DETECTION OF MINE GASES

BY

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I am under special obligations to the Ohio Institute of Mining Engineers of this State for the pleasure they afford me in giving this address. I was very much afraid, however, that I would have to postpone my address on account of what is now a fashionable complaint that is going about, called the grippe, which got hold of me for about thirty days, and I was out of sick bed one week before I came here, and consequently am a little hoarse.

I want to say that, in the matter that I want to present here to-night, the final purpose and object of all this apparatus is to give you positive evidence of the presence of dangerous gases, in contra-distinction to the negative evidence given by the Davy Safety Lamps. I was induced to take up this matter about four years ago, but I had causes that actuated me in this direction thirty odd years ago. I had occasion when I was in my teens, to make special apparatus for generating heat by gas to get the maximum amount of heat from the minimum amount of gas. We then had pure carburetted hydrogen and ordinarily one cubic foot of that gas would consume eight cubic feet of air, but in order to consume it properly it was necessary to make a mixture of the air with the gas, prior to burning, and when you did that, you made an explosive mixture. To prevent this explosive mixture from igniting, I resorted to Sir Humphrey Davy's discovery of the wire gauze partition made prominent in the safety lamp, and then I learned how impossible it was to construct a gauze partition between the gas and mixing chamber that could be relied upon at all. I found that there were times when the gas would ignite outside of the partition, and there was no guarantee against this troublesome feature no matter what character of gauze was used and it was a problem to me for a long time before I learned the cause, but it taught me one thing of the highest importance, that the safety lamp was only a safety lamp under certain conditions, which conditions of safety do not always exist in a fire damp mine.

Now here I hold in my hand the Davy Lamp of which I am talking. In experiments which I made with the mixing chamber I had the gauze in horizontal position and I had a draught to draw the flame away from the gauze in a vertical direction. In the case of the lamp here it is under more unfavorable circumstances because the gauze is in a vertical position.

There are five different circumstances under which this alleged safety lamp will ignite explosive gases. It depends on the percentage of $C H_4$ present in the air. There are times when a man could let the gas burn with perfect safety inside of his lamp, presuming the gauze is perfect; this flame can be permitted with six, seven or eight per centum of gas, but when that gauze is on fire with ten percentum of $C H_4$ (such as you find frequently in mines) a man is in peril of his life, and to move the lamp in a draught of 7½ feet per second as in the act of stumbling, or in a draught of seven or eight feet per second flowing over the lamp, it will surely light the gas outside of that lamp.

Now I don't want to condemn this lamp, because it has performed a very important office and always will perform it, but I believe, that lamp has caused many an accident that was attributed to other causes. Now there is a feature that I will illustrate furthur on, in reference to the ignitable character of these gases, that they do not always ignite at the same temperature, for example, there are times that you can, if you choose, smoke a cigar at a bright red heat which would be fully a thousand degrees (at the point of highest temperature) and yet fail to ignite the gas; and again at times these same gases will readily ignite at a temperature less than 270° centigrade. This makes explosive mixtures especially perilous. The reason I give for these quick changes is the "ozonized" condition of the air, and I will demonstrate that feature to you later on.

I propose now to submit this lamp to a critical test, such as perhaps none of you have witnessed unless I, myself, have shown it to you, for strange as it may seem, with my contact with thousands of mine bosses &c., I have yet to meet the first man that ever put his lamp to a critical test.

We have regular text books that instruct us how this lamp will behave in a certain manner under certain circumstances. I want to say that these instructions will have to be varied considerably to bring them more in the lines of exact truth. The other point that I want to dwell on is, the feature, that these gases are not made evident to our senses. That is the unfortunate part. We have evidence of that feature to-night by an accident in this city, blowing up two houses close to this hall. I want to say to you that it is possible for me to put this room in a condition so violent that when it ignites it would blow these walls out, and yet we could sit here as comfortable as we are now without any evidence whatever to our senses.

