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BROWN, H.R.   1 OF 1

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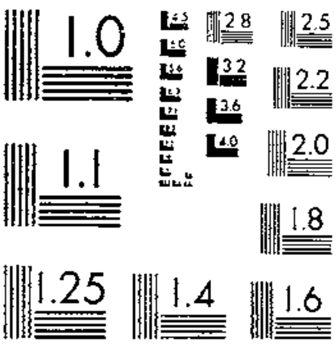

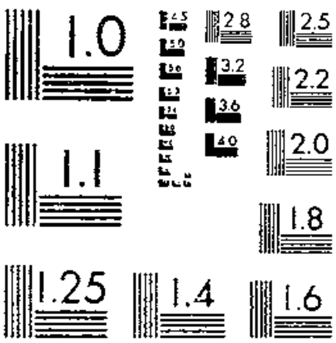

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

THE VALUE OF INERT GAS AS A PREVENTIVE OF DUST EXPLOSIONS IN GRINDING EQUIPMENT

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CONTENTS

INTRODUCTION

The records for a 20-year period show that in feed-grinding plants alone the 30 principal explosions caused the loss of 60 lives, injury to 118 persons, and property damage amounting to approximately $5,000,000. The fact that 18 of these 30 explosions originated in the grinding equipment, where it was impossible to prevent the formation of dust clouds or eliminate sources of ignition, the two known methods of dust-explosion prevention, together with the knowledge that feed grinding was only one line of industry where the hazard existed, focused attention on the need for a method of preventing dust explosions which could be used where grinding machinery was operated.

[1] A. C. Gerlach, formerly of the Bureau of Chemistry, was responsible for much of the preliminary work of selecting and obtaining suitable equipment for the plant. R. M. Baker, of the chemical engineering division of the Bureau of Chemistry and Soils, designed the building for the experimental plant and assisted in the installation of equipment and also in giving many of the demonstrations. P. W. Edwards and R. W. Harrison, of the chemical engineering division, made analyses of gas samples to check the results obtained with the Orsat apparatus at the experimental plant. W. C. Beckner erected much of the equipment and attended to the mechanical operation and care of the plant during the period of the tests. The attrition mill was lent by Sprout Waldron & Co., Muncy, Pa. Oat hulls used in the tests were furnished by the Quaker Oats Co., Chicago, Ill.

The fact that inert gas would extinguish fires directed attention to the possibility of using it to prevent fires and resulting explosions. The experimental work described in this bulletin was undertaken to show that it is practicable to use inert gas to prevent dust explosions in feed-grinding equipment.

EARLY INVESTIGATIONS

During 1913 and 1914, engineers in the United States Bureau of Mines and the Bureau of Chemistry of the United States Department of Agriculture investigated the use of inert gas as a means of preventing dust explosions in grain-handling plants and designed an inclosed system for grinding and conveying grain in an atmosphere containing sufficient carbon dioxide and other inert gases to prevent explosions (*11*).[2] From the records now available it appears that inert gas had been used in at least one industrial plant in this country before 1913. In this plant carbon dioxide was employed to render inert the atmosphere in which sulphur was ground. This equipment was probably in operation as early as 1909, but at that time it was considered a trade secret, and no information concerning it was published. Late in 1914, while studying methods of using inert gas to prevent explosions, an engineer of the Bureau of Chemistry inspected the equipment in this plant and found it operating satisfactorily.

Laboratory experiments had been conducted in the Bureau of Chemistry to determine the conditions necessary to prevent explosions of grain dust of various types. These experiments (*3*) showed that grain dust would not explode in an atmosphere containing 12 per cent of oxygen, or less, provided the remainder was inert gas. For some grain dusts a higher percentage of oxygen could be used without danger of an explosion, but 12 per cent was recommended.

In order to check the laboratory results, large-scale tests were made at a plant where full-sized factory equipment could be used. A reel, screw conveyors, bucket elevator, and storage bin were arranged so that they could be closed tight and carbon dioxide could be admitted while the product was circulating. Cornstarch or dextrine circulated in this system did not explode when the atmosphere contained less than 14 per cent of oxygen and the remainder was inert gas (*12*). In view of the fact that the laboratory conditions might sometime exist in the plant, it was considered advisable to continue to recommend an atmosphere containing 12 per cent oxygen as the safe atmosphere in which to grind all grain products.

Later laboratory work with sulphur and hard rubber, reported by Frevert (*5*), showed that it was necessary to reduce the oxygen content of the atmosphere to 8.5 per cent, with the remainder consisting of inert gas, in order to prevent explosions of sulphur; an atmosphere containing 13 per cent oxygen and the remainder inert gas prevented explosions of hard-rubber dust.

As a result of the early experiments and recommendations several industrial plants installed inert-gas systems. They were principally hard-rubber grinding factories and sulphur-grinding mills. None was installed in grain-handling plants.

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[2] Italic figures in parentheses refer to Bibliography, p. 23.

PRELIMINARY STUDIES

In considering the use of inert gas to prevent explosions in feed-grinding equipment, it was found that few data were available on the quantity and quality of inert gas necessary, and methods of introducing the gas into the feed-grinding equipment. Accordingly, experiments to obtain these essential data were planned.

Before the proposed investigations were begun, however, an effort was made to obtain all information on the uses of inert gas which might in any way have a bearing on the experiments to be conducted. Demonstrations of inert gas extinguishing cotton fires were witnessed, and the plans of other engineers for the use of inert gas in dust-explosion prevention were considered. Data were obtained from companies who were using inert gas in solvent-recovery work, and equipment employed for this purpose was inspected. Methods employed for obtaining and handling the inert gas were studied, and information was obtained concerning changes which had been made either because they were necessary or because it was thought they would improve operating conditions. Conferences were held with a number of persons interested in the use of inert gas, including officials of sulphur companies employing this method of preventing explosions during sulphur grinding and officials of a company that manufactures sulphur-grinding equipment in which provision is made for the introduction of inert gas.

These preliminary studies indicated the need of experiments with factory-size equipment to check the laboratory results and to demonstrate the feasibility of using inert gas to prevent explosions during feed grinding. It was considered advisable, therefore, to erect an experimental feed-grinding plant, both to obtain information concerning the quality and quantity of inert gas necessary to prevent explosions and to demonstrate to feed manufacturers that, if properly used, inert gas would invariably prevent dust explosions.

THE EXPERIMENTAL PLANT

BUILDING

As it was desirable to have the testing plant near a boiler house in order to show the ease with which a supply of inert gas could be obtained from such a source, a site for the plant was selected close to the boiler house at the United States Department of Agriculture experiment farm, Rosslyn, Va.

The building (figs. 1 and 2) designed to house the machinery and material was a two-story structure of corrugated iron on a wooden framework. It was large enough to hold the grinding mill and other necessary equipment on the upper floor, and had space for motors, drive shaft, and elevator boot on the lower floor.

Figure 1 shows the general features of the building, as well as the location of the equipment. Figure 2 shows the completed building.

DESCRIPTION OF EQUIPMENT

As most of the equipment in the experimental plant was standard, only a brief description of it is necessary.

A standard 24-inch double-runner attrition mill was used for both the tests and the demonstrations.

