reversible flow, each box being 15 feet in diameter and 12 feet high, containing two layers of oxide each $4\frac{1}{2}$ feet in depth. The hourly capacity, according to the Steere formula, would be 61,845 cubic feet, if the gas contained 200 grains of H_2S per 100 cubic feet. Now, assuming that the depth of each layer could be increased by 6 inches, the capacity would become 66,262, an increase of capacity of 14 per cent.

If the space available for oxide is being utilized to the fullest extent, then rearrangement may be in order. As has been suggested in several cases, reversible flow may help considerably. Let us assume an installation of three rectangular boxes, each 25 by 25 by 12 feet, each containing two 5-foot layers of oxide equipped for straight flow only, and with a given sequence as ABC, BCA, CAB. Such an installation purifying gas containing 200 grains of H_2S per 100 cubic feet would have a maximum hourly capacity, according to the Steere formula, of 133,000 cubic feet of gas.

Let us assume that this installation is overloaded and that it is desired to increase its capacity about 35 per cent. This increase may be accomplished in either of two ways, namely, by making the three existing purifiers perfectly flexible as to arrangement and reversibility or by installing a fourth box of the same size as the existing boxes, arranged for straight flow only. Leaving out of consideration for the present the difference in operating cost which would be in favor of the former arrangement, let us consider the probable relative costs of the two arrangements. At present prices, the cost of a new box of the size given, arranged for straight flow only, would probably be somewhere between \$12,000 and \$16,000. The installation of three 6-inch reversing valves, together with alteration of the manifold whereby the three existing boxes could be made entirely flexible as to arrangement and reversibility, would cost somewhere between \$6,500 and \$11,000, depending of course upon the amount of work and material that would be required and the amount of material from the old manifold that could be applied to the change. It is evident then that if the existing purifiers were in good condition and conveniently arranged for operation, rearrangement would be decidedly cheaper than the addition of another box of the same type. The economy of operation would also be distinctly in favor of rearrangement. A number of installations have been observed

in which such a change with corresponding increase in capacity was apparently feasible.

In a few cases where old 4-box sets with center-seal connections are in use, a change in the connections whereby all the boxes could be used at one time would be advantageous.

A few cases have also been observed where a small increase in capacity could be realized by putting into series boxes now arranged in two parallel groups, but in most of the cases of this kind observed, such a change would hardly give enough increase in capacity to pay unless all the boxes were made reversible and arranged so as to be used in any desired sequence. In most cases where two parallel groups are in use, one of the groups consists of shallow single-layer boxes. Frequently these shallow boxes are of considerable cross-sectional area and where substantial foundations exist and plenty of head room is available, it might be feasible to build up the boxes to double height, installing an additional layer of oxide. Such a rebuilt group of boxes, if arranged for reversible flow and for rotation with the boxes of the deeper group, also equipped for reversible flow, would usually increase the capacity of the system very materially. For example, in Plant No. 6 already described, such a reconstruction, if feasible, would increase the capacity by about 66 per cent.

Of course, in making any alterations of the kinds described several things have to be considered. It would obviously be unwise to go to considerable expense to alter the connections or reconstruct boxes which through long service had become unsound. And it might be unwise to prolong the use of boxes so arranged that the cost of operation was excessively high on account of inconvenient location or poor facilities for handling oxide. In any case it would be advisable to carefully compare the cost of rearrangement or reconstruction with the cost of new equipment necessary to give an increased capacity equivalent to that expected from the proposed change. The possibility that the space now occupied by purifiers especially when in substantial buildings, might be used to advantage eventually for some other purpose should also be considered. Since present practice is almost unanimously in favor of outdoor purifiers, it might be obviously unwise to perpetuate the use of valuable buildings for this purpose. The economic as well as the physical features of such a change need consideration. In all cases where possible changes have been suggested in this paper, it is to be understood that only the results to be expected from such changes have been considered. The considerations just named and physical conditions existing in the various plants might make the suggested alteration entirely impracticable. Each case would have to be considered carefully by itself.

RESULTS OBTAINED IN PLANTS INSPECTED

As will be seen clearly in Tables 3 and 4, purifier capacity alone will not necessarily insure good purifying results. Some of the best results found in Illinois plants at the present time are in overloaded plants.

A study of Tables 3 and 4 shows how difficult or impossible it is to harmonize the results actually obtained with the conditions under which they were obtained. In general, one cannot but be impressed by the difference between the results shown and those generally considered as typical of the best practice. Text books and treatises on gas manufacture usually state that spent oxide will contain from 50 to 60 per cent of sulphur, thereby implying that this degree of sulphiding is usually attained before the oxide is discarded. Yet the results shown in the tables indicate that in the average Illinois plant, at least, not nearly the usually accepted standard of performance is actually realized. In the water-gas plants, excluding Plant No. 5, which was a mixed-gas plant when the material was fouled, the average percentage of sulphur in the spent oxide was only 21.7 per cent. In the mixed-gas plants, on the other hand, including Plant No. 5, the average was 37.4 per cent. These results are somewhat lower than those reported by Mr. Evans in the paper already referred to. The average absorption in the water-gas plants studied by him was 35 per cent sulphur and in the coal-gas plants 44 per cent. The latter figure is, we understand, for straight coal-gas, whereas the results reported by us in Table 4 are for mixed-gas plants. It is probable, too, that the plants whose results are reported by Mr. Evans are considerably larger in size than the plants in Illinois inspected by us, and therefore the conditions were probably more favorable for good results. Even so, it is apparent that the results generally obtained fall considerably below those considered as good standard practice.

In comparing Tables 3 and 4 one is impressed with the very considerable difference in sulphur absorption in the two gas-making processes. A number of reasons for the difference may be suggested. Coal-gas usually contains considerably more sulphur per unit volume than does water-gas, and according to the law of mass action, the greater concentration of the H_2S in coal-gas increases the rate of absorption. The coal-gas production is also more uniform and the peak loads on the purifiers usually represent a greater rate of water-gas purification rather than of coal-gas, so the average load conditions with coal-gas are more favorable. The ammonia in coal-gas, of which traces pass through the purifiers, may also assist materially in the purifying process by keeping the oxide alkaline. A section of the Purification Committee of the American Gas Association is now studying the effect of this factor.

TABLE 3.—Purifying Results Obtained In Water-Gas Plants Inspected.

