THERIS.


HAROLD WILLIAM PAINE
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WORK OF PREVIOUS INVESTIGATORS.
RESUME OF WORK OF PREVIOUS INVESTIGATORS.

In certain chemical industries, essential constituents of the product are used in the form of gases. These may carry dirt and dust, which must be removed to avoid contamination of the finished product. Such is the case in the Chamber process for sulphuric acid, in which iron pyrite is burned to furnish the sulphur dioxide gas to the lead chambers. This gas is laden with dust, mainly ferric oxide, which if not removed would soon clog up the interstices in the Glover tower and eventually contaminate the acid as ferric sulphate. In other industries some of the waste products may be in the form of dust laden gases. This dust may be valuable in itself or it might create a nuisance if allowed to escape into the air. In either case the dust must be removed.

But at present the most crying need of gas cleaning and purification is in the steel plants where blast furnace gas is used to run large gas engines. If the dust is allowed to get into the cylinders it will cause excessive grinding action and wear away the sliding parts. It will clog the valves and springs, render inefficient the delicate governing devices, and sometimes cause premature ignition through remaining incandescent after the preceding explosion.

Because gas engines running with blast furnace gas are becoming so numerous much of the literature
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Because gas engines running with blast furnace gas are becoming so numerous much of the literature
upon the subject of gas cleaning was found to bear
more upon the purification of blast furnace gas than
upon sulphur dioxide gas but the same principles apply
to both. And in looking over the literature, besides
noting the methods of determining the dust in the
gases, attention was also turned upon the apparatus
for purifying, washing, scrubbing, and filtering the
gas upon a large scale.

This apparatus may be divided into two classes;
wet washers and dry separators. The latter will be de-
scribed first. Two kinds of separators are used, sett-
ling chambers and filtering towers. The former are
simply large rooms in which the gas under reduced vel-
ocity deposits the heavier particles of dust. Some-
times there are vertical baffle plates against which
the dust impinges and falls to the floor. Or these
plates may be arranged obliquely or horizontally as
shelves upon which the dust is allowed to settle.
Horizontal shelves are used in the Dust Chamber or
Fume Arrester which will be tested during this thesis.
This Chamber will be fully described below. Many de-
vices have been suggested and patented. All work upon
the idea of causing the dust to settle out upon baffle
plates of various peculiar shapes.

Filtering may be done in coarse burlap bags but
is usually accomplished in filtering towers. These are
high towers in which are placed horizontal gratings
with layers of coke, sawdust, or other heterogeneous masses to act as the filtering medium. But the dust being extremely fine is not all retained on these filters. Frank Roberts (Iron Age, 1907, I, 1415) states that the size of the dust from two blast furnaces was as follows:

I.
Retained on 50 mesh sieve
  " " 50 " "
  " " 100 " "
Passed through 100 mesh sieve
  5.25%
  2.00%
  3.30%

II.
Retained on 40 mesh sieve
  " " 60 " "
  " " 100 " "
Passed through 100 mesh sieve
  84.45%
  0.50%
  2.70%
  3.50%

When it is realized that a 100 mesh sieve has 10,000 openings to the square inch, the extreme fineness of the dust becomes at once apparent.

There are also two methods of cleaning by the wet way, stationary scrubbers and rotating scrubbers. The former are towers similar to those used in dry filtering except that water is sprinkled from the top while the gas passes up from the bottom, leaving part of its dust behind as it goes through the interstices of the layers on the gratings. Sometimes the gas is merely passed through a spray of water.
Rotary scrubbers are of two kinds, slow and fast. The first class is best represented by the Bian apparatus (Die Gas Maschinen, Teil I, 397, Bock, Ed. 1907). This is a long cylindrical drum, half full of water, in which knives or blades like the spokes of a wheel slowly revolve and rub against perforated disks through which the gas is forced to pass. Water is sprinkled over the disks from the top and before the gas has passed through the drum it has been thoroughly mixed with the water and left most of its dust behind.

But by far the best cleansers are the rapidly revolving scrubbers. These may be heavy centrifugal fans into which water and gas are introduced together. Both are thrown violently against the casing of the fan and a large part of the dust separates from the gas and runs off with the water. Many centrifugal scrubbers have been invented but that of Theisen of Munich seems to be the most widely used, at least in Germany (Die Gasmaschinen, Teil I, 397, Bock, Ed. 1907). It consists of two cylindrical drums, one swiftly rotating within the other. The movable drum has helical blades or scrapers on its outer shell, while the inside of the outer drum is roughened and corrugated. The gas and water are forced between the drums while the rapid rotation and grinding effect caused by the inner drum rubbing against the outer produces an in-
timate mixing of the dust and water and accomplishes a very thorough cleansing. The Theisen apparatus and other centrifugal scrubbers require more power than the other cleaning devices and is more expensive at first, but if thorough cleaning is required the rapidly rotating scrubbers are the most efficient.

As regards the efficiency of the various cleaners the following figures might be given. Authorities do not agree but the average of several was taken. Dry cleaning takes out all but from 4 to 6 grams per cubic meter, the wet scrubbers from 1 to 1.5 grams per cu. m., and the centrifugal washers from .03 to .004 grams per cu.m.