Since this is a fact, we are treating with an invisible enemy, and what we want, since our senses will not tell us, is to have some instrumental control that will give us positive notice, not of that negative character such as the safety lamp shows, but of a positive character that would be unmistakable to the unskilled. Take four per cent. of gas in the air and with the test lamp it almost takes a microscope to see it. Now four per cent. is a very high amount! It is a dangerous amount! It is dangerous to carry one-half of one per cent in the out-going currents. The igniting point of gases found in mines, (that is CH_4) occurs at six per cent. but there is no violence at that point as I will show by experiment later on. If I had four feet deep, up at that ceiling of this hall, of six per cent. marsh gas in the air, I could light it in one corner and it would seem like a cloud of steam moving slowly across the room, and this velocity increases slightly up to ten per cent. when it gets violent. That is pure CH_4. The igniting point of the gas of your main street here, occurs at about eight and a half per cent. I presume from this fact that this is either water gas, or is somewhat diluted. Now many people think that a very large bulk of gas is necessary to produce a disaster. I want to say that it takes a very small amount of gas. A barrel of gas is sufficient to produce a disaster, and I propose to give you some illustrations. I propose now to put a mixture of this street gas in that cylinder gas gun such as will make about fifteen per cent. While my assistant, Mr. Fitts, is filling that measure, I want to say that the Fire-boss will still go his rounds and carry, as part of his duty as Watchman Extraordinary, that lamp, but this system aids him in his efforts to an exact knowledge of the condition of the gases, and we will show you later on, that by this instrument he can tell before he goes down into the mine, the general character of the gases in the mine. He is always a Watchman Extraordinary to look for falls and other matters and he will always be a necessity in and about the mine.

Prior to the invention of this lamp of Sir Humphrey Davy, three-quarters of a century back, the people in England dug for coal until they came to gas, and then they ceased to dig for fear of disastrous consequences.

In Richmond, Virginia, Englishmen who came over here in our early history and dug one shaft after another,—and that district bears evidence now of numerous shafts—ceased as soon as they came to gas, hence this Davy lamp with all its faults, has been a very valuable invention, in offering a measure of safety to miners in gaseous mines.

While Mr. Fitts is filling that cylinder I will give you a a simple illustration here which was one of the earlier experiments of Sir Humphrey Davy, where he made the gas burn above the gauze and he believed at that time that it was a perfect partition between the flame and the ignitible gas, although he afterwards declared that it was not a perfect protection. Of course the party using it, being careful to carry the lamp in the low percentages, it is a perfect protection. If this chamber was confined and the gases mixed in proper proportions you would have ignition in the chamber below.

This gun test is useful in making a number of experiments, more than time will permit this evening. Most of the gas in that chamber has gone to the top by means of levitation. I mix it more thoroughly by inverting it for a short time. Now that gas should be ignitible at the touch hole. [Fire being applied at the small touch-hole an explosion followed.]

You see it was quite violent although the contents of the gun is only seven litres, and about one litre was used on this occasion. Now imagine what a barrel of gas would do under like circumstances.

Of course we have now the after-result, the presence of choke damp CO_2 which you all know is fatal to animal life, and where a large quantity of gas is exploded, the foul gases blow through the mines and asphyxiate the men.

The only time that carbonic oxide is generated is where there is an excess of CH_4, marsh gas permitting only one supply of oxygen. For example, where the mixture would run up to twenty or twenty-five per cent. there would not be enough oxygen to reduce it to CO_2. I have met men who were overcome with this gas and they seemed never to have fully recovered from the effects of it. The problem to solve and the one I want to present is, how are we to have any instrument that will in any manner recognize the presence of these gases, and how shall we take hold of these gases and get instrumental control, and have positive evidence of their presence? I have a diagram which I presume can be seen at the back part of the room. [At this point the lecturer made an explanation from the diagram, after which he continued as follows]:

We are hunting for some constant feature in these gases whereby we could take it as a means of measurement. I found that the igniting line was a proper line of demarcation that could be taken as a point of measurement, and that at that line, at the first point of igniting, the flame was so pale that we could not observe the flame, but it was made evident by the expansion of the air in that tube by the ignition, and it had sufficient expansive force to propel a piston valve against a gong making an audible sound. Now that feature struck a line of demarcation between the ignitible and the non-ignitible gases, that placed it beyond the pale of argument, because whenever that gong would ring no man could argue that the gases were not ignitible, for the reason that it was the act of ignition that caused it to ring, and if it refused to ring no man could argue that the gases are ignitible, because they are flowing over an igniter in the center of tester, and the gases are caused to flow out of there continually, and when ignited, the result is as demonstrated here, an audible sound.