Plant	Average daily production— M cu. ft.	Max. make hr.—per cent of max. purifier capacity	Bushels oxide per M cu. ft. max. hourly production	Kind of oxide in use	Weight spent oxide— lbs. per bushel	Sulphur in spent oxide—per cent dry basis	Tar in spent oxide— per cent dry basis	Sulphur—lbs. per bu. dry spent oxide	Tar—lbs. per bu. dry spent oxide	Grs. H ₂ S per 100 cu. ft. unpurified gas	Total gas purified per bu.—M cu. ft. ³	Method of revivification	Purification labor costs—per M cu. ft.	Purification materials cost—per M cu. ft.	Total purification cost per M cu. ft.
1	1650	45.6	168	Rusted borings..	34.6	18.2	8.2	6.3	2.8	180	26.0	1% air in gas and outside of box.	...	...	....
2	1400	277.0	40	Rusted borings..	44.1	12.0	3.4	5.3	2.4	100	88.5	Outside box only	.50	.20	.70
3	617	196.0	58	Natural.....	26.9	26.7	19.0 ¹	7.2	5.1	190	26.6	1½% air in gas and outside of box...	.77	.50	1.27
4	170	88.0	100	Rusted borings..	35.2	15.1	4.6	5.3	1.6	175	22.5	Outside of box only	.30	.80	1.10
5	360	119.2	78	Rusted borings..	65.3	40.1 ²	2.0	26.2	1.3	130	.....	2% air in gas and outside of box...	.10	.98	1.08
6	1450	186.0	63	Rusted borings..	33.3	33.0	1.8	11.0	0.6	125	65.5	1% air in gas and outside of box...	.20	.50	.70
7	3880	136.0	61	Natural.....	50.5	21.2	8.7	10.7	4.4	100	106.0	1% air in gas and outside of box...	.10	.40	.50
8	3200	168.8	62	Natural.....	38.4	25.8	2.3	9.9	0.9	125	58.9	1½ 2% air in gas and outside of box.....	.60	.50	1.10
Averages...	145'8		79	.....	41.0	21.7	6.9	7.9	2.5	140	49.3	.....	.37	.55	.92

¹ Indications are that this oxide was tarred badly after it had absorbed most of its sulphur content.

² This plant was making strait water-gas when inspected but the spent oxide had been fouled chiefly by coal-gas. Results averaged in Table 4.

³ The figure in this column are based upon the assumption that the H₂S content averaged the same throughout the life of the oxide as at time of inspection.

TABLE 4.—Purifying Results Obtained In Mixed-Gas Plants Inspected.

Plant	Average daily production— M cu. ft.	Make max. hr.—per cent of max. purifier capacity	Bushels oxide per M cu. ft. max. hourly production	Kind of oxide in use	Weight spent oxide— lbs. per bu.	Sulphur in spent oxide—per cent dry basis	Tar in spent oxide— per cent dry basis	Sulphur, lbs. per bu. dry spent oxide	Tar—lbs. per bu. dry spent oxide	Grs. H ₂ S per 100 cu. ft. unpurified gas	Total gas purified per bu.—M. cu. ft. ¹	Method of revivification	Purification labor cost—cents per M. cu. ft.	Purification materials cost—cents per M. cu. ft.	Total purifying cost— cents per M. cu. ft.
5	360	119.2	78	Rusted borings..	65.3	40.1	2.0	26.2	1.3	130	.....	.....	.100	.980	1.080
9	850	91.8	107	"Home-made" rusted borings	62.8	44.1	5.3	27.7	3.3	90	228	Outside of box only	.608	.600	1.210
10	600	245.0	38	Rusted borings..	65.4	37.2	2.1	24.3	1.4	230	78	Outside of box only	.357	.396	.750
11	200	39.4	246	Rusted borings..	70.3	40.7	3.2	28.7	2.2	340	63	Outside of box only	.386	1.255	1.640
12	550	111.5	71	"Home-made" rusted borings	71.0	32.5	6.0	23.1	4.3	220	78	Outside of box only	.540	.....	.540
13	440	114.5	92	Rusted borings..	58.9	30.2	1.7	17.8	1.0	150	88	Outside of box only	.....	.....	.....
14	1500	73.0	153	"Home-made" rusted borings	67.2	44.4	4.8	29.8	3.2	165	134	Outside of box only	.840	.200	1.040
15	170	256.0	45	Rusted borings..	50.0	21.4	4.4	10.7	2.2	350	23	Outside of box only	1.407	.840	2.250
16	1400	34.0	351	"Home-made" rusted borings	75.0	36.4	2.6	27.3	2.0	480	42	In off box with air	.342	.576	.920
Averages		120.6	138		65.1	37.4	3.6	24.0	2.3	239	91		.572	.692	1.180

¹The figures in this column are based upon the assumption that the H₂S content of the unpurified gas throughout the life of the oxide was same as at time of inspection.

In the columns of Tables 3 and 4 marked "Total gas purified per bushel—M cu. ft.", the assumption has been made that the H_2S content of the gas was constant and the same as at the time of inspection. The figures reported are probably quite as accurate as the results reported in the purification records of most plants, but owing to the uncertainty of the assumption on which they are based, no claims to great accuracy are made for them.

CAUSES OF LOW EFFICIENCIES

OVERLOAD

The cause of the discrepancy between standard purification practice and the actual results observed in Illinois plants is a complex one. It is probably due to some extent to overload. That an overloaded condition of the purifying equipment can result in low-sulphur absorption is evident from a consideration of the effect of overload on operation. Where the gas has to be passed through the boxes at an excessive rate, although the oxide may at first completely purify it, the condition where it cannot completely remove the sulphur is reached sooner than would be the case if the rate of gas flow were slower. The time between box changes will therefore be shorter with the faster rates.

The complete absorption of hydrogen sulphide requires a measurable time of contact between gas and oxide. When the material is fresh a shorter time of contact seems adequate, but as the surface of the oxide becomes sulphided, a longer time of contact seems to be necessary for complete absorption of hydrogen sulphide by the inner particles of oxide. With very rapid rates of gas flow, the absorption seems to be at first largely superficial, and after the superficial capacity of the material has been utilized, longer contact seems necessary for complete absorption of H_2S .

The absorption of sulphur per change will therefore be less with an overloaded purifying system, and to get the same absorption an oxide will have to be handled more times than would be necessary were the flow slower. Each time an oxide is handled it becomes finer from breakage, and with frequent handling the oxide soon becomes so fine as to favor packing and back pressure. Conditions which lead to overload of the purifiers also usually favor overload of the other gas-cleaning equipment, so that more tar is likely to be carried into the boxes, other conditions being the same, when the purifiers are worked beyond their capacities. Therefore, more rapid tarring and excessive breakage of oxide in an overloaded plant are likely to result in depreciation and discard of the purifying material sooner than in a plant operated at normal capacity.

We note, however, that some of the overloaded plants excel other similar underloaded plants in absorption realized, so this does not appear to be the only or perhaps the most serious cause.

TAR IN THE GAS

Tar in the gas is also a contributory cause, but it is difficult to say in a particular case to just what extent efficiency was reduced by it, for some of the spent oxides collected that are high in tar are also high in sulphur. This would lead one to think offhand either that tar has little effect on sulphur absorption or that most of the sulphur absorption had taken place before the oxide was tarred. In order to determine roughly the effect of tar in the oxide upon efficiency of its absorption of hydrogen sulphide, an experiment was carried out, the results of which are shown in Figure 4.