Several methods of determining the dust will now be described. Perhaps the best material was furnished by Chamberlain, Chemist of the Carnegie Steel Co. He recently investigated several methods to find the best one to use on the blast furnace gases of the corporation's plants. All investigators agree that the gas should be drawn from the flue through some form of sampling tube by suction and the amount of gas measured by a meter or in any convenient container. But they differ in the style of sampling tube used and in the filtering medium. Some advise a straight tube inside the flue while others prefer a tube bent in the direction from which the gas is flowing, so that the opening of the tube is pointing towards the stream.
of gas. It is in the filtering mediums and methods of filtration, however that our chief interest lies. Following is a description of several methods.

WATER ABSORPTION:— The gas is passed through distilled water in bottles, flasks or a series of tubes, then filtered and the collected dust weighed. Or the water may be evaporated off and the residue weighed. Tissandier used this method in 1874 in determining the dust content of the air. (J. Chem. Soc., 1874, 672.) In its essentials the method is now used by Howard at the Merrimac Chem. Co. except that he uses caustic soda solution in place of water. The method is open to an objection in that when gas bubbles through water or other liquid there is a tendency for some of the gas to go through without coming in contact with the water. This gas is that portion which is the interior of a bubble. The bubble passes through the liquid and only the outer surface gets wet. Hence some of the dust, being occluded within this gas bubble does not touch the water at all and remains in the gas, making the determination low.

TUBE FILTERS:— Straight metallic or glass tubes are filled with plugs of cotton-wool or asbestos as a filtering medium and the gas drawn through. The tube is weighed before and after the filtration and the amount of dust in the gas drawn calculated from the difference in weights. There are three objections to cotton as a filtering medium. Being extremely hy-
grosopic, it is hard to weigh it accurately; unless packed in carefully in layers the dust will get through in small channels; and it cannot be used for hot gases.

GOGG TUBES:—These are the same as above but using Gogch funnels in place of the straight tubes.

SIMON APPARATUS:—This consists of a glass cylinder with a glass stopper, upon which is a flange inside of the cylinder. The flange holds a fat extraction thimble which acts as the filter. (Stahl und Eisen, 1905, 1009.) There are various modifications of this idea, using metal cylinders in place of the glass one and various ways of holding the thimble. A sketch of the apparatus as used at one of the steel works is on the next page.

FILTER PAPER:—There have been tried many adaptations of a filter paper; folded, flat, held in a funnel, etc. Leo Martinus (Stahl und Eisen, 1903, 735.) suggests an apparatus having a filter paper held flat on a perforated disk in an iron funnel. The accompanying sketch shows the arrangement. The funnel is placed in a box heated by an electric light to prevent moisture from depositing on the paper.
The Carnegie Steel Co are using a filter modelled after the Martius apparatus. The accompanying sketch gives an idea of the construction.

OPTICAL METHOD: - J. Tyndall (Jahresbericht der Chemie, 1871, 170) determined the carbon dust in smoke by an optical method, using a polariscope as the means of determination.

COLLODION FILTER: - M. Hahn (J. Soc. Chem. Ind., 1907, 1144) passed the gas through a collodion filter dissolved the filter in ether and alcohol and estimated the dust content by a colorimetric method, the turbidity of the solution being compared to that of standard solutions.
Inlet Pipe

Edgar Thompson Filter

Filter Paper

Rubber Union

Glass Tube

Full Size

4 2/4 D
OBJECT OF THESIS.
OBJECT OF THESIS.

The object of the thesis is to first try out the different methods used in determining the dust and second to test the efficiency of the Howard Dust Chamber at the Merrimac Chemical Co., South Wilmington, Mass.

In order to test the methods, an apparatus to supply a stream of dust-laden gas will be constructed. Then various methods will be used to determine the dust in this stream of gas. When it is thought that a satisfactory method has been found, this method will be used to test the Dust Chamber. The dust content of the sulphur dioxide gas will be determined before it enters the Chamber and after it leaves. Then from the dust content, the pounds of ore burned per day, and the percentage of sulphur in the ore, a calculation will be made to find the dust that enters, the dust that remains, and the dust that leaves the Chamber per day.
EXPERIMENTAL WORK. PART I.
CONSTRUCTION OF APPARATUS:— About twenty-five feet of five inch stove-pipe were connected, as shown below, to a centrifugal fan driven by a small electric motor. The fan and motor were bolted to a wooden platform to hold them rigid. The pipes were about ten feet high and the uprights about two feet apart.
To furnish a view of the interior square holes were cut on opposite sides of the pipe and pieces of window glass luted in with litharge and glycerine. Three other holes were also made, two for the sampling tubes and one for the introduction of the dust. Brass tubes one inch in diameter were soldered into these holes to make tight joints with the rubber stoppers holding the sampling tubes. The two holes for taking samples were cut close together and as far as possible from the bend at the top. The air was blown down in this section so that it traversed a long straight piece of pipe before reaching the sampling tubes. Any bend near the holes would have caused local convection currents and disturbed the steady flow of dust. After setting up the pipes some magnesium carbonate was put in as dust and the fan started. Immediately most of the dust blew into the room through the joints of the pipe. Accordingly the joints were made air-tight with the same lute that was used on the windows. Much trouble was encountered in making the pipe sufficiently air tight.