This instrument is now located on this table. I presume that you all can see it. [At this point the lecturer made an explanation of the machine, using the machine to illustrate, which would not be intelligible on paper, after which he continued as follows]:

Now, that is the character of the sound. And that admixture of gas could be ignited in the mine chamber without any unfavorable results as it is not explosive. The man who is in charge of this instrument at the table has positive and full knowledge that the gas in that mine is at a dangerous point, but the miner does not know. I will now depress this key and blow a whistle in the mine with air under high pressure, which sounds a whistle in the mines, but the man at this instrument has no knowledge that that whistle has been heard until the man below sounds a whistle up here, which he does by the simple act of pressing the rubber tube. Now you have a positive signal downward, and a positive signal upward, and a positive test of the gases. Those three acts are performed by that one tube. Now I think I have given you evidence here, that this test is of the most positive character so far as the gases are concerned, because a blind man would know that in any section of this room. If that lamp was carried in that same gas that rings that gong, you would have to watch it very closely to see a slight change in the lamp. After I had made that part of the instrument, I expected to stop and thought that my labors were done in solving that one problem of positive test, and when I first announced that discovery to a scientific body and that I had produced an instrument for the detection of gas in air that struck a line of demarcation between the ignitible and the non-ignitible, and that said line was sharp within one per cent., they applauded it as a wonderful event, and the instrument a great invention, but it is in point of fact sharp and accurate to the one thousandth part.

Instead of having my labors finished, having accomplished the only one feature I started out to accomplish, viz., the construction of an instrument to give positive tests of the ignitible gas in the air, I found that in point of fact my labors had only begun, and that the construction of a new invention in all its various phases by man is not very unlike the construction of a plant in nature; presuming that man had the power to construct a tree he might start out with the idea of constructing only the trunk of the tree, but he would soon find out that to complete the work, the roots and the branches would have to be provided, and finally the leaves and the fruit, and so this thing grew upon me faster than I expected. For example, after I had located this instrument, I thought it would be much better to bring the gases to the man, than to send the man to the gases, in order that we might protect the fire-boss that much before he went to his work. This feature, however, possesses no novelty as the tubes have been used for over thirty years in bringing gases from mines, and I do not claim anything new or novel in that.

Now, in handling this signal system, by the act of opening this valve, I blow that whistle (supposed to be in the mines), through a length of 700 feet of tube. That sound travels a mile a minute in a ¼ inch tube with 100 lbs. pressure, and it indicates to you so far, one signal. That whistle means something, whatever you want it to mean, and when the miner whistles back it means only that one thing too, adapted to any pre arranged signal.

Now I want the two to be able to communicate with each other, and I wanted also to increase the speed of these signals. This air pressure traveling only a mile a minute is very slow compared with the electric current, but it is lightning speed compared with the special messenger system employed about mines. I found that if I struck a pipe like that ¼ inch iron pipe, that you will hear it at the other end; this is a common matter and well understood, but that sound is lost ordinarily in the quarter of a mile. I found, however, that if the pipe was suspended in an elastic or flexible manner, and a tuning fork of certain tone placed at one end, and a similar one placed at the other end, that that sound travels three miles a second, so that we only use the whistle as a call, and the talking is done by rapping — like that [strikes the fork with ¼ inch rod]. That will travel three miles a second.

I constructed a code of signals whereby we could communicate with the miner, and in establishing that code of signals we had to take cognizance of the fact that men of various nationalities were working in the mines, and also that it was important that a man of ordinary intelligence could learn the code in a few minutes. I might have adopted the Morse system, but it would take six months for the miners to learn it. I so arranged this code that I can send an English message to a German who knows nothing of English and he will receive it in German, and he can send me a German message back, and I [I know nothing of German] will receive it in English, in other words this code interprets any language. That sounds very ludicrous until explained. The code is constructed in this way. This card is laid off in squares, and we have from one to seven on the top column, and one to nine on the side column. The one square means yes. That is in the upper left hand corner, and it means yes, in all languages, for if the party is German he carries a German card and spells it yah. That applies to any other language. Suppose, for example, I will read some of these squares off. All hands come up; that is, 4–4. Suppose any one of you gentlemen had this card and I sounded 4–4 taps, what does that mean? Well? There is the figure 4 in the top row and 4 in the side row, and in that corner the signal reads, "All hands come up," and that 4–4 is given in this way by taps upon the tuning fork, and this method of signaling can be learned in a few moments of time.