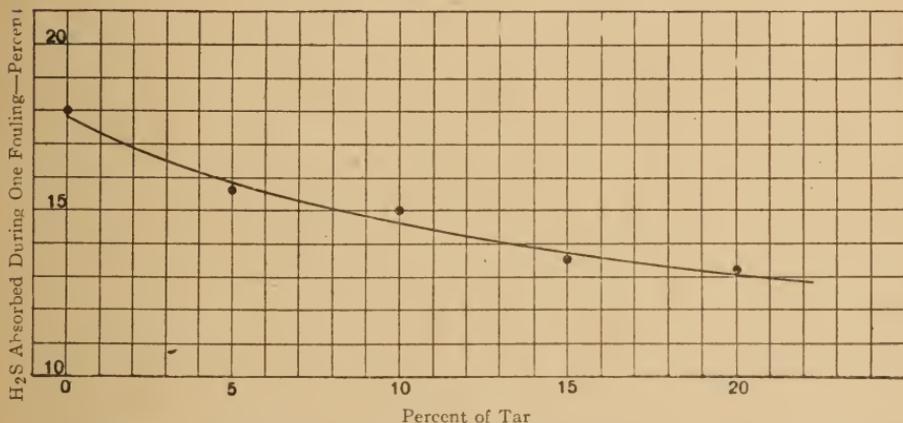


FIGURE 4. Effect of tar on the absorption capacity of an oxide for hydrogen sulphide, first fouling.

The absorption capacity of a particular oxide for pure hydrogen sulphide was determined by the Kunberger method. Portions of the same oxide were then treated with various percentages of tar, and their absorption capacities after treatment were similarly determined. The tar was applied by making up a solution of water-gas tar in pure carbon bisulphide. Each sample of oxide was treated with an amount of this tar solution corresponding to the required percentage of tar. The tar solution and oxide were thoroughly mixed; then the carbon bisulphide was removed by evaporation in the air. The tar was left deposited on the oxide, which was then subjected to the fouling test.

While the conditions of the test and the results obtained are not strictly comparable with practical conditions, they indicate something con-

TABLE 5.—Distribution of tar through beds of oxide in two plants.

PLANT A—WATER-GAS ¹ .				PLANT B—COAL-GAS ² .			
Level where sampled	Per cent moisture and light oil	Per cent sulphur—dry basis	Per cent tar—dry basis	Level where sampled	Per cent moisture and oils	Per cent sulphur—dry basis	Per cent tar—dry basis
Top of upper layer.....	39.8	16.86	3.28	Surface of layer.....	16.2	23.86	2.20
Bottom of upper layer.....	28.0	23.28	3.46	1 foot below surface.....	25.3	28.21	.96
Top of lower layer.....	32.8	24.01	1.60	2 feet below surface.....	22.4	29.78	1.50
Bottom of lower layer.....	38.6	17.69	1.59	Bottom of layer.....	28.6	28.77	1.70

¹Load on purifiers 169% of rated capacity at time of maximum make. Box contained 2 layers of oxide, each 3 ft. deep.

²Load on purifiers 73% of rated capacity at time of maximum make. Box contained only 1 layer of oxide, 2 ft. 6 in. deep.

cerning the effect of tar in coating oxide and decreasing its absorption capacity. Of course, the ability of the material to revivify is also affected, so that tar is a disadvantageous thing to have present at any and all times.

It was thought at first that the reason for the comparatively high sulphur percentages in some rather tarry oxides might be due to the tar-extracting action of a portion of the oxide batch, permitting the remainder of the batch to foul more completely on tar-free gas. It was expected that analyses of oxide from different levels in an upward-flow box would show a concentration of tar in the lower part of the box. Samples of oxide were therefore taken in two plants, one water-gas and the other coal-gas, at various levels. Each sample was collected from several points at the same level, to insure a representative sampling. Analyses of the samples and the levels where taken are shown in Table 5. It is surprising to note that the tar is not concentrated at the bottom. In the water-gas plant the greatest percentage of tar was found in the bottom of the upper layers, while in the coal-gas box, the top of the batch contained the most tar. Likewise, there is no apparent relation between the percentages of tar and sulphur in these batches. The highest percentage of sulphur in each case is coincident neither with the lowest, nor with the highest percentage of tar. One naturally concludes that each batch must have absorbed the larger part of its sulphur in each case before the tar was present to any great extent. The concentration of tar in the upper part of the batch may be caused by tar condensing out of the gas, due to the cooling action of the purifier box cover, and dropping down into the oxide. Of course, in practice the accumulation of tar is relatively slow, and since the rate of sulphur absorption in a given part of an oxide batch is slowing down as the concentration of iron sulphide increases, it is difficult to determine in a particular case to just what extent the accumulation of tar is affecting the performance.

The means of removing tar differs considerably in different plants. Table 6 shows the gas-condensing and scrubbing equipment in use in the different plants. For convenience, the final tar-extracting apparatus in each case is printed in italics. It will be noted that the shavings scrubber appears to be the favorite tar-extracting equipment in water-gas plants, though the P. & A. tar extractor and the bubble washer are preferred in a few plants. The writers of this bulletin have had no opportunity to study the relative merits of these various types of apparatus under conditions which were comparable. As will be noted in the table, the amount of tar in the gas at the inlet of the purifiers varies considerably even with the same type of tar extractor, and it seems to be possible, under favorable conditions, to obtain practically complete extraction with any one of these

TABLE 6. — Tar-Extraction Apparatus In Use.

P. ant	Kind o gas	% water gas	Lbs. tar per bu. oxide	Lbs. tar per million cu. ft. gas at box inlet at time o. insp.	Tar-removing apparatus	Temp. at box inlet at time of insp.	Remarks
1	Water	100	2.81	13.2	Multi. Cond., Tr y Ser., R. Hold. Mult. Cond., P. A., Sh. Sbr....	Degrees F. 101	
2	Water	100	2.45	84.4	Ser., Cond, R. Hold., B. Wash.....	121	} R.Hold. has only one con- nection.
3	Water	100	6.33	81.4	Se., P Cond., Sec. Cond. Sh. Ser.....	130	
4	Water	100	1.62	252.0	Ser. 3 Mult. Cond. (Water) R. Hold., Sh. Ser.....	123	} 2 shavings scrubbers in- stalled since.
5	Water	100	1.32	17.2	² C. G.-Pri. Cond., P. & A., Ser., Cond., R. Wash., Lloyd Ser., W. G.- Multi-Cond., R. Hold., P. & A.....	98	
6	Water	100	.67	24.8	Ser., 2 Cond., R. Hold., 2 Sh. Ser. (parallel).....	86	
7	Water	100	4.40	9.7	R.Hold., 2 Cond., 3 Sh. Ser. (parallel).....	90	
8	Water	100	.87	8.3	4 Cond. (parallel), R. Hold., Sh. Ser.....	103	
9	Mixed	60	3.30	40.6	C. G.-P. C., P. & A., Sec. Cond. W. G.-P. Cond., Sec., Sh. Ser., R. Hold., P. & A.....	109	
10	Mixed	10	1.36	113.6	C. G.-P. C., Sec. C., 2 Scr..... W. G.-P. & A., R. Hold., Sh. Ser.....	107 87	
11	Mixed	25	2.20	7.0 C. 10.8	C. G.-P. Cond., Sec. Cond., Wash. 2 Scr..... W. G.-Cond., Ser., R. Hold., P. & A.....	90	
12	Mixed	10-15	4.26	W. 2.2	G. G.-P. Cond., P. & A., 3 W. Cond., W. Ser., Rot. Ser..... W. G.-R. Hold. Cond., B. Wash.....	100 99	
13	Mixed	40	1.00	0.0	C. G.-2 P. Cond. (Air) Multi-Cond., Wash. Ser. Wash. Sh. Ser.... W. G.-Cond. Ser., Sh. Ser.....	100	
14	Mixed	5	3.27	C. 35.0	C. G.-P. Cond. P. & A., Wash., Ser., Int. Ser. Map. Wash. (Gas oil) W. G.-Sc. Buf. Ser.....	86	
15	Mixed	40	2.20	130.0	C. G.-P. & A., Multi. Cond. Coke Ser., B.-H. Wash. Ser..... W. G.-Ser., R. Hold.....	93	
16	Mixed	7	2.00	5.2	C. G.-2 P. Cond., 4 Multi. Cond., Bub. Wash. Rot. Ser..... W. G.-Ser. R. Hold., P. & A.....	80	