**Testing Filters:**--The method used in testing all filters was as follows. A straight glass tube 3/8 inches inside diameter was put through a rubber stopper and inserted in the sampling hole. The other end was bent at right angles and connected by another rubber stopper to the filter. A rubber tube connected the lower end of the filter to a two liter bottle filled about 2/3 full with distilled water and a few drops of...
phenolphthalein. The bottle had a two-hole rubber stopper, holding two glass tubes, one dipping into the water and the other above the water as in a wash-bottle. The second tube was the one connected to the filter and the first was connected by rubber tubing to a steam aspirator. This bottle will be hereafter referred to as the test-bottle. By varying the amount of dust in the pipe and the velocity of the fan, a stream of air fairly rich with dust was obtained. The dust was an intimate mixture of magnesium carbonate and soda ash, 120 grams being used in the pipe. The purpose of the soda ash and the test bottle was to detect any dust that came by the filter. If during a run any red color appeared in the test bottle it showed that the filter was not acting as it should, but that some dust was coming through. Several blank tests were made, drawing a sample through the test bottle with no intervening filter. And in every case the color appeared instantaneously in the water. This was thought to give an accurate method of testing the efficiency of various filtering mediums.

COTTON: A filter was made by filling a Gooch funnel to a depth of 2 inches with cotton wool. The cotton was placed carefully in layers, each layer being firmly pressed down and the whole covered by a piece of copper gauze. This filter was tried and it removed all the dust. Several runs were made and then the depth of the cotton layer was gradually reduced to 1/4 inches.
and the cotton still removed the dust.

WATER:— The next filtering medium used was water. Another bottle, like the test bottle was placed between it and the pipe. This bottle also contained water and phenolphthalein. A sample was drawn through the two bottles and in a short time the color in the test bottle became almost as strong as in the one supposed to be filtering the gas. Consequently it is plain that water as a filtering medium will not do.

ASBESTOS:— After the water, asbestos was tried. It was used in two ways, one in which the dry fibre was put in a Gooch funnel in the same manner as the cotton, and the other in which the fibre was suspended in water and poured into the filter under suction. A bit of glass wool was put in the wet asbestos to support it until dry. Then the wet filter was dried at 105 degrees C. Both of these filters removed all of the dust when tried.

FILTER PAPER:— As suggested by Brink (Iron Age 1908, II. 1687), a piece of filter paper was folded and held in a Gooch funnel as shown below.
This filter took out all the dust, but a large part of it collected upon the cork and on the end of the glass tube. This dust could be brushed into the filter paper and weighed, but better methods were found.

An apparatus upon the lines of the Martius and the Edgar Thompson filters was made next. Two tin pans with wide flanges were taken, the edges hammered out flat and thickened with a layer of solder. Then holes for bolts were bored in the flanges, and in the bottom of the pans larger holes were bored. In one hole a one-inch brass tube was soldered and in the other a quarter-inch tube. One was for the sampling tube and the other for the connection to the test bottle. A perforated iron plate was used as a support for the filter paper and the whole put together as shown below with a rubber ring as packing on each side of the perforated plate.
This filter took out all the dust if the filter paper was held in firmly, but even then some of the dust collected on the inside of the upper pan and around the inside where the filter paper was held by the packing. To make the filter dust tight it was necessary to have the paper large enough to go between the flanges and to put the bolts right through the paper. This made it difficult to remove the paper after collecting a sample upon it. So it was thought that this filter would not be convenient to handle although it removed all the dust and the filter paper would not be difficult to weigh. It is possible to make an apparatus like the Thompson filter that would hold the filter paper by clutching the edges between the smooth edges of the upper and lower covers, but with the time and available material this was not practicable. The inside of the upper cover would need to be highly polished to prevent dust from collecting upon it. So considering the difficulties it presented, it was decided to abandon this style of apparatus.

SIMON APPARATUS:—The next to be tried was the extraction thimble as proposed by Simon. A short piece of three-inch pipe threaded on each end was reduced at one end to a 1/2 inch pipe for the suction tube. A cap was screwed to the other end and a one inch hole bored in the center of the cap and a pipe screwed in. This last mentioned pipe was filed off smooth on the end that was inside of the large pipe and fitted into an extraction
thimble. The thimble used was one inch in diameter and six inches long. The sampling tube was put through a cork in the inch pipe and the air drawn through as usual. The thimble removed all the dust from the gas and offered but little resistance to the passage of the air through it. But the dust collected on the cork and the inside of the inch pipe and upon the end of the sampling tube. This could be remedied in part by polishing the inside of the pipe and the remainder of the dust on the cork and tube could be brushed into the thimble before weighing. But this was not done as a better method was found, as will be shown below.

This concluded the testing of filtering mediums and the next problem was to find out what filters were the most easily weighed, easiest to handle, and simplest. Some of the filters could be rejected at once because of deficiencies already discovered. These were water, flat filter paper, and the extraction thimble. This leaves cotton and asbestos and further tests were made upon these filters.