Now the signals that I have provided here are largely to prevent accident, and to render aid in case of accident, and also to aid those working in the mines. Here is one signal, "Come up the slope." What does that mean? It means that the manway is cut off or some accident has happened, and how often in times of accident we desire to send a message quickly to the mines. Any one who has worked about the mines, knows when you have an accident and desire to warn the men in the mines, how unreliable a special messenger is at that time. He is tempted, for his own safety, to hide in some place in the gang-way long enough to come out and report his message delivered, and the men have no information at all. There was a case of that kind in the Connellsville District I am told, and the men were killed in consequence. But this messenger [touching the key that sounds a whistle in the mines] — has no fear and runs no risks. It travels a mile a minute and in addition the operator can communicate this way through the sound system that I spoke of, which travels a mile in one-third of a second. So you are enabled to warn your men and receive intelligence from them. I regard it of the highest importance to have this communication with the men in times of danger.

Now, you might wonder why I adopted that system of carrying the sound in preference to ordinary methods in commercial use; it is because the instruments in commercial use will not work in a mine. For example, if the bell-pull were used, the stretch of wire is so great that it would be impractical except in modern lengths of slope or shaft, and the speaking tube would fail to carry sound the distance required. The telegraph and telephone are dangerous in a fire damp mine for the reason that both of them will at times carry the static or the silent current, and the silent current alone will surely ignite the gas.

I want to give you evidence that the silent current which is so low in tension and heat, that it will fail to ignite gun-cotton, and yet will ignite these gases readily, and I assure you that the mere rubbing of your coat, or certain substances, or rubbing your slippers over the carpet floor may ignite it, as you may have seen persons (in a certain experiment) rub their slipper on the floor and then ignite the gas with their finger. Now I hold, if it is a fact that the silent current which causes no more sensation to your finger than a cob-web, will ignite these gases, that it is dangerous to run a wire through a fire-damp mine. I regard this feature as unfortunate, because we should be able to use electric light in mines, and this can only be done by preceding the light with a test instrument of this character.

I have fitted up the Morrell mine which has over fifty miles of passage ways, and is a very gaseous mine. When we put this apparatus in we sometimes had as high as seven per cent. of gas over a large section, and frequently a violent mixture. Now we have a record of that mine and perhaps it would be pertinent at this time to speak of it. The instrument has been running there some nine months. Here is a record of August 5th, where they carried 17.2 per cent. in the morning and 15 per cent. in the afternoon, and here is a circumstance that had arisen during that day. The Superintendent was in the office at 4:45 P. M. That is, he was in the office where this instrument is located and he learned of the fan having stopped through a test of gas a mile distant, before he got information from the fan house one square distant, which shows how quickly any alteration in the air is detected by this instrument. We have a number of pipes that run in that mine and those pipes all lead to this one instrument; in that case we maintain a partial vacuum in a chamber like an ordinary cylinder boiler and we have a steam ejector that maintains a vacuum of 14 inches of mercury in the tubes and these different tubes all connect with that chamber, and the gases that they bring up are blown to the outer air by the steam ejector. There is a pump on the table of three times the capacity of this testing chamber running thirty strokes a minute. That takes a slice of gas, so to speak, out of say No. 10 pipe, and on the down stroke it delivers that gas to the instrument and the instrument reports whenever gases are dangerous, and if the operator desires, it will continue taking from pipe No. 10, so long as he desires; or it can be allowed to change from pipe to pipe automatically with every stroke of the pump, so that the operator can be sitting at this table and reading a paper, or attending to any other matter, so long as the air is in a safe condition in the mines, receives no signal, but if that gong rings he knows that the gas is running to a high percentage in the mines but not violent, because the indication occurs at six per cent., which is four per cent. ahead of the violent line.

By looking at the disc valve which is indexed for each separate location, you will notice, that when the gong rings the operator will find it at No. 9, 10, or any other number, and he knows by that which section it is that affects the instrument. We have a series of valves on the table, all connected with air under high pressure. The operator goes to the valve No. 9, for example, and depresses the key which sounds a small whistle in the mines and lets the man know in No. 9 that he wants his attention, and through the code of signals informs him that the gas is accumulating. To show the importance of quick and accurate tests of explosive gases I have known [in the mines in Penna., where we have this system] the gases to change to dangerous proportions in five minutes time, and that has occurred in these mines dozens and dozens of times. If the operator will watch that section that reported an accumulation of gases, he will find in a few minutes that it is blown or brushed out by the miner in that section, unless something has occurred to prevent him, in which event the instrument will continue to show danger.