¹ Only coal-gas being run at the time.

² Coal-gas plant now shut down and apparatus being connected for use with water-gas.

Abbreviations: P. Cond., Primary Condenser; Sec. Cond., Secondary Condenser; Ser., Scrubber; Sh. Ser., Shavings Scrubber; R. Hold., Relief Holder; Multi. Cond., Multitubular Condenser; Wash., Washer; Bub. Wash., Bubble Washer; Rot. Ser., Rotary Scrubber; Wash. Ser., Washer Scrubber; Int. Ser., Intensive Scrubber; Nap. Wash., Napthalene Washer; Buf. Ser., Baffle Scrubber; C. = Coal-gas; W. = Water-gas.

types of apparatus. At the time when the tar tests were taken, from which the pounds of tar per million, as given in Tables 3 and 4, were computed, the temperature was very high. Hence, the results represent probably the most unfavorable conditions. The tar-extracting apparatus of many of the plants was overloaded at that time. The overload was due in some cases to inadequate apparatus and in others to the temperature of the cooling water in the various units being unavoidably high. It will be noted that where the temperature at the inlet of the purifiers is above 100°F. the amount of tar remaining in the gas is usually excessive, regardless of the apparatus, though this is not an invariable rule. The water-gas plants show higher average temperature at the purifiers than do the mixed-gas plants, and a comparison of the tar contents of the gases shows the average water-gas to contain about twice as much tar per million cubic feet as does the average mixed-gas. Where shavings scrubbers are employed, there seems to be in many cases no regular routine observed in regard to changing the shavings, and the indications are that in some cases they are allowed to remain unchanged too long. The frequency of changes would of course depend upon the tar content of the gas at this point in the system, and this in turn would be affected by the operation of the previous equipment. In one plant at least, notably Plant No. 7, a regular routine is observed, each bushel of shavings cleaning approximately 100,000 cubic feet of gas. It will be observed that the tar entering the boxes amounted to only 9.7 pounds per million cubic feet of gas. That this efficiency had not been realized at all times, however, is indicated by the previous column, which shows that spent oxide from this plant contained a rather high tar content of 4.4 pounds per bushel. On the other hand, some plants which at the time of the test showed high tar, give indications of better past performance, as judged by the analyses of spent oxide. It seems as though regular tests of the gas for tar by a tar camera or other device would be worth while in the better purifying results effected. It is, however, by no means common to find plants which possess the necessary apparatus but seldom use it. This subject deserves more consideration than is ordinarily given to it. It is probably safe to say, in spite of the difficulty in demonstrating to a certainty, that tar interferes with purification efficiency more than any other single cause.

METHODS OF REVIVIFICATION IN USE

Inspection of Tables 3 and 4 is likely to surprise advocates of revivification in place. It will be noted that whereas most of the straight water-gas plants introduce from 1 to 2 per cent of air into the gas prior to purification, the mixed-gas plants with one exception resort to the old method of

revivifying oxide in the open air. Revivification in place has been in use for many years. Its theoretical advantages, especially under the now almost universal heating-value standard, are almost unquestionable. Why then is it not more universally used? One coal-gas operator, when questioned in regard to this matter, stated that his retort settings leaked so that enough air was admitted. Whether the leakage was really air or furnace gases was not demonstrable by any tests made in his plant. Other operators stated that so light a seal was carried on the hydraulic main that air was drawn in every time a retort was opened. While it is perhaps true that there is oftentimes considerable leakage of air or gas into the gas system, this is a most uncertain and doubtful way of revivifying in place, and possesses other disadvantages as well. When the retorts are leaky, it may be inadvisable for the time being to dilute the gas any further, but it would hardly seem reasonable that this uncertain method of introducing air is in vogue in a majority of the coal-gas plants. Other objections to revivification in place are frequently advanced, including the additional cost of enrichment to make up for the inert nitrogen introduced into the gas. Another objection frequently advanced is that the oxide has a tendency to cake very hard when revivification in place is tried. It is probably true that where an attempt is made to completely foul an oxide to its capacity with one handling, the caking will be pronounced, but it is believed that an attempt to carry revivification to this extreme is seldom practiced. Where caking has been found to occur with revivification in place, study should be given to the subject with a view to relieving this condition without abandoning revivification in place altogether. Some operators state that a lack of a proper amount of moisture in the gas is a fruitful cause of caking. An excessive loading of the material with iron, whereby the weight per bushel is greatly increased, might cause trouble, especially in deep beds of oxide. Under such conditions, consideration might well be given to the question whether the extra iron really pays for itself in amount of absorption obtained. It may be that a lighter oxide capable of revivifying rapidly might realize a considerably greater absorption in the long run. The carrier used may also be a factor in the case. If the carrier consists of planer chips, then consideration might well be given to the size of the chips; perhaps the particular size used packs too much, giving a better opportunity for the sulphur deposited during revivification to cement the particles of oxide together. The nature of the carrier is one of the objections which has been presented to the use of blast-furnace slag as a carrier for oxide. It is claimed by some that such oxide is especially likely to mat together, giving a product which is heavy and difficult to handle. It may be that this type of material might be objectionable in some cases.

Another reason why revivification in place is neglected to such an extent may be that it has been tried and that results do not bear out the performance expected. In such cases, it would be well to ascertain to what extent the introduction of air really affected the matter, and whether, as a matter of fact, the results might not have been due to other conditions.

Timidity about introducing air into the gas may be a cause of hesitancy on the part of some operators. It may be feared that the quality of the gas will be unduly affected, and that the general public may learn of the practice and misunderstanding the motive behind it, raise a clamor. There seems little real foundation, however, for such forebodings, as is evidenced by the fact that some of the best-operated plants have used the method for years without serious protest.