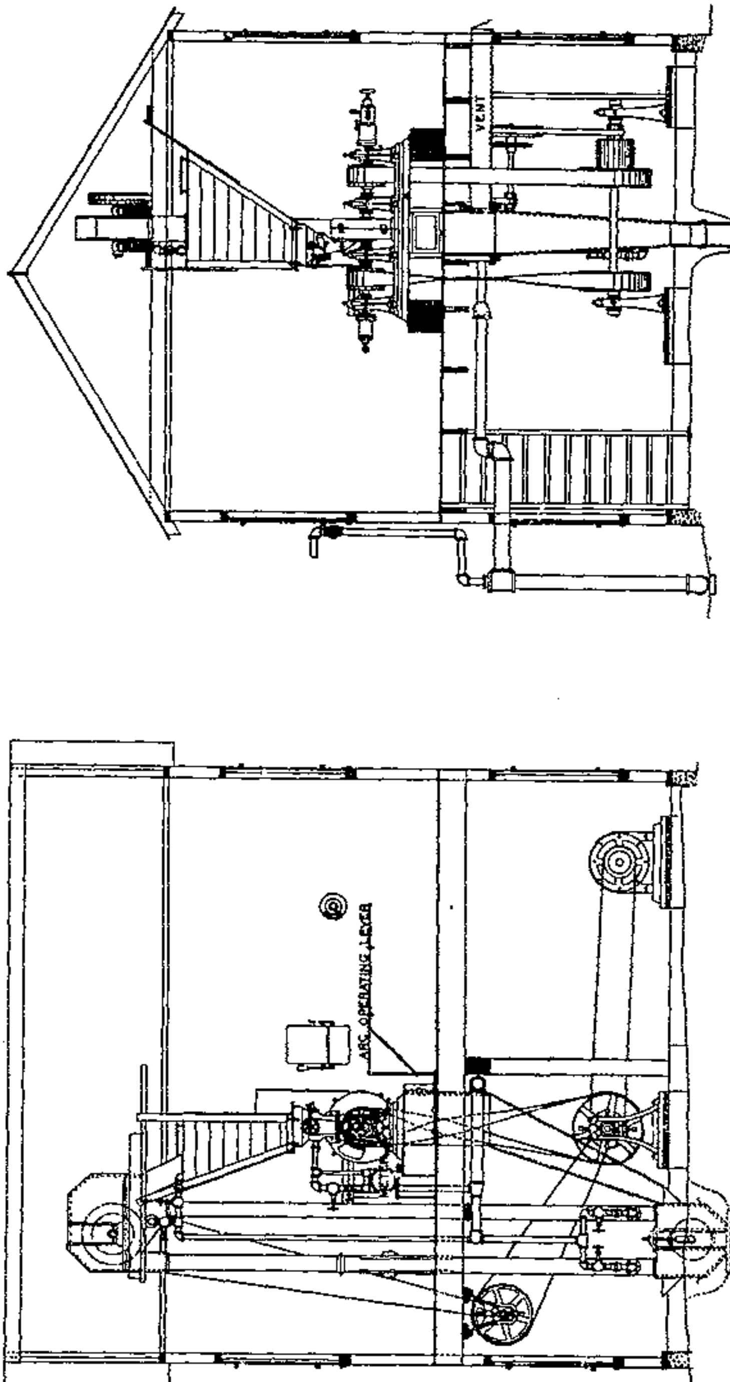

FIG. 1.—Experimental mill using inert gas for the prevention of dust explosions

The elevator selected was of the all-metal type having head, boot, and legs of galvanized sheet iron, reinforced with angle iron. The belt was of 6-inch woven cotton and had buckets about 16 inches apart. The elevator measured 18 feet from the center of the head shaft to the center of the boot shaft.

The blower was of the high-pressure type having a number of blades or paddles which slide in and out of slots in a central drum in order to follow the contour of the eccentric shell in which they and the central drum revolve.

A 25-horsepower 25-cycle 220-volt induction motor, running at 750 revolutions per minute, operated the mill and the elevator. A 3-horsepower 220-volt alternating-current motor drove the blower. It ran at 1,400 revolutions per minute, but pulleys of different sizes

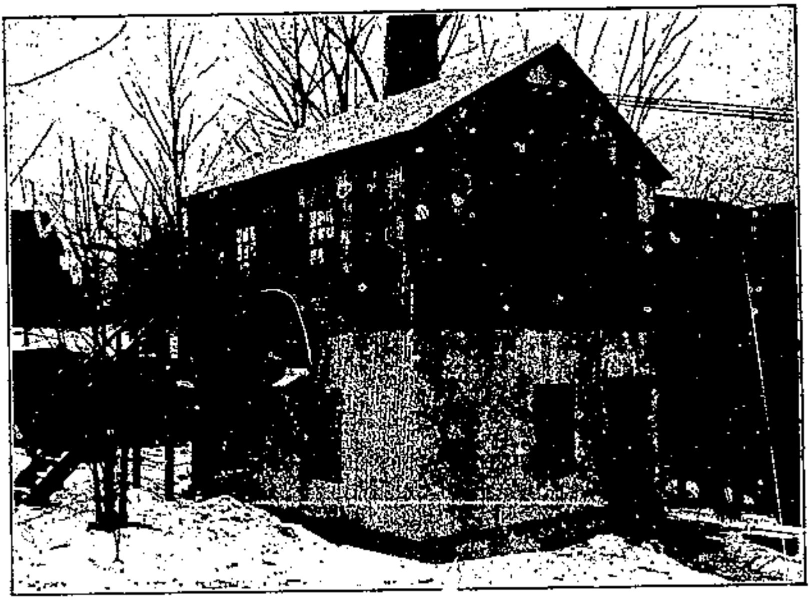

FIG. 2.—Building erected to house the equipment used in the experiments to determine the value of inert gas as a means of preventing dust explosions in grinding equipment

reduced the speed to that required to operate the blower about 250 revolutions per minute.

The meter in the milling system was of the dry type similar to that used in households and had a capacity of 165 cubic feet per hour.

To carry the gas from the boiler to the mill, pipe most readily available was used. Five-inch iron pipe was used for the main supply line, which was laid directly on the ground from the boiler house to the experimental plant. A much smaller pipe would have served as well. Inside the experimental plant, 3-inch and 1½-inch iron pipes distributed the gas to the various injection points. Standard globe valves controlled the flow of gas in the various pipe lines.

The equipment for the electric arc consisted of one fixed and one movable carbon holder, made up of pipe fittings, and a rheostat to regulate the current producing the arc.

At first the gas in the milling system was drawn from the breeching between the chimney and a battery of four horizontal tubular boilers which supplied low-pressure steam for heating the buildings and greenhouses on the farm. Later a change was made, and gas was drawn from a small vertical tubular boiler in one corner of the boiler house. This boiler, which produced low-pressure steam, was fired throughout the year, and offered a more dependable supply of gas, since the others were fired or shut down according to the heating requirements.

INSTALLATION OF EQUIPMENT

The blower and the motor to drive it were placed on concrete bases close to the boiler house, and inclosed with sheet metal to protect them from the weather. A pipe connection was made between the blower and the boiler breeching, and a pipe line was laid from the blower to the building. The attrition mill was placed on the upper floor of the building, and the bucket elevator was assembled and erected.