METHOD: In order to have the conditions the same and to get results that should check, two filters should be used and the samples drawn simultaneously, but this was found to be impracticable, because but one apparatus for measuring the gas was available. It was hoped that a gas meter could be used to measure the sample and a steam aspirator to furnish the suction, but a set back was here encountered. The pressure on the me-
ter caused by the partial vacuum in the pipe and meter. Method was too much for the meter and it would not work. So a gasometer was used. It was suspended from overhead pulleys by a rope and counterweight. A lead pail was used as a counterweight and by varying the weights in the pail the gasometer was raised or lowered at will. The volume of air drawn was measured by noting the distance the gasometer moved up. Two filters were used at each test, the air being drawn through one, the volume noted, then by means of a T-tube and pinchcocks, the other was put into the circuit, and the same volume drawn through. Two test bottles were used, in order to test the filters independently and be sure that no dust was coming through at any time. The accompanying sketch and photograph show the arrangement of the apparatus for filtering and measuring and also the construction of the whole apparatus.
C. — Counterweight.
G. — Gasometer.
T. — Tube leading to second test bottle and filter.
T.B. — Test bottle.
F. — Filter.
P. — Pipe.
COTTON:— Using the method described above tests were made on cotton filters. The filters were made as told above, dried at 105 degrees C., stoppered and weighed to constant weight. Then the sample was drawn through and they were again dried, stoppered and weighed, the difference in weight giving the amount of dust in the measured volume of gas. Great difficulty was encountered in weighing the cotton to constant weight. Being extremely hygroscopic it takes on moisture so fast that accurate weighing is almost impossible. One of the filters was left for a minute in the weighing case where the air was made fairly dry with a bottle of sulphuric acid to absorb the moisture. Yet even in this dry air the cotton took up one milligram of moisture in a minute. Another objection to cotton is that it cannot be used at high temperatures. And if there were any appreciable amount of moisture in the gas to be filtered the usual method would be to heat the filter while drawing the sample. Of course this would be impossible with the cotton filter. So for the above reasons cotton filters were dropped.

ASBESTOS:— This left only asbestos. The filters made with the dry asbestos were tried first and it was found that these were harder to weigh accurately than those made with the wet asbestos. This was probably because of the higher hygroscopic qualities of the dry fibre. In testing the Gooch type of filter, at first, glass Gooch funnels were used. But it was found that
in putting in the cork of the sampling tube that there was much danger of breaking the glass. The cork had to be put in rather firmly to make the joint air tight. And glass is always objectionable where metal can be used as well. So accordingly two tin funnels were made. A tin box was cut off at one end and a tin funnel soldered on. A brass tube 1/8 inch in diameter was also soldered to the end of the funnel and a brass cap fitted over the open end. A cover screwed on the box and thus the moisture was kept out while weighing. Then the glass wool and suspended asbestos were put in as they were in the glass funnel. The sketch below shows a section of the filter. Several runs were then made with these filters and as far as easy weighing and
in putting in the cork of the sampling tube that there was much danger of breaking the glass. The cork had to be put in rather firmly to make the joint air tight. And glass is always objectionable where metal can be used as well. So accordingly two tin funnels were made. A tin box was cut off at one end and a tin funnel soldered on. A brass tube 1/8 inch in diameter was also soldered to the end of the funnel and a brass cap fitted over the open end. A cover screwed on the box and thus the moisture was kept out while weighing. Then the glass wool and suspended asbestos were put in as they were in the glass funnel. The sketch below shows a section of the filter. Several runs were then made with these filters and as far as easy weighing and easy handling are concerned they gave good satisfaction. But no check results were obtained. It was then found that a large amount of dust did not come through into the filter but remained in the sampling tube. As this dust belongs to the volume measured, it was added to the dust in the filter and weighed. Still the results did not check. About 0.80 of a cubic foot of air was drawn and a few results are given below. They are calculated in grams per cubic meter. Each of set I should check with the corresponding value in set II.
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<td>1.78</td>
<td>2.26</td>
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<td>2.20</td>
<td>1.45</td>
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<td>9.55</td>
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It is evident that there is some source of error. Up to this, the sampling tubes had been put on opposite sides of the pipe, and it was thought that possibly the flow of gas was not constant on the two sides. So the remaining runs were made with the tubes put into the same side of the pipe. A run was made using one filter, then the filter alone was changed and another sample taken in this filter. At once the results became more comparable, although still outside the limits of accurate analytical work. The set of results below is calculated as above described.

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<tr>
<td>2.50</td>
<td>3.71</td>
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<td>3.07</td>
<td>1.74</td>
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<td>2.53</td>
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<td>2.09</td>
<td>3.04</td>
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These results were thought to sufficiently accurate to show that the filter itself was satisfactory. So it was decided to use this in preference to any of the other filters.

** STYLE OF SAMPLING TUBE:** — The next question was what kind of tube should be used to furnish a means of
drawing the sample. Two kinds of tubes were tried, a straight tube, and one bent in the direction of the gas stream. The sketch shows the two kinds of tubes.

Several tests were made, one filter using the straight tube and the other using the bent tube. In every case the latter gave an enormously higher result. The relative velocity of the suction and of the air in the pipe were changed as much as possible but still the bent tube gave the higher results. Some of these results are given below. They are expressed in grams per volume drawn, the volume being the same in each case, although it was not measured.

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<td></td>
<td>.1580</td>
<td>.0099</td>
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<tr>
<td></td>
<td>.1386</td>
<td>.0094</td>
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<td></td>
<td>.1514</td>
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These results are astonishing and an explanation was sought and it is thought that the following might be the reason for the discrepancy. The bent tube facing the stream as it does covers a certain cross section of the pipe. Now all of the dust that would pass by
this section if the tube were not there will now be caught in the tube, no matter whether or not that amount of dust belongs to the volume of air that is drawn and measured. But in the straight tube this will not be the case. The latter will only get that amount of dust that belongs to the measured volume, while the bent tube gets more than it should. Moreover with the bent tube the relative velocity of the suction and in the flue would make more difference than with the straight. For example, if the suction velocity is slower than that in the flue a larger amount of dust would tend to settle in the tube and the gas drawn by the suction would just pass over it. With a straight tube this would not be the case. (All of these observations presume of course that the dust in the sampling tube is added to that in the filter) Another important observation might well be made here. Suppose that the dust in two flues was to be measured and compared. In one flue the gas flows vertically upwards and in the other it passes vertically downwards. If bent tubes were used and each bent towards the flow of gas the following would be the inevitable result. In the second flue above, the tube will collect a lot of dust that doesn't belong to the measured volume and in the first flue if any dust did tend to settle in the tube it would fall out when the suction is stopped and make comparable results impossible. The value of this observation will be seen when
the work upon the Dust Chamber begins.