Revivification in the off-box was practiced in only one of the plants inspected, namely, in Plant No. 16. The cost of purification in this plant was lower per unit of hydrogen sulphide in the gas than in any other plant. A brief description of the method as applied in this plant may be helpful.

A box is blown shortly after it begins to show foul, as tested by lead acetate paper. At that time the box is usually removing about 60 per cent of the H_2S in the gas (this would, of course, depend a great deal upon the nature of the oxide). The rate of circulation of air through the box is about 2,000 cubic feet per minute (about double the maximum rate of gas flow). The air is blown through the box opposite to the direction of gas flow, just previous to the time of turning off the box. The air is not cooled during circulation, nor is any steam introduced with the air. This was tried at one time but resulted in warping the grids. Temperature observations are taken on the air as it leaves the box. The blowing is continued until a $20^\circ F.$ rise in temperature is observed. At this point the fresh air supply is cut off and the deoxygenated air circulation is continued until a decided drop in temperature is observed. Some trouble from channelling and local heating has been experienced. The oxide is usually removed from the box only twice before final discard. The oxide has a tendency to cake harder with this method than without. Even with such difficulties as are encountered, the superintendent in charge considers it the most economical means of revivification. As has been mentioned in the detailed description of the purifying equipment of this plant previously given, the boxes in which this method of revivification is used are arranged for reversible flow, but there is only one sequence of boxes possible. The superintendent of the plant expresses the opinion that were the sequence of the boxes capable of alteration, together with the reversible flow, it would be possible to blow the boxes before they became very foul and that chan-

nelling and local heating troubles as well as caking of the oxide would be largely avoided.

While this opinion as expressed may be conjecture only, it accords quite well with the conclusions drawn by O. B. Evans in his paper, entitled "Revivification in place", already referred to. It seems likely that the temperature rise during revivification dries out the oxide to a considerable extent and thereby favors caking. Were a surface condenser or other means used whereby the air would become thoroughly saturated with moisture during circulation, it seems likely that the caking would be diminished, since the water-saturated air would have a tendency to keep the oxide moist.

This method variously modified has been used for years by several large gas companies and from the experiences in the plant mentioned above it would seem to merit more attention from Illinois operators than it has received.

Even the practice of revivifying oxide in the open air could be improved in a number of cases. It is not uncommon for a considerable portion of the batch to overheat during revivification in the open, which, of course, has a detrimental effect on the sulphur-absorbing capacity of the material.

Revivification in place seems by far the preferable method. Its advantages might well be studied by those who are not now using it. The writers can do no better than to refer to O. B. Evans' paper, "Revivification in place", presented to the American Gas Association at their October, 1919, meeting. It is believed that the Association can supply copies of this paper for a few cents each.

LACK OF TESTS AND RECORDS

In every plant inspected by the writer, inquiries were made relative to the chemical control of purification practiced and the nature of the purifying records kept. It was rather surprising to learn how few operators really do make any systematic effort to study their purification problem from a technical standpoint. In a majority of plants the lead acetate paper test was the only sulphur test made aside from the total sulphur test on the purified gas, required by the Public Utilities Commission. About half of the plants visited possessed a Tutwiler apparatus, but in several cases the instrument was broken, or the stop-cocks were stuck, and in only one case which we recall were systematic tests made every day. The operators usually had only a hazy idea as to what their various purifiers were doing.

The purifying records were in many cases fragmentary and in a few cases kept on loose sheets of paper. In a few cases a separate oxide batch

record was kept. The usual record showed the amount of gas passed by the first box of each sequence, between changes, and usually the purification of all this gas was credited to the first box. The sulphur content of the unpurified gas often varied considerably from day to day, but this was not taken into account in crediting a particular batch. The assumptions were really made, so far as the records went, that the H_2S content of the gas was uniform, and that the various batches as they came into first position would average up: viz., the first batch would receive credit for more than actual purification to offset the unearned credit given to other batches while they were in first position. In some plants analyses of spent oxides had been made, chiefly to value the oxides for cyanide recovery, and in such cases the sulphur per bushel was reported, but except in such cases, the records showed no figures from which the total sulphur absorption of a batch per bushel could be computed with any degree of accuracy. In the one plant where tests were regularly made and records kept of batch performance, it is interesting to note that the total cost of purification per 100 grains of H_2S in the gas to be purified is lower than in any other plant. In view of the small expenditure of time and equipment to gain this information it seems worthy of more consideration.

COST OF PURIFICATION

The ultimate criterion by which the gas operator judges purification performance in his plant is cost per 1,000 cubic feet of gas purified. So long as the sulphur content of the unpurified gas remains low and purification does not present an undue amount of difficulty from an operating standpoint, the operator is likely to be satisfied, provided the costs are reasonably low. It is when the necessity or advantage of using fuels of higher sulphur content presents itself or when the costs begin to mount that the average operator begins to inquire into purification efficiencies.

The cost figures given in Tables 3 and 4 are averages for 1919. Even a casual inspection of these figures in connection with the load and other conditions in the various plants shows that there is no direct relation between purifier load and purifying costs so far as can be ascertained from a comparison of different plants. Operating methods, size of plant, sulphur content of the gas, cost of labor, facilities for handling oxide to and from the boxes, cost of purifying materials (including freight), all have much influence on purifying costs. The only way to determine the effect of a single factor as purifier load, would be to make an extensive comparison of costs before and after an extension of the purifying system, care being taken to keep all other factors constant. The writers have no data from which any conclusions can be drawn relative to this point.

Inspection of Tables 3 and 4 indicates that the average total purification cost in the mixed-gas plants (average about 25 per cent water-gas) is about one-third higher than the average cost for water-gas plants, but the sulphur content of the mixed-gas averages considerably higher than that of the water-gas plants. Calculated to a basis of sulphur absorbed per bushel of oxide, the cost of mixed-gas purification would probably be considerably lower than that of water-gas purification. The gas operator figures all his operating costs, including purification, to a basis of 1,000 cubic feet. While this is necessary in order to be in harmony with his other operating costs, purification results, especially in different plants, could be better compared on the basis of cost per pound of sulphur (or H_2S) absorbed per bushel of oxide. This could readily be determined from the purifying cost per thousand if the sulphur content of the oxide and the average H_2S content of the gas were known. Regular tests and a form of record such as is suggested in Appendix B of this paper would furnish the necessary information.