Metal-lined wooden hoppers were constructed above and below the mill to store material to be ground and to collect the feed. Provision was made to circulate and regrind the feed by having the bucket elevator, which received the stock below the mill, elevate and discharge it into the hopper above the mill.

The motor which was to operate the mill was put in the lower story of the building and belted to a jack shaft directly below the attrition mill. An extra pulley on the jack shaft was belted to another small shaft, from which the bucket elevator was driven.

Various points on the attrition mill, elevator, and hoppers were connected with the main supply pipe which brought the inert gas from the boiler house. Valves were placed on all lines in order to regulate the quantity of gas going to any point.

Carbon holders and the necessary equipment for an electric arc to ignite the dust cloud were provided directly below the attrition mill, and a window was placed in the front of the compartment so that the operation of the arc could be observed. The starting boxes and switches for the main motor, the motor operating the blower at the boiler house, and the electric arc were placed on the main floor of the building, where they would be readily accessible. Figure 3 shows the arrangement of this equipment.

A metal-lined wooden spout, or duct, was constructed from the hopper under the mill to the outside of the building to provide for the venting of pressure should an explosion occur within the system. A wooden frame, covered with heavy paper, was fitted into the vent opening where the duct entered the hopper below the mill, to form a seal and retain the inert gas within the system as well as to prevent the escape of dust from the hopper into the duct. The outer end of the duct was covered with a metal flap, to keep out rain and snow.

When all the equipment had been set up and connected, several test runs were made for the purpose of determining how efficiently all parts were operating. As a result of these test runs several changes in the equipment were found necessary.

Since too much gas was being forced into the milling system a by-pass around the blower was provided. Valves in the by-pass permitted the flow of only the required quantity of gas. A waste pipe having a valve that could be operated from within the building was connected with the main supply pipe where it entered the mill building. With the valve at the blower set to deliver the desired quantity of gas it was possible to use the valve on the waste pipe to increase or decrease slightly the quantity entering the mill, and in this way to regulate the percentage of inert gas in the system. A gas meter was put in the pipe line running to the attrition mill to provide means of determining the quantity of flue gas admitted, and taps from which samples could be drawn were inserted at various points in order that gas in any part of the system might be analyzed. The diagrammatic sketch (fig. 4) shows the general arrangement of the equipment in the plant.

SAMPLING AND ANALYZING THE GAS

It was considered especially important in conducting these tests to secure a uniform distribution of gas throughout the system, since it

FIG. 3.—Interior view showing some of the equipment used in the experiments with inert gas as a means of preventing dust explosions during feed grinding

might prove disastrous to start an explosion in an atmosphere just capable of supporting combustion and have the small flash propagate into an area or pocket where the percentage of inert gas was lower, thus producing a higher pressure than was expected. Accordingly, provision was made for collecting samples at a number of points. Openings through which samples could be drawn were made in the base of the mill, in the hopper, in the feed bin, in the elevator boot, in the elevator head, in both the up and the down leg, in the pipe line entering the building, and at the boiler.

Orsat apparatus of a standard type was used for the gas analysis. In taking a sample the usual method followed was to attach one end of a rubber tube to the intake of the apparatus, and insert the other end of the tube through the opening in the mill, hopper, elevator, or wherever it was desired to take a sample. After enough gas to clear the tube had been drawn and wasted, a 100 c. c. sample of gas was drawn into the Orsat. It was analyzed by being passed through pipettes containing potassium hydroxide, alkaline pyrogallate solution, and ammoniacal cuprous chloride solution, which absorbed in turn the carbon dioxide, oxygen, and carbon monoxide. The number of cubic centimeters of each gas absorbed represented that part of the 100 c. c. in the apparatus or the percentage of that particular gas in the original sample. At intervals samples of gas were drawn into bottles from the same source and at the same time that the sample was drawn into the apparatus. These samples of gas in sealed bottles were taken to the laboratory where they could be analyzed more carefully and more accurately on a more sensitive apparatus, and the results were compared with those obtained with the Orsat at the plant.

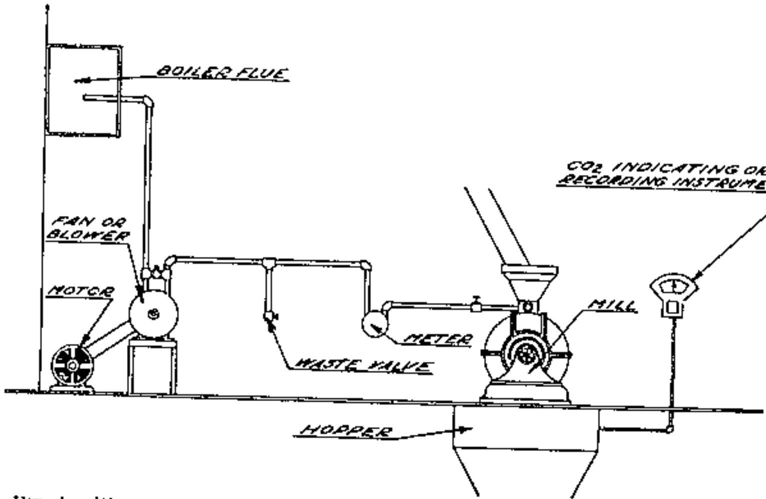

FIG. 4.—Diagrammatic layout of equipment used to provide inert gas for feed mill

PRELIMINARY TESTS

Before the tests to determine the quantity of gas required to prevent explosions in the milling system under various conditions were begun, several series of preliminary tests were made to determine the quality of gas produced by the boiler, the quantity which the blower could handle, the velocity of the gas in the pipes, the best method of obtaining uniform distribution of the gas in the system, the proper regulation of the feed being ground, and the natural suction and drafts created by the mill when in operation.

As soon as the mechanical equipment was operating satisfactorily, tests were made to determine the quality of gas produced by the boiler. The analysis of the samples of gas collected at the boilers under different weather conditions and different firing conditions also served to check the operation of the Orsat apparatus. It was found that the carbon-dioxide content of the gas coming from the boiler ranged from 8 to 12 per cent.

When it was found that the supply of gas obtained from the boilers was sufficiently high in carbon-dioxide content to be utilized as the explosion-prevention medium in the feed mill the quantity of gas which should be delivered to the mill through the blower and pipe line was determined. The given capacity of the blower according to the free-air rating was 74½ cubic feet per minute. With this figure and the known cross-sectional area of the 5-inch pipe through which the gas was delivered the velocity in the main supply line was calculated to be 546 feet per minute. An anemometer fitted into the supply pipe indicated an average velocity of 537 feet per minute. It was assumed, therefore, that the blower was delivering gas at approximately its rated capacity. This quantity of gas was too large, however, for a milling system of this type, especially since all joints had been made as tight as possible. Recirculating the feed also helped to make unnecessary such a large quantity of gas. Moreover, it was objectionable because its escape from the few openings available in the milling unit would carry quantities of dust out into the atmosphere of the room where it would be necessary for employees to work. Accordingly, the valve in the by-pass around the blower was opened so that only a part of the output of the blower was delivered into the pipe. The remainder was recirculated. This method made it possible to control the gas so that the quantity entering the mill was only slightly more than enough to take care of the natural leakage.