This concluded the work upon the filters and tubes and the second part of the experimental work was done at the Merrimac Chemical Co.
EXPERIMENTAL WORK. PART II.
DUST CHAMBER:— The Howard Dust Chamber was mentioned above but not fully described. The old Herreshof Chamber, chamber for separation worked upon the idea that if a gas is expanded into a large chamber, it would partly lose its carrying power and deposit its dust particles upon the bottom of the chamber. Baffle plates were placed in the chamber to interfere with the onward flow of the gas and thus aid in the deposition of the dust. The sketch shows such a chamber.

Henry Howard believed that it would materially increase the efficiency of the separation if the dust were given something to settle upon before it fell way to the bottom of the chamber. A dust particle entering with the gas would gradually fall, but the gas might pass through the chamber before it reached the bottom. So
he built a chamber with a number of horizontal shelves Dust Chamber, which were but a few inches apart and the dust had to fall but a short distance before reaching the shelf under it. The system constituted in effect a number of small chambers each of which would separate its aliquot portion of dust. The patent as taken out by Howard is shown on the next sheet. It is fully described in the patent specifications and needs no further description. A particularly important feature is the means whereby an even distribution among the shelves is secured. It is described in the paragraph beginning on line 71.

LOCATION OF CHAMBER:-- The chamber is placed just Tests, about 60 feet from the pyrite burners and is used to clean the sulphur dioxide gas used in the Contact Process for sulphuric acid. The only place available for getting at the flues was right at the inlet and outlet as shown at A and B in the drawing on the patent sheet. An inch iron pipe extends into the middle of the flue at the outlet and the inlet. This may be used to hold the sampling tube.

HOWARD'S METHOD:-- The first test made was carried out, using Howard's method. A 3/8 inch glass tube was inserted in the iron pipe and connected to a Wolff absorption bottle by a rubber tube, and this to a test bottle as used in the laboratory. The test bottle was connected to a Tufts gas meter and the suction was
To all whom it may concern:

Be it known that I, Henry Howard, a citizen of the United States, residing at Boston, in the county of Suffolk and State of Massachusetts, have invented certain new and useful Improvements in Fume-Arresters, of which the following is a specification.

This apparatus is especially designed to remove suspended particles of solid matter from the hot gases escaping from roasting and smelting furnaces, but is applicable to the separation of dust from any gas-current of non-atmospheric temperature.

The apparatus, in its preferred form, comprises two parallel chambers each of which contains a considerable number of superposed horizontal shelves, vertical passages at the ends of these shelves serving to receive and deliver the gases by means of a valve-controlled inlet at the upper end of one passage and a valve-controlled outlet at the lower end of the other passage. The valves enable the gases to be delivered at will through either or both chambers.

Referring to the accompanying drawings, which illustrate a specific apparatus for removing dust from the sulfurous gases produced in pyrites burners: Figure 1 is a longitudinal vertical section on the line 1—1 of Fig. 2; and Fig. 2 is a transverse vertical section on the line 11—11 of Fig. 1.

The apparatus illustrated comprises two parallel rectangular chambers 1, each of which contains a number of superposed horizontal shelves 2. At one end of each set of shelves is a vertical gas-supply passage 3 and at the other end is a vertical gas-discharge passage 4. At the upper end of the supply-passage 3 is a gas-inlet 5 controlled by valve 6. Above the valved inlets 5 of the two chambers 1 is a horizontal passage 7 to which the gases are supplied by pipe 8. At the lower end of the vertical passage 4 is an outlet 9 which delivers the gases into an uptake 10 having an outlet 11 controlled by a valve 12. A horizontal passage 13 having a delivery pipe 14 extends over the outlets 11 of both chambers. The outer wall of each chamber, at its receiving-end, is provided with a vertical series of removable tiles 15. Lateral cleaning-openings 16, with doors, are provided at the lower ends of the passages 4, 10.

In operation, the valves 6, 12 are opened and gases supplied through the pipe 8 pass into the horizontal chamber 7 and thence through the openings 5 into the vertical supply-passage 3. The entering gases then subdivide and pass between the shelves, whereon the dust is deposited. The gases leaving the shelves enter the discharge-passage 4 and escape through the openings 9, uptakes 10, openings 11, horizontal passage 13 and pipe 14. The collected dust may be removed from the shelves of either chamber 6 without interrupting the flow of gases by closing its valves 6, 12, removing the tiles 15, forcing the dust from the shelves into the passage 4 and removing it at the bottom through the openings 16.