The operating cost is of course only a part of the cost of purification. The capital charges on the equipment are just as truly a part of the cost and in some cases they may approach the cost of operation. In making extensions to existing equipment, if greater efficiency of operation is the main thing sought, it is well to inquire whether the total purification cost will be decreased by the added equipment. A concrete example will serve to illustrate this. A certain plant in Illinois has a total annual gas output of about 550 million cubic feet of gas. Its present purifying capacity is 40,000 cubic feet per hour. The maximum hourly production is about 110,000 cubic feet. The purifying apparatus is therefore operating at about 275 per cent of its rated capacity. In spite of this heavy overload, the total purifying operation cost for 1919 was reported as only 0.7 cents per 1,000 cubic feet of gas purified. Great difficulty has been experienced in completely purifying the gas before distribution and therefore the management has let a contract for a new purifier which together with the necessary connections to tie it in with the existing boxes will cost about \$18,000. The capital charges on the old equipment are not known and need not be considered, since these charges will remain as before, even after the new box is installed. Capital charges on the new investment will be about 14 per cent per annum, or \$2,520. This amount will correspond to about 0.46 cents per 1,000 cubic feet of gas purified, which is considerably more than half of the total purifying operating cost per 1,000 for last year. It is obvious, therefore, that unless the purifying operating cost can be reduced to about 0.24 cents per thousand there will be no immediate financial gain from the new installation, though the company will be

relieved from much of the anxiety under which it has been placed. This, while perhaps not expressible in dollars and cents, is worth considering. The purifying operating cost for 1919, namely, 0.7 cents per thousand, is lower than in a majority of plants of the same size, and it is possible that it is not absolutely accurate. There is often considerable difficulty, for example, in equitably distributing the cost of oxide purchased over a proper period of time. That such an error might have been present in this case is indicated by the fact that the purifying materials cost was only 0.2 cents per thousand, about one-fourth that in plants obtaining similar efficiencies. The labor cost, 0.5 cents per thousand, was somewhat higher than the average, as might be expected from the exceptionally overloaded conditions prevailing. The total purifying operation cost was therefore probably nearer 1.3 cents per thousand. The cost of removing, revivifying, and replacing the oxide was probably at least 5 cents per bushel. This would correspond to about 25 changes of oxide per year, or one change every two weeks. The gas purified per change was only about 10,577,000 cubic feet, or 4,800 cubic feet per bushel. The sulphur absorption was therefore only about 0.65 pounds per bushel per change. If the analysis of the spent oxide from this plant is typical of the performance obtained, each batch probably had to be handled about eight times to get an absorption of 5.3 pounds of sulphur per bushel, and the oxide was discarded when it had taken up only about one-third as much sulphur as is usually absorbed in water-gas practice.

The new installation will increase the computed capacity from 40,000 cubic feet to about 117,000 cubic feet per hour. The arrangement will be such that there will be complete flexibility as to sequence of boxes and direction of flow. Other projected improvements should result in bringing gas containing much less tar than heretofore, to the purifiers, so that it will probably be possible to operate with much less handling of oxide. Assuming that each batch could be fouled to 35 per cent sulphur with two changes, this would amount, with the present sulphur content of the gas, to a removal and a replacement of about 7,800 bushels per year. At 5 cents per bushel for handling, the annual labor cost would amount to \$390, or .07 cents per thousand. An average of about 3,900 bushels of oxide would be discarded per year. Assuming the cost of 40 cents per bushel of oxide f. o. b. the gas plant, this would amount to \$1,560 per year or 0.29 cents per thousand. The total purifying operation cost then would appear to be about 0.36 cents per thousand, or about 0.94 cents per thousand less than the probable cost of purification for 1919, or 0.34 cents less than the reported cost. The total cost including capital charges will be about 0.82 cents per thousand. It seems then that after adding capital charges, even

if operation as good as that assumed above is obtained, the company can hardly hope to purify the gas as cheaply as they reported last year. However, even after adding to the operation costs, the capital charges due to the new installation, they will save about 0.48 cents per thousand, as compared with the probable actual costs of operation last year. In arriving at these conclusions, some assumptions have been made which may or may not be accurate, but the example serves to illustrate the nature of the problem which faces the operator who contemplates an extension to his purifying system.

As has been previously mentioned, while extensions are undoubtedly needed in a number of cases, good operation may go a long way to offset insufficient equipment. On the other hand, cases have been observed where it seemed that a much over-size installation gave such a sense of security to the operator that his watchfulness was relaxed and he lost the opportunities for operating economy which his plant facilities would have permitted.

CONCLUSION

Though considerable improvement in purifying conditions in individual cases can be expected by application of the various suggestions which have been made, the process itself has inherent faults which cannot be avoided. It is cumbersome, requires heavy investment, and since it involves the handling of solid material must be costly in operation. Many gas engineers have looked forward to the day when some liquid purification process or some other process of similar theoretical merit would supplant oxide purification. Many such processes have been suggested and more than one has had promise of practicability. The fact remains, however, that millions of dollars are now invested in existing equipment for purifying gas by iron oxide. Oxide purifiers are continually being built to supplement those now in use, and even were a more economical process worked out for purifying gas, the replacement would necessarily be slow; since not all companies would be able to scrap existing equipment at once. Any study which will improve operation with present equipment is therefore worth while. It seems as though the greatest promise of material advancement in oxide purification generally lies in a more thorough knowledge of hydrated oxide of iron itself. Our knowledge of the material and the chemical and physical conditions affecting its performance is incomplete. Research work to bring forth this knowledge is needed. Standard testing methods by which the value of a particular material can be quickly and fairly judged are also needed. Until such studies are made, little radical advancement in the art of oxide purification is to be looked for.

A cooperation for carrying on this work has been entered into by the American Gas Association and the agencies of the Illinois Cooperative Mining Investigations and it is hoped that research work now in progress will solve some of the problems of oxide purification.

APPENDIX A

The Steere Engineering Company¹ formula for gas purifiers:²

$$G = \frac{3000 \times (D+C) \times A}{S}$$

or,

$$A = \frac{G \times S}{3000 \times (D+C)}$$

Where G=maximum amount in cubic feet of gas, corrected to 60°F., to be purified per hour.

S=factor for grains H₂S per 100 cu. ft. of unpurified gas, as given in table below.

D=total depth of oxide through which the gas passes consecutively in the purifier set, and is obtained by multiplying the depth of such oxide per box by the number of boxes in series in the set. Where a single catch box is used for two or more sets, disregard the catch box in obtaining the factor "D".

NOTE:—Duplex boxes, with two layers of oxide each and divided flow of gas, whereby half the gas passes through each layer, present the combined area of the two layers but the depth of one layer only to the passage of the gas. Therefore the area "A" of a duplex box is the sum of the areas of the two layers of oxide or double the cross-section of the box. The depth "D" is the depth of one layer of oxide per box multiplied by the number of boxes, in series, in the set.

A=cross-sectional area in square feet of the oxide through which the gas passes on its way through any one box, in series, of a set.

C=factor, 4 for two-box, 8 for three-box, and 10 for four-box series, respectively.

Where a single catch box is used for two two-box sets, use factor C=6.

3000=assembling constant.

Value of S is:

Grains H ₂ S per 100 cu. ft. unpurified gas	Factor
1000 or more	720
900	700
800	675
700	640
600	600
500	560
400	525
300	500
200 or less	480

¹For detailed explanation see Gas Age, vol. 43, pp. 227, 1919, or Steere Eng. Co., Bulletin No. 37, 1919.

²Reprinted by permission of the Steere Engineering Company.