In addition to the analyses made at the boiler house, samples of gas drawn from the main supply pipe and various points in the milling system were analyzed for the purpose of comparison and to determine how uniformly the gas was being distributed. The gas in the main supply pipe differed very little from that at the boiler, but slight differences were noticed in the samples of gas drawn from different parts of the inclosed unit at the same time. An attempt was made to regulate the flow of gas in the branch pipes so that uniform readings could be obtained at various points, but it was soon found that the early discrepancies were owing to differences in temperature and that the gas could be distributed uniformly without regulating the valves. In fact, it was possible to distribute it uniformly by closing the valves in all pipes except the one leading to the hopper of the grinding mill. In this particular system the gas admitted at the mill hopper mingled with the feed and was circulated throughout the system, producing a uniform mixture of air and gas.

Owing to the frictional heat produced by the mill during grinding, the temperature within the mill was much higher than elsewhere. Almost all the tests were made in cold weather, when there was an appreciable difference between the temperature inside and outside the mill. It was necessary therefore to allow for the difference in temperature between the place at which the sample was taken and the place at which it was analyzed, or to establish uniform conditions before making the analysis. When the Orsat apparatus was used such precautions were necessary, since often there was a difference of 70° F. between the temperature inside and outside the mill. As the volume of a gas under constant pressure is proportional to its absolute temperature, a 100 c. c. sample collected at the mill where the temperature was 100°, would decrease in volume to 87.8 c. c. at the outside temperature of 32°, and the number of cubic centimeters of the various constituents indicated by the analysis would not be that part of 100 c. c., but a part of the volume to which the original 100 c. c.

sample contracted during the test. This condition was controlled by water-jacketing the measuring tube of the Orsat apparatus and by allowing samples of gas taken at various points to cool to a uniform temperature before the analysis was made. In making the explosion tests, however, it was desirable to attempt to ignite the dust as soon as possible after drawing the sample. Accordingly, two samples were taken, one to be analyzed at once, to obtain an approximate idea of the quantity of gas present, and another to be analyzed when better control of conditions was possible.

A sufficient number of samples were analyzed to indicate the approximate proportions of the various component parts of the gas being used, but only the carbon-dioxide content was determined immediately before an explosibility test was made. The percentage of the other gases was either estimated or determined afterwards. In this way the operator was assured just before making an ignition test that sufficient inert gas to prevent a serious destructive explosion was present, and the time between taking the sample and making the ignition test was so short that the possibility of a change in the quality of the gas was reduced to a minimum.

Regulation of the feed entering the mill was one of the factors requiring attention. When gas was entering the inclosed unit through the feed-hopper connection only, it was found that the natural suction of the mill increased in proportion to the quantity of feed entering. Accordingly, when the feed was heavy a larger quantity of gas was drawn in, and a higher carbon-dioxide content was obtained within the system. These observations indicated the possibility of dispensing with the blower in some systems and utilizing the natural suction of the mill to draw in the required quantity of inert gas. In this particular system, however, the boilers were connected with high brick chimneys, and the suction of the mill was not able to overcome the natural chimney draft sufficiently to obtain the required quantity of gas. Tests conducted while the blower was not operating and with the by-pass open to form a direct connection between the boiler and the mill showed that the suction and natural draft balanced within the pipe line near the mill, and the mill was able to obtain gas only intermittently as the balance point fluctuated back and forth within the pipe.

Anemometer and manometer readings showed that the velocity or pressure of the gas in the distributing pipes had little or no effect on the distribution of the gas within the milling system. The natural drafts created by the operation of the mill and the bucket elevator as well as the passing of the feed through the spouts and hoppers served to mix thoroughly and distribute through the milling system the gas introduced into the mill at the breather just below the feed hopper. As a result of these tests it is felt that when necessary or desirable inert or flue gas could be forced for considerable distances in small pipes under pressure instead of low-pressure fans and large-diameter wind trunking being used, as is now the custom. The pressure could be reduced before the gas entered the milling equipment or the gas could enter at the higher pressure, provided it had no disturbing or injurious effect on the process or the material.

After the preliminary tests showed that the plant was operating as desired and a sufficient number of gas analyses and check tests had been made to assure the operator that the quantity and quality of gas within the mill could be fairly well controlled, tests were started to determine the point at which just enough gas to prevent an explosion was present.

EXPLOSIBILITY TESTS

In making the explosibility tests a record was kept of the temperature inside and outside the plant, the barometer reading, and the wet and dry bulb readings. Special attention was given to these conditions when explosions were produced in order to determine what effect, if any, such factors would have on dust ignitions.

As earlier laboratory and small-scale tests had shown that oat, corn, or wheat elevator dust is not explosive when suspended in atmospheres containing from 14 to 14.5 per cent oxygen, the first attempt to ignite the oat-hull dust within the mill was made when the gas analysis showed 8.2 per cent carbon dioxide and 12.5 per cent oxygen in the mill. It would not ignite. Later, when the mill had been grinding for some time and more fine dust was being circulated, a still lower oxygen percentage was obtained before an attempt was made to ignite the dust. Several tests were made when the analysis of gas samples collected from the chamber below the mill showed that they contained approximately 9 per cent carbon dioxide and 11.5 per cent oxygen. Although the electric arc was probably a more certain and a more intense source of ignition than would be found in actual practice, the dust did not ignite.

Then began a series of tests in which the quantity of flue gas entering the mill was gradually reduced, and consequently the oxygen percentage of the atmosphere within the inclosure was increased. These tests were continued until the carbon-dioxide content had been reduced to 4.2 per cent and the oxygen increased to 16.5 per cent, when an ignition and slight concussion followed the lighting of the electric arc. The base of the mill filled with flames, smoke or dust was forced from cracks in the equipment, and the cover of the opening on top of the feed hopper above the mill was lifted partly off.

Additional series of tests were made from time to time under different weather and operating conditions. Each time the mill was filled with inert gas until the oxygen percentage was reduced to a point at which it was known no ignition could be produced. Then while attempts were being made to ignite the oat-hull dust the oxygen percentage was allowed to increase gradually until it reached the point where an explosion occurred.

A sample of gas was drawn, and at least the carbon-dioxide content was determined before each attempt to produce an explosion. As the critical point was approached samples of gas were taken in bottles to be analyzed more accurately in the laboratory, and the results were checked against the results obtained with the Orsat apparatus at the plant. Hundreds of analyses were made.

About 50 explosions took place in the mill. It was not possible to start an explosion when the oxygen had been reduced to 15 per cent. In a few cases the dust ignited when the oxygen content was 16 per cent, and explosions resulted almost invariably when 17 per cent of oxygen was present. It should be remembered, however, that these figures apply only to the grinding of oat hulls under the conditions and with the equipment described. It is not intended that they should be taken as an indication of the condition under which other products could be safely ground in equipment of different types. In fact, 12 per cent oxygen, which was recommended as a result of the early laboratory tests already referred to, should be used to insure 100 per cent protection. The fact that no explosions were obtained in the mill when the oxygen content was less than 16 per cent would indicate that the most favorable conditions for an explosion did not exist at the time the ignition test was made. The degree of fineness of the dust, the moisture in the dust, the percentage of volatile matter it contains, and the density of the dust cloud are factors which must be considered in determining explosibility. Undoubtedly the fluctuations in the volume of feed passing through the mill and the intermittent operation of the plant had some effect in producing conditions unfavorable for an explosion.