When the entering gases are evenly distributed between the several shelves, the efficiency of the apparatus varies directly as the number of shelves. In order to effect such even distribution of gases of non-atmospheric temperature, it is essential that the gas-inlet and outlet of each chamber be located respectively at the upper and lower ends of the vertical passages, or in the case of hot gases that the inlet be at the upper end of the vertical supply-passage and the outlet at the lower end of the vertical discharge-passage. This fact was determined by practical test of an apparatus provided with a gas-inlet and outlet both located at the top of the vertical passages, the efficiency of which was found to be actually lower than when the superposed shelves were omitted. When gases of superatmospheric temperature are introduced into a chamber externally cooled by the atmosphere, portions of the gases are partially cooled by the walls and subside, while the hot gases subsequently entering and escaping through openings at the top take the shortest path between these openings and pass between the upper shelves only, at such high velocity that little of the suspended dust is deposited.

When the inlet and outlet are at the top and bottom, however, the distribution of gases between the different shelves is substantially perfect. If the hot gases begin to flow too rapidly between the upper shelves, the vertical column of gas in the discharge-passage acquires a relatively higher temperature and lower specific gravity than the gas-column in the supply-passage, the lower portion of which, moving slowly into the spaces between the bottom shelves, is abnormally cooled by prolonged contact with the outer walls and is thereby densified. The relatively light gas-column in the discharge-
passage thereupon exerts a back pressure and retards the escape of gases from the top shelves while the heavier gas-column in the supply-passage forces the gases between the lower shelves. The present arrangement of passages and openings thus effects an automatic compensation and even distribution of the gases and in practice substantially identical amounts of dust are deposited on the shelves at the top and bottom. The gas inlet and outlet, one at the upper end and the other at the lower end of the passages at the opposite ends of the superposed shelves, constitute, in connection with these passages, means for passing substantially equal amounts of gases of non-atmospheric temperature through all of the spaces between the shelves.

When the apparatus is employed to treat gases which are cooler than the atmosphere, the inlet is located at the bottom of the supply-passage and the outlet at the top of the discharge-passage. The apparatus shown in the drawing may be used for such cooler gases by introducing the gases through pipe 14 and delivering them through pipe 8.

By employing a large number of closely-spaced plates, it is possible to obtain a separation of solid particles practically as complete as that effected by a filter, while the shelves offer little resistance to the flow of gases.

I claim:
1. A fume-arrester, comprising a chamber containing superposed shelves, passages at the opposite ends of said shelves, an inlet at the upper end of one passage, and an outlet at the lower end of the other passage.

2. A fume-arrester, comprising chambers each containing superposed shelves, passages at the opposite ends of said shelves, an inlet at the upper end of one passage, and an outlet at the lower end of the other passage, and means for passing gases selectively through either or both chambers.

3. A fume-arrester, comprising chambers each containing superposed shelves, passages at the opposite ends of said shelves, a valve-controlled inlet at the upper end of one passage, and a valve-controlled outlet at the lower end of the other passage.

4. A fume-arrester, comprising a chamber containing superposed shelves, passages at the opposite ends of said shelves, an intake communicating with the upper end of one passage, and an uptake communicating with the lower end of the other passage.

5. A fume-arrester, comprising chambers each containing superposed shelves, passages at the opposite ends of said shelves, a valve-controlled intake communicating with the upper end of one passage, and a valve-controlled uptake communicating with the lower end of the other passage.

In testimony whereof, I affix my signature in presence of two witnesses.

HENRY HOWARD.

Witnesses:
EDWIN R. BOND,
W. F. OBURG.
furnished by a steam aspirator. Both bottles were 2/3 full of 10 Be.caustic soda solution. The Wolff bottle was supposed to take out all the dust, but the test bottle was put on to see if it did. Before the test was started the iron pipe was blown out with an air blast and then the glass sampling tube was luted in with tar. Ten cubic feet of gas were then drawn through the system. Upon taking out the sampling tube it was found that sulphuric acid had condensed in the tube. The tube and also the rubber connection were washed out and the wash water added to the solution in the Wolff bottle.

TEST FOR IRON:— The ore that was being burned at the time of the tests was very dusty and was called Rio Tinto Fines. It is mainly iron sulphide, but contains a trace of selenium, a small amount of arsenic, and a little lead. Hence most of the dust is iron oxide and if any of it gets by the Wolff bottle it would give a test for iron in the test bottle. The solution in the test bottle from the run above was acidified with hydrochloric acid and treated with potassium sulpho-cyanide. It gave a distinct test for iron. This was expected from the test of water filters in Part I, and showed that one bottle did not take out all the dust.

ASBESTOS AND PAPER FILTERS:— Before beginning the work at the Chemical Co., it was expected that the tin funnel and asbestos filter would be used. But this was
found to be impossible. The gas as it comes from the pyrite burners is saturated with sulphur dioxide and also contains some free sulphuric acid and sulphuric anhydride. To determine how much acid there is in the dust the following test was made. A long glass rod closed at one end was inserted into the Chamber through an opening at the side and a sample of dust taken. The tube was then sealed up before any moisture could get in. The total weight of the material in the tube was found and then the tube was opened under water, the contents being washed into a beaker. Then the acid in the solution was titrated in boiling water against normal caustic soda using phenolphthalein as an indicator. The precipitated ferric hydroxide interfered with the titration so small samples were filtered off to determine the end-point. The total acidity was calculated as sulphuric acid, and from the average of two samples the percent of acid was found to be 20.2.

It can easily be seen what an effect this acid would have upon paper of any kind or even the tin funnel which held the asbestos filter. The highly concentrated acid that would condense in the filter would assuredly corrode the tin and make channels at the place where the tin and asbestos were in contact. This corroding action would be aided by the high temperature of the gas. This temperature was taken by a flue thermometer and found to be 975 degrees F. or 525 degrees C. at the inlet and 456 deg. F. or 232 deg. C. at the outlet.
It was no easy matter to take this temperature as it was necessary to punch a hole in a double brick wall, 13 inches thick. Acid at this temperature is exceedingly corrosive. So considering the difficulties, it was decided that absorption by the caustic soda solution would have to be used.