APPENDIX B

Sample record forms and computations for keeping account of oxide performance and the status of various oxide batches in use:

The following record forms are suggested only as embodying most of the essential features of a record which would give the gas operator a continuous knowledge of the performance of his purifiers. The absorption record is made out for a 3-box series but could of course be modified to suit the conditions in any given plant. The actual figures given are not meant to indicate just what absorptions would be obtained by each box; they are illustrative only. The remarks column could be enlarged to give ample space for other notes, such as when the direction of gas flow in a particular box was reversed. In the case illustrated the clean box is purposely put first and the rotation is backward, the successive sequences being A — B — C, C — A — B, A — B — C. This method might be applicable to any order desired. The time between changes of sequence in the illustrated form has no significance. In some cases several weeks might elapse between changes in sequence and months between refillings of a box. As stated, the illustration only suggests a form which the operator can adapt to his own needs.

Sulphur Absorption Record

Plant..... Month.....19.....

Date	H ₂ S at purifiers inlet— Grs. per 100 cu. ft.		Box A		Box B		Box C		Gas purified for the day Corrected M cu. ft.	Lbs. H ₂ S absorbed			Remarks
	H ₂ S after box. Grs.	H ₂ S removed	H ₂ S after box	H ₂ S removed	H ₂ S after box	H ₂ S removed	Box A Batch 1	Box B Batch 2		Box C Batch 3			
1	125	20	105	10	10	10	0	10	2200	330	31	31	Order ABC
2	130	25	105	20	5	5	0	20	2120	318	15	60	
3	100	35	65	5	30	30	0	5	2272	211	97	13	
4	105	25	75	5	20	20	0	5	2310	248	16	248	
5	110	40	70	10	60	60	0	10	2005	200	29	29	
6	90	50	40	30	20	20	0	30	2736	172	78	117	
7	135	55	80	10	45	45	0	10	2500	286	110	36	
8	120	10	10	10	10	10	0	100	2234	32	32	320	
9	105	5	10	0	5	5	0	15	2365	34	17	306	
10	95	5	5	0	5	5	0	17	2340	17	17	283	
11	120	5	20	0	5	5	0	25	2379	68	17	322	
12	100	10	20	0	10	10	0	30	2480	71	35	245	
13	125	15	20	0	15	15	0	35	2680	76	57	342	
14	100	5	40	0	5	5	0	45	2369	135	17	187	
15	95	15	30	0	15	15	0	50	2385	58	29	170	
16	90	0	5	15	5	5	0	10	2465	18	270	36	
17	125	0	10	25	100	100	0	15	2542	36	363	54	
18	105	0	5	20	20	20	0	15	2434	17	290	51	
19	100	0	15	35	75	75	0	20	2505	54	36	36	
20	110	0	15	35	75	75	0	25	2675	57	285	76	
21	110	0	10	35	75	75	0	35	2430	35	260	87	
22	95	0	5	40	55	55	0	35	2395	17	187	119	
23	100	0	5	45	55	55	0	40	2480	18	198	144	
24	90	0	15	50	40	40	0	15	2562	55	146	125	
25	105	50	55	15	35	35	0	15	2635	208	132	37	
26	110	55	52	10	45	45	0	10	2620	206	108	37	
27	115	70	45	15	58	58	0	15	2720	214	114	58	
28	130	75	53	15	60	60	0	15	2651	206	225	56	
29	95	Off	Off	15	80	80	0	15	2525	.....	288	54
30	100	15	85	10	5	5	0	10	2410	Batch 4 293	17	34	
31	115	20	95	5	15	15	0	5	2320	314	50	17	
Totals									75734	Batch 1— 3341	4203	3521	
										Batch 4— 607			

NOTE:—The pounds of H₂S absorbed daily by each box are computed by multiplying the grains of H₂S removed by the box by 10 times the corrected volume of gas passing through the system and dividing the product by 7000.

Where a box is emptied during the month, the total absorption by that batch during the month up to the time of emptying could well be entered in the column, preferably in red ink. Likewise the number of the batch substituted for the batch removed should be entered in the same column ahead of the daily entries. The total absorption by each batch while in a box is entered in the batch record, a suggested form of which follows:

Batch Record

Batch No. 1 Kind of oxide. *Natural* Bought from.
 Date purchased. 1-3-20 Wt. oxide per bu. 25 Price per bu. (on ton). \$20 ton
 No. bushels in batch. 2500 Wt. new sponge per bu. (air dried). 35

Date put into purifier	Box No.	Date taken out of purifier	Pounds H ₂ S absorbed	Equivalent lbs. sulphur	Lbs. sulphur per bu. oxide	Remarks
1/12/20.	A	7/6/20.	23500	22100	8.85	
8/1/20.	C	2/15/21.	23000	21600	8.65	
3/16/21.	4	8/17/21.	20000	18820	7.54	41.0% sulphur
9/30/21.	B	2/25/22.	18000	16900	6.76	
3/15/22.	C	6/20/22.	8000	7540	3.01	Batch dis- carded
Totals.			92500	86960	34.81	

% sulphur in spent oxide 49.5 % tar in spent oxide. 2.0
 % cyanides.

NOTE:--If laboratory facilities are available, the percentage of sulphur in the oxide could be checked each time before the batch was returned to use. This would give more accurate total results than the sum of the Tutwiler tests, though the latter are very useful in enabling the operator to know at all times the condition of his purifying material. The sulphur equivalent to a given weight of H₂S is found by multiplying the latter by 16 and dividing the product by 17. The batch throughout its usefulness should be accompanied by a batch number, preferably of metal, which is laid on the box cover or otherwise significantly placed while the batch is in the box and is stuck into or laid upon the batch while the latter is revivifying out of doors. The use of such a number will avoid mistakes as to the identity of a given batch.

The above forms could of course be printed in book form or made up as desired. The absorption record would require a page per month, while the batch record might well occupy a page per batch. The number of entries per batch would depend upon the practice in a given plant. Ordinarily one would not expect to handle a batch more than four or five times, perhaps less, but there are conditions which make many more handlings necessary. Any space remaining on the page after the entries might well be devoted to an extension of the remarks giving some information relative to the operating methods employed, rapidity of the material as to fouling and revivification, presence or absence of tar, fineness of the material before and after use, caking, etc. Also, if any laboratory tests of the material had been made prior to or during use, the agreement of these tests with practical results observed might eventually be valuable.