From a study of the temperature and barometric readings taken at the time the explosion tests were conducted it appears that weather conditions have little or no effect on the explosibility of material being circulated within the milling system, provided the operating conditions are uniform. With the mill operating at constant speed and with a regulated flow of feed through the plates a temperature of about 100° F. was maintained in the chamber directly below the mill.

DEMONSTRATIONS

A series of demonstrations to acquaint manufacturers and users of grinding equipment with the possibilities of inert gas for explosion protection were given. The demonstrations were attended by representatives of various industries, such as manufacturers of mill machinery, dust collectors, chemicals, wood flour, films, ground cork, insecticides, and feed, by representatives of insurance companies and railroads operating grain elevators, and by officials of various organizations.

In giving a demonstration the method of obtaining the inert gas from the boiler flues, the equipment which forced it through the pipe line from the boiler house to the feed mill, and the method of distributing it to various points in the milling system were explained, and the electric arc as a source of ignition was pointed out. Attention was called to the location of safety vents which released the pressure of an explosion to the outside of the building. Then the machinery was started to show the system of feed circulation.

When an analysis showed that the content of inert gas was sufficient to prevent an ignition, the electric arc was turned on, and through the observation window it could be seen burning in the dust cloud directly below the attrition mill without causing an explosion. The control valves were then closed sufficiently to reduce the flow of flue gas and thus reduce the percentage of inert gas within the mill to the point where the dust ignited. Owing to the damping effect of the inert gas remaining in the mill, the resulting explosion was just sufficient to fill the mill with flames, force dust and smoke from cracks or small openings in the equipment, and then vent itself without damaging the mill, by forcing off the cover of the feed hopper.

As a result of these demonstrations a number of companies have installed inert-gas equipment in their mills, so that it is now possible for anyone interested in the use of inert gas for explosion prevention to see not only the demonstrations in the experimental plant but large-scale systems in industrial plants.

QUESTIONS ASKED ABOUT INERT GAS

The questions usually asked by anyone contemplating the use of inert gas for explosion protection in industrial plants are, (1) Will the gas have any injurious effect on employees? (2) What effect will the gas have on the material being ground? (3) How much gas will be needed? (4) What equipment will be needed?

EFFECT OF GAS ON EMPLOYEES

Before installing a new device it is logical for the plant manager to consider the effect it may have upon the health or safety of employees. Owing to a misunderstanding of the recommended method of using inert gas for explosion and fire prevention, the question concerning the possible injurious effect of the gas on employees is asked frequently. It would, of course, be impossible for a man to work in an atmosphere sufficiently low in oxygen to prevent explosions, and it is not intended that the gas should be used in a room or inclosure where employees work or which they even enter. The system has been developed and is recommended for inclosed grinding, conveying, or handling equipment, and when used as intended will have no injurious effect on employees. Inclosed milling systems are constructed to prevent the escape of dust and can easily be made tight enough to prevent the escape of any appreciable quantity of gas into the room or building where employees are at work.

When flue gas is used as the medium for reducing the oxygen content of the air to the percentage necessary to prevent explosions in grinding equipment and the gas is also introduced into bins or inclosures to which the ground material passes, employees should not enter these bins or inclosures. The use of flue gas in such places introduces two hazards, namely, the reduction of the oxygen percentage of the atmosphere below that necessary to support life, and the possible presence in the flue gas of carbon monoxide. It is unlikely that the quantity of carbon dioxide ordinarily used for explosion and fire protection would be sufficient to render the atmosphere rapidly poisonous, and with the modern efficient methods of operating boilers it is unlikely that any appreciable quantity of carbon monoxide will be found in the flue gas. Nevertheless, no one should be permitted to enter an inclosure into which flue gas has been introduced until it has been thoroughly ventilated.

EFFECT OF GAS ON MATERIAL GROUND

The use of flue gas for dust-explosion prevention has been recommended because as a rule it offers a ready source of carbon dioxide, and it appears to be most logical to use carbon dioxide for this purpose. No question arises concerning the effect of carbon dioxide on the material being ground. Its use in the preservation of food products and the making of carbonated beverages and the fact that it passes off quickly upon exposure of the product to the air indicate that this gas would have no injurious effect upon the material. There is, however, the possibility of other gases being present in flue gas, particularly when the fuels are sulphurous or arsenious, which would necessitate the cleaning of the gas. In the inert-gas tests described by Price and Brown (*12*), various products were exposed to both washed and unwashed flue gases. A coke scrubber with a spray of water running counter to the flow of gas was effective in cleaning the gas in these tests. Examination of the starch, dextrine, and flour exposed to the gas showed that the scrubber removed all the soot and practically all the sulphur dioxide. When the gas was not washed, traces of soot were detected in the flour, and a tarry odor was noticeable. Cleaning or conditioning is therefore recommended when flue gases are used during the manufacture or handling of food products or feeding stuffs.

In the tests described in this bulletin no scrubber or cleaner was used, but as the mill was some distance from the boiler house the long, exposed pipe line through which the gas passed evidently had a cleaning effect. By the time it reached the mill the gas was cooled to atmospheric temperature, and most of the excess moisture, if not all, was condensed and drained from the pipe through a water seal at the low point. The low velocity in the pipe, the screen over the intake which was connected to the breeching at right angles to the flow of gas, and the recirculation of the gas at the blower evidently eliminated much of the soot and impurities which might otherwise have entered the mill. In the systems now operating in hard-rubber grinding, cork grinding, and pyrethrum-flower grinding mills the gas is not cleaned, and no effect on the product has been detected. When the condition of the gas or the nature of the product necessitates cleaning or purifying the gas the ordinary coke scrubber or a filter or one of the many types of air washers now on the market can be used.

QUANTITY OF FLUE GAS REQUIRED

The quantity of flue gas necessary to prevent explosions during grinding depends upon the size and type of equipment used, its condition, and the kind of material being ground. Since the idea seemed to be general that enormous quantities of gas are necessary and many who were considering its use expressed concern over the possibility of obtaining a sufficient quantity of gas at the mill, or near it, measurements were made of the quantity of flue gas required to maintain within the experimental mill an inert atmosphere capable of preventing an ignition or explosion of ground oat hulls.

A gas meter was placed in the pipe line through which the gas was forced into the mill hopper, and the valves in all other pipes were closed tight. As the percentage of inert gas required to prevent an explosion within the mill had been determined in the explosibility tests, it was necessary in this series of tests to determine only the quality of the flue gas coming from the boilers, adjust the valve in the pipe until an analysis of the atmosphere within the mill showed that sufficient gas to maintain the inert atmosphere necessary to prevent an ignition of the oat hulls was entering, and then read the meter to determine the quantity of gas passing through the pipe. These tests were made with the mill in operation and with the same conditions under which the explosibility tests were made.