BENT TUBES:— It was pointed out on page 26 that the bent tube could not be used in certain places. This was the case here. As shown in the patent drawing, the outlet flue rises vertically and the inlet flue comes in at the side. So one tube would have to be bent downwards and the other sideways. Hence the condensed sulphuric acid would drop out of the former tube and carry dust with it, thus spoiling the determination.

FINAL METHOD:— Having decided that the caustic solution must be used as a filtering medium it was the next problem to improve this method. So two Wolff bottles in series were tried with the test bottle next to the meter. Each bottle was 2/3 full of 10 Bé. caustic soda solution. A run was made using this arrangement and the solution in the test bottle tested for iron. But there was only a trace of iron found and it was thought that two Wolff bottles were enough to absorb the gas and collect the dust. Perhaps three bottles would have been better but it was thought that the gain in accuracy would not be enough to warrant the extra trouble. From data obtained from the final tests it was calculated that the second bottle collected
8% of the total dust. Assuming that the third bottle would take out the same proportion of dust as the second bottle, it was calculated that the amount in the third bottle would be 0.9%. But this was found by experiment to be not so. For in the test bottle, which was virtually a third absorption bottle, there was no residue of iron that could be recovered, although the solution gave a faint test for iron. The conclusion is that the last traces of dust are exceedingly hard to collect and that the error introduced by their loss is unavoidable and inappreciable. Accordingly the final tests were made with two Wolff bottles.

CALIBRATION OF THE METER:—The meter was calibrated and found to be somewhat in error. A carboy of water on the laboratory table was connected to the meter and to another carboy on the floor by rubber tubing. The arrangement is shown below in the sketch.
Water was siphoned from the upper carboy to the lower and weighed. The suction drew air through the meter at a rate equal to that used later in the tests on the Chamber. It was found that one revolution of the large hand of the meter measured 0.116 cubic feet of air.

ARSenic:— The question was raised as to whether the arsenious oxide in the gas being soluble in the caustic ought to be recovered by precipitation or otherwise. But when the lowest temperature in the flue was found to be 232 deg. C., it was seen that as arsenious oxide is volatile at 218 deg. C. it would not be present in the flue as a dust.

FINAL TESTS:— The final tests were now made in the following manner. As shown in the photograph the two Wolff bottles, the test bottle, the meter, and the aspirator were connected in series. The dust in the iron pipe was blown out by a blast of air, the glass tube inserted, and luted in, and ten cubic feet, as measured by the meter, aspirated through the Wolff bottles and test bottle. The temperature of the meter was recorded, the glass tubes and rubber connections washed out and the wash-water added to the Wolff bottles. If the solutions were not alkaline they were made so and then left to stand for two hours. The time taken to draw a sample was thirty five minutes. At the end of two hours the insoluble iron oxide had settled very well and the supernat-
ant liquid was decanted or siphoned off. The iron was then filtered off, ignited, and weighed as ferric oxide. This gave directly the amount of dust in the volume of gas drawn. Below is a photograph of the apparatus.

S. -- Sampling Tube.
WW. -- Wolff bottles.
M. -- Meter.
B. -- Test bottle.
T. -- To Suction.

Steam Aspirator.

Three runs on as many days were made, each run consisting of a test on each side of the chamber. The results in grams per volume drawn are as follows.

<table>
<thead>
<tr>
<th>Date</th>
<th>Inlet</th>
<th>Outlet</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 11</td>
<td>1.0355</td>
<td>0.3556</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.4938</td>
<td></td>
<td>0.1600</td>
</tr>
<tr>
<td></td>
<td>0.4964</td>
<td></td>
<td>0.1510</td>
</tr>
</tbody>
</table>
In some of the tests the dust in the first and second bottles was weighed separately in order to find out how much dust got through the first bottle. These results were as follows:

<table>
<thead>
<tr>
<th>Date</th>
<th>Inlet I</th>
<th>Inlet II</th>
<th>Outlet I</th>
<th>Outlet II</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 11</td>
<td>0.9449</td>
<td>0.0376</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot; 13.</td>
<td>0.1474</td>
<td>0.0126</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot; 16</td>
<td>0.4522</td>
<td>0.0341</td>
<td>0.1385</td>
<td>0.0125</td>
</tr>
</tbody>
</table>

These results were calculated into grams per cu. ft. and per cu. meter at 60 deg. F. Below is a sample calculation upon the inlet dust of May 11.

**Calculation of meter:**

Gas was drawn until the large hand of the meter had gone around 100 times. But one rev. is equal to 0.116 cu. ft. 100 times 0.116 equals 11.6 cu.ft.

**Calculation of volume to 60 deg. F.**

Assuming that the gas is a perfect gas and therefore volumes are proportional to absolute temperatures, the volumes measured at 80 and 90 deg. were calculated to 60 deg. F. 11.6 is to vol. at 60 as 459.5 plus 90 is to 459.5 plus 60. Solving the vol. at 60, measured at 90, equals 10.98 cu.ft. Vol. at 60, measured at 80, equals 11.17 cu.ft.