APPENDIX C

Determination of the further usefulness of a given batch of oxide, according to the formula¹ of Fulweiler and Kunberger:²

Average cost of purification	=A¢ per M cu. ft. of gas
Cost of new oxide	=B¢ per bushel
Residual value of old oxide	=C¢ per bushel
Cost of removing, revivifying, and replacing	=D¢ per bushel
Gas already purified by one bushel	=E thousands of cu. ft.
Number of times oxide has already been used	=F times
Average H ₂ S content per M cu. ft.	=G pounds
Weight of one bushel of oxide	=H pounds
Per cent of H ₂ S removed by test	=I per cent
Capital charge per M cu. ft.	=J¢ per M

Then

$$A = \frac{(B-C) + (F \times D)}{E} + J$$

But J is a constant (practically for such a problem) that does not affect this calculation, so we may write it:

$$\text{Operating cost} = (A - J) = \frac{(B-C) + (F \times D)}{E}$$

The question then, whether or not it will pay to use a batch again with any given absorption test I, depends upon whether

$$\frac{(B-C) + (F \times 1)D]}{E + \frac{H \times I}{G}}$$

is equal to; greater than; or less than the average (A-J). For the sake of a numerical example, let us assume that

$$\begin{aligned} (A - J) &= 1.0¢ \\ B &= 35.0¢ \\ C &= 0 \\ D &= 5¢ \\ E &= 40. \text{ (M cu. ft. of gas)} \\ F &= 4 \text{ times} \\ G &= 0.25 \text{ lbs.} \\ H &= 50 \text{ lbs.} \\ I &= 5\% \end{aligned}$$

Then

$$(A - J) = \frac{(35 - 0) + (5 \times 5)}{40 + \frac{(50 \times .05)}{.25}}$$

¹Used by permission of W. H. Fulweiler.

²Some of the physical characteristics of ferric oxide: Proc. American Gas Institute, 1913, Vol. 8, Pt. I, p. 476.

so that using this batch would increase the average cost considerably. To get the minimum economical percentage that would just equal the average cost, we have—

$$I = \frac{G}{(A-J) \times H} \left\{ (B-C) + [(F+1) \times D] - [(A-J) \times E] \right\}$$

Substituting the assumed values we obtain—

$$I = \frac{0.25}{(1 \times 50)} \left\{ (35-0) + [(4+1) \times 5] - (1 \times 40) \right\}$$

I = .10 or 10%

In applying the above formula part of the information is known and the remainder may be obtained by test. For example, the monthly cost statement, if carefully prepared and correct, will give the value (A—J), viz., the purifying operating cost (includes purifying labor and purifying supplies per M). Invoices for purifying material purchased plus freight and handling into storage give the value B when figured per bushel. The value of C will be 0 in many cases, but if the oxide is sold or used in such a way that a money value can be assigned to it, then the value per bushel can be readily obtained. D may be estimated by keeping careful account of the cost of emptying a box, handling the oxide during revivification, and putting back in the box, and dividing by the number of bushels so handled. The value of E is not so definite, since a particular batch may be credited with some work done by other batches. If the plan for keeping account of oxide performance suggested in the text of this paper and illustrated in Appendix B is followed, no difficulty should be experienced, since the average H₂S content of the gas (in pounds sulphur per M) as recorded, divided into the pounds of sulphur absorbed per bushel by the oxide, will give the thousands of cubic feet of gas already purified. Or, if an analysis could be made for sulphur content of the oxide, the number of cubic feet of gas of average H₂S content corresponding to the sulphur per bushel could be readily computed. For example, assume that the air-dried oxide averaged 30 per cent sulphur, and that oxide weighed 50 pounds per bushel, the sulphur per bushel would be .30 × 50 = 15 pounds.

15 pounds = 105,000 grains of sulphur, or

$$\frac{105,000 \times 34}{32} = 112,000 \text{ grains H}_2\text{S.}$$

If the average H₂S content of the gas is 100 grains H₂S per 1 cu. ft., then this gas purified by the oxide per bushel is

$$\frac{112,000}{1} = 112,000 \text{ cu. ft.}$$

The number of times the batch in question has been used, *F*, can also be quickly ascertained from the batch record as illustrated in Appendix B. *G*., the average H_2S content per *M* cu. ft. can readily be obtained from the record referred to over any period of time. The average content in grains per 100 cu. ft. is multiplied by 10 and the product divided by 7,000 to convert grains to pounds. The weight per bushel of oxide, *H*., can probably be obtained with sufficient accuracy by spreading out and air-drying a bushel of oxide made up from samples taken from all parts of the batch and then weighing on a good scale. The value of *I* has to be obtained by a laboratory test. The apparatus employed (aside from a chemical balance, which is essential) is shown in the accompanying sketch, Figure 5.

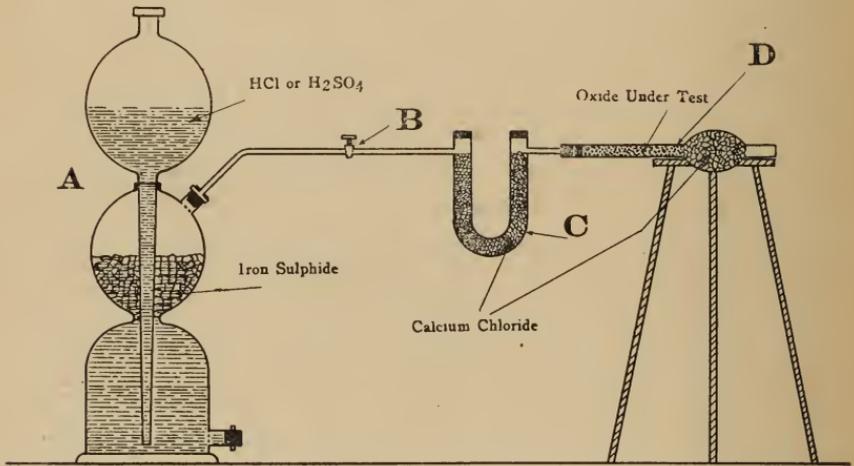


FIGURE 5—Kunberger apparatus for testing oxides for gas purification. A is a Kipp gas generator. B is the stop cock controlling the generation and flow of gas. C is the drying tube. D is the tube containing the oxide under test and calcium chloride for absorbing the water liberated.

In the sketch, A is Kipp gas generator made of glass in which H_2S is generated by the action of hydrochloric acid or dilute sulphuric acid on ferrous sulphide. The generation and flow of gas is controlled by the stop-cock B. The U-tube C contains granulated fused calcium chloride to dry the H_2S . The calcium chloride tube, D, contains in the straight part of the tube, 5 grains of the oxide to be tested, mixed with about 2 grains of coarse sifted sawdust, followed by granulated fused calcium chloride in the bulb of the tube. Little wads of glass wool are placed in the ends of this tube and between the oxide and the calcium chloride to retain the materials in their proper places and prevent any from dropping out while weighing. Where sponge, viz., mixed oxide, is to be tested, no sawdust is mixed with

the samples. A coarsely ground sample of the sponge is used. Care must be taken to get a truly representative sample.

After the tubes are filled, D is weighed on a chemical balance. Then it is connected to the apparatus, as shown, and dried. H_2S is passed through it slowly for one hour. During the reaction H_2S is decomposed by the oxide and water is formed. The water formed is retained by the calcium chloride in the bulb of the tube therefore, the gain in weight of the tube during the time gas is passing through the tube is the weight of the H_2S absorbed, and the percentage is computed by dividing this gain in weight by the weight of the sample taken for test.