This series of tests showed that when the flue gas coming from the boilers contained approximately 10 per cent carbon dioxide it was necessary to use only 3 cubic feet of flue gas per minute in order to maintain an atmosphere within the mill which would not permit the ignition of ground oat hulls. It must be remembered that this figure applies only to the system described—a 24-inch attrition mill having bucket elevator and metal-lined hoppers and spouts arranged to permit circulating both the feed and the gas. All openings were closed so that it was necessary to supply only enough gas to replace the natural leakage through small cracks and crevices which could not be detected or readily closed. Plastic cement closed small leaks. This figure is probably much lower than could be obtained in industrial plants, where feed entering the mill would carry with it a certain quantity of fresh air, and removing the ground material from the mill or storage bin would permit the escape of some of the inert atmosphere. It does indicate, however, that obtaining a sufficient supply of gas is not as difficult as it is sometimes felt to be, since in almost all grinding mills it will be possible to cut down the natural leakage and provide for the recirculation of the inert gas, if necessary.

The quantity of flue gas required must be determined for each proposed inert-gas system. Methods of determining the required quantity are explained under the heading "Designing an inert gas system for explosion protection in industrial plants."

EQUIPMENT REQUIRED

It is difficult to give a direct answer to the question concerning the equipment necessary to supply inert gas for explosion protection, as the equipment depends largely upon the type of material being ground, the location of the plant with respect to existing sources of inert gas, and various qualities of the gas itself. In general, it can be said that it is necessary to have (1) a source of supply, either the flue gas from boilers or furnaces or the product of inert-gas-producing equipment; (2) a fan, blower, pump, or compressor to force the gas to the place where it is to be used; (3) a system of distributing pipes with the proper control valves; and (4) indicating or recording equipment to show that the necessary percentage of inert gas is in the system. These are the essential parts of every inert-gas system.

As previously pointed out, it may be necessary when easily contaminated material is being ground to provide apparatus to clean, cool, or otherwise condition the gas to prevent any injurious effect upon the product. When the gas is obtained from boilers using coal or oil with a high sulphur content, additional equipment may be required to remove or neutralize the fumes which, when they condense, produce an acid that attacks the metal pipes and equipment through which the gas passes. When inert gas is obtained from boilers some distance from the mill in which the gas is to be used, it will probably be unnecessary to use any cooling apparatus other than the pipe line through which it passes. In the experimental plant the iron pipe carrying the gas from the boiler to the mill was laid on the ground, and the passage of the gas through this pipe reduced the temperature to approximately that of the atmosphere at the mill. No cleaning equipment has been necessary at the experimental plant or in the systems in operation at hard-rubber grinding, cork grinding, and pyrethrum-flower grinding mills, although in one industrial plant the flue gases pass through a cinder-vane fan before entering the breeching from which they are drawn by the fan of the inert-gas-distributing system. At the experimental plant no damage to the pipe line or equipment from the sulphur fumes has been detected. In one of the industrial systems, however, it was evident that the galvanized-metal pipes used for distributing the gas were being attacked. Such difficulties can usually be overcome through temperature control either by maintaining the gas at a temperature above the dew point until it has passed through the system or by cooling, condensing, and collecting the moisture it contains. When such measures are not practicable or effective, the gas may be passed through a neutralizing spray, or in place of the fan which generally forces the gas through the distributing system a pump of the hydroturbine type may be used. It is believed that substituting a neutralizing liquid for the water generally used in such pumps will overcome many, if not all, of the difficulties caused by acid fumes.

Another solution of this problem which has been found effective in one of the industrial systems is to line the distributing pipes with rubber. A special product which can be employed for this purpose is manufactured, and in addition there is on the market hard-rubber pipe and fittings which can be used where acid fumes are especially annoying and where they can not be removed or neutralized effectively. In the inert-gas systems now operating no great difficulty has been experienced because of sulphur fumes in the gas, and in view of the various methods of counteracting or preventing the acid action of such fumes no concern need be felt on this score.

DESIGNING AN INERT-GAS SYSTEM FOR EXPLOSION PREVENTION IN INDUSTRIAL PLANTS

Where a steam-power plant is operated in connection with a mill or factory, designing and installing inert-gas equipment for explosion protection is comparatively simple. As a rule, it can be safely assumed that in such plants sufficient inert gas to provide the protection desired is available in the flue gases going to waste up the chimney, but it is advisable to study thoroughly all the factors involved. Whether the gas is to be obtained from a source already available or from gas-producing apparatus to be installed with the other equipment, the following factors should be carefully considered: (1) Quantity of air which normally enters the machines or equipment, (2) reduction of oxygen necessary to prevent explosions, (3) oxygen percentage of the gas used to create the inert atmosphere, (4) quantity of gas required, (5) availability of the required quantity of gas, (6) the gas-conditioning equipment, if any, and (7) the gas-distributing system.

NORMAL AIR REQUIREMENTS

The volume of air entering the machines or other equipment into which it is planned to introduce inert gas should be determined in cubic feet per minute. In storage bins and in packing, conveying, or elevating machinery which do not receive a supply of inert gas with the feed or material coming from the mills, the normal air leakage or rate of air change per minute represents the volume of air to be considered. This determination can be made by actual measurement or by computation. Some manufacturers of machinery supply these data. In many grinding systems the air taken in by the mill represents the total quantity to be considered, since the natural drafts created by the operation of the mill place the air in the equipment following under slight pressure so that any leakage is outward and the infiltration of fresh air which would weaken the inert mixture is prevented. The attrition mill at the experimental plant required normally about 180 cubic feet of air per minute when no provision was made for recirculation. Some attrition mills have required as much as 1,200 cubic feet of air per minute.

These figures are given only to indicate the range which might be expected, and should not be used even as an approximation where an analysis of air requirements is being made. The speed of the mill, the type and quantity of material being ground, and the construction as well as the arrangement of the machine must all be considered. Actual measurements should be made or test data of the manufacturers should be used to determine the air requirements, and when any doubt exists it should be remembered that it is better to have too much inert gas than not enough.

NECESSARY REDUCTION OF OXYGEN

The percentage of inert gas or the reduction of oxygen necessary to prevent ignition or explosion of the material being handled should be accurately determined. Table 1 indicates the percentage to which the oxygen of the air must be reduced by the addition of inert gas in handling the materials listed. In other words, for each material sufficient inert gas must be introduced into the atmosphere within the mill to reduce the oxygen from approximately 21 per cent, the quantity normally present in fresh air, to the percentage given in the following tabulation:

TABLE 1.—*Percentage of oxygen necessary to prevent an explosion*

Material	Oxygen	Material	Oxygen
	Per cent		*Per cent*
White dextrine (5)	12	Hard-rubber dust (5)	13
Wheat starch (5)	12	Cork dust [1]	14.1
Wheat-, corn-, or oat-elevator dust (5)	14	Pyrethrum-flower dust [1]	15.5
Pittsburgh coal dust (5)	16	Ground oat hulls [1]	13.7
Sulphur (5)	8.5		

[1] Percentages determined by P. W. Edwards and R. W. Harrison.

The figures given above are the results of laboratory experiments and may be considered accurate for average plant-operating conditions. When any unusual or unexpected conditions exist, the percentage of oxygen should be reduced below the figure given in order to guard against possible dust ignitions.