**Grams per cu.ft. and cu.m.**

1.0325 divided by 10.98 equals 0.0943 grams per cu. ft.
1 cu. ft. equals 0.0283 cu.m.

10.98 " \times 0.310 = 

1.0325 divided by 0.310 equals 3.335 grams per cu. m.

The remaining values were calculated in the same manner and all the results are given in the table below.

<table>
<thead>
<tr>
<th>Date</th>
<th>Inlet (g/m^3)</th>
<th>Outlet (g/m^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 11</td>
<td>0.010943</td>
<td>0.0211</td>
</tr>
<tr>
<td>13</td>
<td>0.0439</td>
<td>0.0143</td>
</tr>
<tr>
<td>16</td>
<td>0.0452</td>
<td>0.0135</td>
</tr>
<tr>
<td>May 18</td>
<td>3.335</td>
<td>0.745</td>
</tr>
<tr>
<td>13</td>
<td>1.590</td>
<td>0.507</td>
</tr>
<tr>
<td>16</td>
<td>1.601</td>
<td>0.473</td>
</tr>
</tbody>
</table>

**DISCUSSION:** The results on May 13 and May 16 seem to check fairly well but on May 11 the dust content was much higher both at the inlet and the outlet. This may be explained by the fact that upon May 11 there was more suction being used to draw the gas into the Contact Process Building. This was fortunate in a way for it shows that the chamber takes out the same proportion of dust whether the gas moves slowly through it or quickly. If the proportion of dust leaving to that entering had been the same upon May 11 as on the other days, there would have been 1.01 grams per cu.m. in the outlet gas. But there is less than that, showing that the chamber works very well with the gas moving a little faster than usual.
CALCULATIONS: Now in order to find out how much dust per day was taken out by the chamber, the following calculation was made. On May 11, 18,000 lb. of ore were burned, each pound giving 0.462 lbs of sulphur as iron sulphide. From the data found in Lunge's Sulphuric Acid and Alkali Manufacture (Ed. 1903, I., 400) it is found that one kilogram of sulphur burned as iron sulphide produces 8144.9 liters of gas at 0 deg. C. Changing this value to cu. ft. per lb. gives 130.7 cu. ft. per lb. Hence 18,000 lbs. of ore containing 46.2% sulphur will produce 1,088,000 cu. ft. of gas at 0 deg. C. This is equivalent to 1,151,000 cu. ft. at 60 deg. F. But from the determination of the amount of dust in the gas it was found that at the inlet 1 cu. ft. of gas contained 0.0943 grams. Hence the total dust content of the gas entering the chamber was 1,151,000 times 0.0943 equals 259.0 lbs. The amount of dust leaving the chamber was equal to 1,151,000 times 0.0211 equals 24,300 kgs. equals 53.5 lbs. This makes 259.0 minus 53.5 equals 175.5 lbs. left in the chamber. Calling the efficiency 100% when all of the dust remains in the chamber, the working efficiency is 175.5 times 100 divided by 259 and equals 73.4%. The values for May 13-16 were calculated in the same way and all results are given in the table below.
<table>
<thead>
<tr>
<th>Dust entering per day</th>
<th>Dust leaving chamber</th>
<th>Left in chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 11. 239.0 lbs.</td>
<td>53.5 lbs</td>
<td>175.5 lbs</td>
</tr>
<tr>
<td>&quot; 13 136.0 &quot;</td>
<td>44.3 &quot;</td>
<td>91.7 &quot;</td>
</tr>
<tr>
<td>&quot; 16 146.2 &quot;</td>
<td>43.7 &quot;</td>
<td>102.5 &quot;</td>
</tr>
</tbody>
</table>

**Results**

Efficiency

<table>
<thead>
<tr>
<th>May 11.</th>
<th>73.4 percent.</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot; 13</td>
<td>67.4 &quot;</td>
<td>70.3 percent</td>
</tr>
<tr>
<td>&quot; 16</td>
<td>70.1 &quot;</td>
<td></td>
</tr>
</tbody>
</table>

This completed the experimental work and the thesis.
CONCLUSION.
CONCLUSION.

It has been shown that cotton is not a good filter because of its hygroscopic qualities and because it cannot be used on hot gases. Asbestos is a good filtering medium for non-corrosive gases with but little moisture. Filter paper may also be used but shows no advantage over asbestos, which may be used on hot gases which would burn the filter paper. Where there is much moisture in the gas or if it contains corrosive constituents filtration by aspiration through some liquid is the better method. One absorption bottle loses at least 3% of the dust but two bottles remove all but an inappreciable amount. It is believed that accurate check results on raw gas are very hard to obtain if not impossible. This is accredited to the fact that the dust content is not always constant even with a steady flow of gas. It is recommended that more work be done on the question of whether a bent or straight tube gives more accurate results in determining the dust content of pipes in which the flow of gas is horizontal.

The Howard Dust Chamber was found to be very efficient, the average of three days tests showing that of the dust that entered the chamber 70.3% remained there. As is seen on page 8, above, ordinary dry cleaners leave from 4 to 6 grams in the dust, and the sprinkling filter towers leave from 1 to 1.5 grams per cu. m.

Since the Howard Chamber leaves but from 0.4 to 0.7
grams per cu. m. it is vastly superior to any of the ordinary cleaners and even better than the wet filters.

The drop in temperature of 525 deg. between the inlet and outlet is also important in that it shows the chamber to be an efficient cooler as well as an efficient dust separator.

Respectfully Submitted.

Harold W. Paine.