Referring again to this signal chart there are many things of importance in it, and I am sorry that you all cannot see it as clearly as I do, being at a distance. All the signals sent up from the mines are marked with a red dash so that a miner who wants to send a signal upward looks for the red dash and finds it at once. But they are readily committed to memory. I tried the experiment on a young man from the country and not well up in these matters. I said one day I will give you ten dollars to learn that by heart. He came in one day and said he knew it. I said, give me the chart. He stood at a distance and I rapped off the signals and he could answer them all from memory, and I found that he had learned it readily and it induced mé to so construct the chart as to favor memorizing.

I will give you an illustration, in one section of the signal chart to show you how quickly you can memorize the portion referred to. The numerals for example, which stand under column 8, are numbered on the side of each figure from 1 to 9, so that 8 taps or signals means 1, and 8 taps followed in short interval by 1 means 2, or 8–2 means 3, in short, the number intended is one more than the last signal, as 8 and 4 taps means 5. This simple illustration applies to all the figures, and I think now, from the example here shown, that any person in this room could now signal any desired numeral from memory alone, and give quickly any number wanted.

Of course I cannot delay long on this subject. I could talk all night on signals alone. This same feature applies also to this alphabet in spelling out any desired words, and I think that if a moderate reward or premium were offered to miners they would readily learn this system of signalling, and the miners in that case would know nearly everything that is said up and down the line of that pipe, for the sound signals can be heard more or less throughout the entire length of that pipe. Now before leaving the pipe question I want to show you the many useful offices that are performed by that pipe. In the first act the gases are brought up and tested in a quick and positive manner. They are not only brought up and tested but large quantities of gas are removed in the act of testing. We remove some 900 cubic feet, in the act of testing, in 24 hours, this quantity will vary of course with the length of tube, and it is possible to carry these tubes in a much larger diameter and remove larger quantities of gas. Wherever this feature is relied upon, for removing gas from dead ends &c., the value of removing several hundred feet of dangerous gas from a dead end not accessible to the ordinary ventilation, can best be determined by observing the effects of a small quantity of gas combined with air in explosive proportions. I could astonish you with the explosions I could produce with 6 cubic feet of CH_4, and 10 cubic feet is sufficient to produce a disaster with fatal results.

I have shown you here in practical tests that it not only tests the gases but removes them in the act of testing and that it is possible to signal downward and upward, but in addition to this there are other useful offices performed. We have here in this cylinder high pressure air, in this case only a small chamber, but in point of fact at the mines, a cylinder some 12 feet in length and 3 feet in diameter, carrying 80 to 100 lbs. of pressure air. We have a duplex steam pump, for pumping air with capacity enough to supply every tube that runs to the mine with air at high pressure whenever called for.

Now there are times when a man will give everything that he is worth in this world, for that single privilege. Suppose, for example, that a man is buried up, in a chamber of narrow limits, his first great want is air to breathe and his second great want is some means of communication with those outside of the mines. Under our old system they have no means of informing those outside and they have to wait until they are hunted out by every species of guess work at long range from the point of disaster.

Under the system, here practically exhibited before you, the miner has a means of communicating above, and letting them know his position. When he signals up "Reverse the current and give us air," this key that controls the valve in that case, is locked down. You hear the air rushing out under high velocity. Now that can be maintained for an indefinite period as the pumps are operated by steam. We can send enough air down under high pressure to sustain the lives of twenty men. What a God-send that would be in the thousands of cases we know of in the history of mining. It has occurred within a few months in my own State, and you have incidents of this character, I have no doubt, in your own State. The first great want of men buried in a mine is air, and we can supply their wants in the manner described. There is nothing to prevent us supplying drink or liquid food in the same manner. See what a valuable thing that is to an imprisoned miner and at what slight cost. The pipe exhibited here is the same as used in the mines, and the total cost of pipe and labor is $150 per mile. What is the interest on that? $9 a year. Are you willing to let your men run the risk of asphixiation or starvation at the extreme ends of these mines, for the sake of saving $9 a year? In addition to the advantages I have set forth, there is another useful office that can be performed by this same pipe. We know that one of the ready means of extinguishing fires is carbonic acid gas, especially in chambers not accessible to water. Ordinarily when a fire starts, the fire is under such headway, before any means of extinguishment is afforded, that you have to drown the entire mines out to save the property, at an expense so great that it at times consumes the entire value of the property; but where you can brick off your sections you can quickly extinguish the fire in the mines by carbonic acid gas, when you have the means at hand as you have in this pipe, for quick application of the same, and in cases where water is desired for extinguishment of fires of moderate degrees, the water can be had for the same tube.