OXYGEN PERCENTAGE OF GAS

If the oxygen or combustible content of the boiler-flue gas or other gas to be used in reducing the percentage of oxygen in the atmosphere within the milling system is not known, an analysis should be made to determine it. When boiler-flue gas is to be used this information can be obtained by analyzing representative samples with an Orsat or other apparatus suitable for gas analysis. A sufficient number of analyses should be made to obtain a fair average reading. When gas-producing equipment is employed, the quality of gas required under specified operating conditions is usually indicated and guaranteed by the manufacturers.

QUANTITY OF GAS REQUIRED

With the data obtained in the three preceding determinations, the quantity of gas necessary for explosion protection can be calculated.

Assume that the first determination showed that a certain mill or piece of apparatus requires 200 cubic feet of air per minute. Assume that the second determination showed that the oxygen percentage in the air used by the machine must be reduced to 12 per cent in order to prevent explosions of the material being handled. Assume that the third determination showed that the flue gas to be used in reducing the oxygen percentage contains 10 per cent carbon dioxide, 11 per cent oxygen, and 79 per cent nitrogen.

Let x=cubic feet of fresh air.
y=cubic feet of flue gas.
a=percentage of oxygen in the flue gas.
b=percentage of oxygen permitted in the mixture.
c=percentage of oxygen in fresh air.
Then, $x+y$=total quantity of gas and air or, as assumed, 200 cubic feet.
$a=11$
$b=12$
$c=21$, the percentage normally present in fresh air.
Now, $cx+ay=b(x+y)$
Substituting the values assumed:

$21x+11y=12\ (200)$
$=2{,}400\ (1)$
but, $x+y=200$
and, $11x+11y=2{,}200\ (2)$

Subtracting (2) from (1)
$10x=200$
$x=20$
Substituting in $x+y=200$
$y=180$

Therefore in order to obtain 200 cubic feet of a mixture of gas and air containing 12 per cent oxygen by mixing fresh air and flue gas containing 11 per cent oxygen, it will be necessary to use 20 cubic feet of fresh air and 180 cubic feet of flue gas.

If carbon monoxide is present in the flue gas it will be necessary to reduce the oxygen percentage slightly below that indicated for the various materials listed in the tabulation on page 17 in order to overcome the increased explosibility of the mixture caused by the presence of a combustible gas.

By means of the curves in Figure 5 the number of cubic feet of flue gas it is necessary to use with fresh air to obtain a mixture containing the desired percentage of oxygen can be determined without computation. Locate on the base line of the chart or the axis of abscissas the line marked 11, which represents the oxygen percentage of the flue gas to be used, follow it vertically to its intersection with the curve marked 12 per cent, which represents the percentage of oxygen permitted in the gas-and-air mixture, and then read the figure at the corresponding height on the left margin of the chart or the axis of ordinates, which in this case is 90, the number of cubic feet of gas for each 100 cubic feet of gas-and-air mixture required. Since 200 cubic feet of the mixture is the quantity which it is assumed is necessary, multiply 90 by 2, which gives 180 cubic feet, the quantity of flue gas containing 11 per cent oxygen which must be used to obtain a gas-and-air mixture containing 12 per cent oxygen.

When it is impossible to control the entire quantity of air entering the machines or used in the process where the explosive dust is created or handled, the problem of obtaining an inert atmosphere is somewhat different from the foregoing. Under such circumstances the problem becomes one of determining the quantity of gas which must be added to the stated quantity of fresh air in order to form a mixture containing a percentage of oxygen low enough to prevent combustion or ignition of the product being handled, instead of determining simply the proportion of gas and fresh air required in a mixture which will prevent a dust explosion.

It is assumed, for example, that the dust is drawn or fed into a machine, hopper, or pipe line from an open room or chamber where it is necessary for employees to work. It is therefore impossible to maintain in this room an atmosphere deficient in oxygen. It is assumed further that 100 cubic feet of fresh air per minute enters

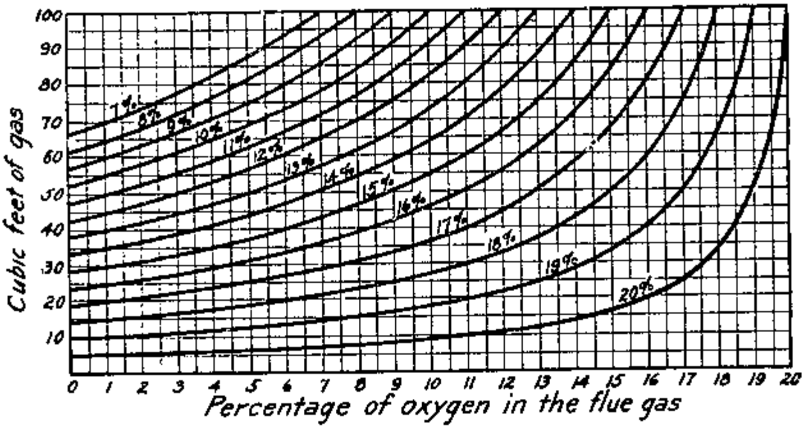

FIG. 5.—Number of cubic feet of flue gas of various qualities it is necessary to use with fresh-air to obtain 100 cubic feet of a mixture containing a desired percentage of oxygen

the machine or other equipment with the dust or product being handled, 12 per cent is the point to which the oxygen must be reduced to prevent explosions, and 10 per cent oxygen is present in the flue gas used to create the inert atmosphere. As in the previous example:

Let x=cubic feet of fresh air.
y=cubic feet of flue gas.
a=percentage of oxygen in the flue gas.
b=percentage of oxygen permitted in the mixture.
c=percentage of oxygen in fresh air.
$x+y$=total quantity of gas and air.

In this case x has been assumed to be 100 cubic feet.

Then, $100+y$=total quantity of gas and air required.

$a=10$

$b=12$

$c=21$, the percentage normally present in fresh air.

Now, $cx+ay=b(x+y)$.

Substituting the values assumed,

$$21\times 100+10y=12(100+y)$$
$$2{,}100+10y=1{,}200+12y$$
$$2y=900$$
$$y=450$$

Therefore in a system in which it is necessary to use 100 cubic feet of fresh air per minute 450 cubic feet of flue gas containing 10 per cent oxygen must be introduced in order to reduce the oxygen content of the mixture to 12 per cent.

The curves in Figure 6 show without calculation the quantity of gas required under various conditions. Under the conditions given in the foregoing example locate on the base line or axis of abscissas

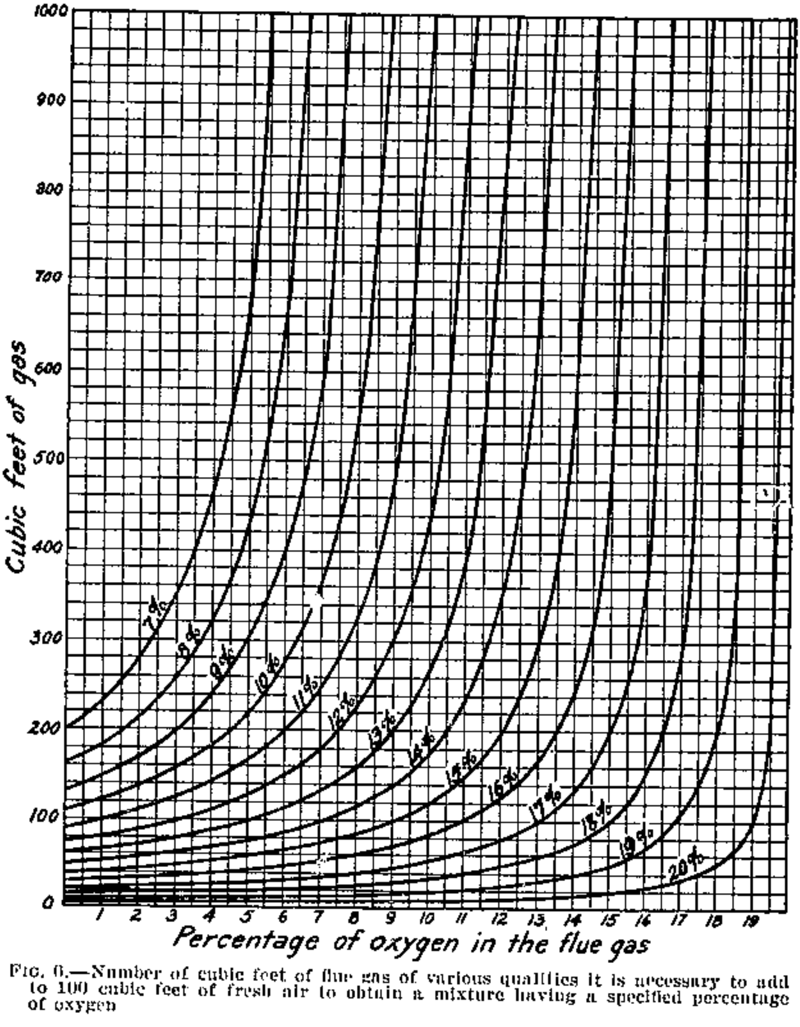

FIG. 6.—Number of cubic feet of flue gas of various qualities it is necessary to add to 100 cubic feet of fresh air to obtain a mixture having a specified percentage of oxygen

the line marked 10, which represents the percentage of oxygen in the flue gas to be used, follow it vertically to its intersection with the curve marked 12 per cent, which represents the percentage of oxygen permitted in the mixture, and read at the corresponding height on the left margin or axis of ordinates the number of cubic feet, in this case 450, which must be added to every 100 cubic feet of fresh air to provide an inert atmosphere.

QUANTITY OF GAS AVAILABLE

After the quantity of flue gas required to provide an atmosphere which will prevent an explosion of the product being handled has been determined, if there is any question concerning the possibility of obtaining sufficient inert gas from the boilers or furnaces being used, the quantity of gas produced can be determined by actual measurement or calculated approximately from the results of the flue-gas analysis, the carbon percentage of the coal, and the quantity of coal burned, since—

$$\text{Weight of air supplied per pound of coal} = \left(\frac{240}{CO_2+CO}\right)C,$$

and the weight of the products of combustion will be equal to the weight of air supplied per pound of coal plus the weight of the coal minus the ash. In this equation CO_2 and CO are the percentages by volume of these gases as found in the flue-gas analysis, and C is the percentage by weight of the total carbon in a pound of coal. Since each pound of flue gas at room temperature occupies approximately 13 cubic feet, the weight of the products of combustion obtained by this formula multiplied by 13, and this result multiplied by the number of pounds of coal burned per minute gives the quantity of flue gas available. It should be remembered that the volume increases with a rise in temperature, and if the gas is to be used at higher temperatures the weight of the products of combustion should be multiplied by the number of cubic feet in a pound of the gas at the desired temperature. Where only a rough estimate is necessary it may be considered that 1 pound of fuel will produce 200 cubic feet of flue gas.

In plants where boiler-flue gas is not available, determination of the quantity of inert gas required will serve as a basis on which to estimate the size of the gas-producing equipment required.

GAS-CONDITIONING EQUIPMENT

The necessity of using conditioning equipment depends entirely upon the material being handled. In the experimental plant and in factory installations for hard-rubber grinding and cork grinding no conditioning equipment has been found necessary. If flour or any other easily contaminated food product is being handled and conditioning apparatus is necessary to clean the flue gas, a spray washer or coke scrubber can be constructed and placed in the line, or the necessary equipment can be purchased from manufacturers of air-conditioning equipment, who will furnish or design and build apparatus to condition the quantity of gas required for the various machines. When spray washers are used, about 400 cubic feet of gas per minute can be cleaned in each square foot of cross-sectional area through the spray chamber. Approximately 5 gallons of water are required to clean 1,000 cubic feet of gas per minute. When cleaning apparatus is used, provision can be made to remove or neutralize during the washing any acid fumes in the gas and thus prevent any damage which they might cause to the equipment or distributing pipes.

GAS-DISTRIBUTING EQUIPMENT

Equipment for distributing the gas to the various machines consists of a fan, blower, or compressor, and piping. In the experimental plant a positive-pressure blower and iron pipes were used. In most of the industrial systems an exhauster fan of the ordinary type, and galvanized or plain sheet-metal pipes have sufficed. The selection of the size of the fan should be left to the manufacturers of the fan since they have test data which enable them to select the size which will meet the requirements. The piping should be such that the cross-sectional areas of the various branch lines leading to the machines are proportional to the quantity of gas they are to carry. The combined area of the branch pipes must be equal to the cross-sectional area of the trunk line carrying the gas from the fan. It will probably be better under certain conditions to use a compressor and small pipes to carry the gas to the machines. Here again the compressor and the size of the piping depend upon the quantity of gas to be used and should be based on the manufacturer's ratings. In every system it is advisable to have valves in all branch pipes in order to regulate the flow of gas to any particular machine.

CONCLUSIONS

As a result of the experimental work and the observations made during actual operation of inert-gas systems in industrial plants, the value of inert gas as a means of preventing dust explosions has been so well demonstrated that its use should be seriously considered wherever an explosion hazard exists which can not be controlled through the elimination of the dust cloud or the source of ignition. The use of inert gas is particularly recommended in grinding, bolting, or any phase of a manufacturing process where an explosive dust is produced or handled within an inclosed piece of equipment.

Although the investigation described in this bulletin was confined to the determination of the value of inert gas as a means of preventing dust explosions during the grinding of oat hulls, the experimental work suggested many other possible uses for inert gas and additional lines of investigation.

Two fires within the experimental plant were extinguished by opening the valves and flooding the inclosure with flue gas. A modern development of this fire-extinguishing principle has been the storage of compressed inert gas in tanks with distributing pipes which lead to the most likely sources of fire and quick-acting valves to release the gas. Such equipment has been employed for fighting fires on ships and has been adapted for factory fires, especially in factories where flash fires are liable to occur during the use of oils, solvents, or other inflammable liquids. It has been used also as a means of extinguishing fire in mines (7). A portable extinguisher consisting of a small tank of carbon dioxide under pressure has recently been placed on the market.

Inert gas, especially carbon dioxide, has many advantages over other fire-fighting mediums since it will not injure metals, fabrics, food products, or other perishable materials. It does not freeze or deteriorate, and as it does not conduct electricity it can be used to extinguish fires in electrical equipment. Carbon dioxide leaves no residue, which is a distinct advantage, since frequently the residue or damage caused by the extinguishing medium constitutes the greater part of the total loss. These advantages indicate that there is a promising field for inert gas as a fire-fighting medium as well as for explosion prevention.

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