I have found more prejudice against the insertion of these tubes in mines than any other feature of my system here exhibited. It has been claimed that the tubes will break, or that they might crush under falls, &c.

The steel pipes that we use are malleable and can be bent cold in a spiral, around a rod ½ inch in diameter without crushing or breaking, and the pipe could be laid on the hard pavement of the street and tons of slate and coal could be thrown upon them from the roof of this building without crushing or breaking the same. I, however, will not take the position that it will never break in practice, under falls &c., but from actual experience with this pipe in the mines, I am satisfied that it will hold intact 99 times in 100 falls, and where there are a number of pipes in one mine, we have the chance in many cases of useing the pipe of an adjoining chamber. Ten of these tubes will be sufficient for many mines, and a maximum of 40 tubes will supply most of the largest mines, and in old mines where the working chambers are located a great distance from the outlet it will often pay to bore a ten or twelve inch hole from the surface over the workings to shorten the pipes that much, and lessen any risks of falls, &c., in long lengths of pipes.

Now I want to take you to a refinement of this system. I found, in my travels around, that the Inspector although authorized by law to look after the interests of the miner in the mines, that he was utterly impotent of apparatus to give him any positive knowledge so far as dangerous gas was concerned, and that all the tests heretofore made by the inspectors and by the superintendents and every man around the mines was purely guess work and their guesses on the presence of ignitible gas had a range of fully 5 per cent., which means 80 per cent. toward the ignitible line without any definite knowledge of that fact. Now that sounds very ludicrous, but I am going to give you some evidence of it here in the latter part of my lecture. What I concluded was necessary at that time, was, that we should have an instrument that would not only give positive knowledge on this point in a quick and certain manner, but one that should measure the per cent. so that the inspector, or any official in power, where there was a doubt or a dispute could say, "You are carrying 1 or 2 per cent. of CH_4, or CO_2, or a compound of these gases," as it may occur in actual practice, and thus remove it beyond the pale of guess work. The men about the mines can guess on this question and can make probably as good a guess as the inspector; it therefore gives the inspector no superiority on this question under the guess work system of lamp tests, but I have provided him an instrument that is accurate in the highest degree and is sensitive to the one thousandth part of fire damp and competent to measure all percentages present in the air.

I found that it was absolutely necessary to have an instrument of this character, in order that the inspector could go to the mines, with an ordinary bag like this, holding 5 gallons, when he desires to settle some question of this character. This is an ordinary diaphram pump that I have in my hand, made light for convenient handling and these 24 inch long extension tubes enable you to lengthen out so that you can take gases from high points in the mines. Now by simply vibrating this pump with thumb and fingers it draws the air from upper point of tube and is delivered in this bag. Then you simply pinch the neck of the bag and cork it with an ordinary cork, and the inspector throws it in his carriage, or in any way he pleases, takes it to his office, where he has his instrument and there makes his test in a few moments of time. I will now show you how to make that test. I want to say that having been engaged in operating mechanics and in engineering operations of varied character and active duty as superintendent &c., &c., for thirty odd years, that I never touched any device that so taxed my ability and patience as the machine I now have before you. The statement I made in my commencement was that I announced before a scientific body that I had a line of demarcation so sharp that it was within one per cent., and that they applauded it as a wonderful event and I was satisfied at the time with that breadth of line and I was willing to stop there, but I found that when I went on with the refinements of this system, that it was possible to have a line of demarcation in the narrow limits of the one thousandth part, and I will here give you illustration of a line of demarcation within the one thousandth part or the one-tenth of one per cent. That sharp line forced me to the most exact construction of this mechanism, and really gave me a great deal of trouble and expense. I found it practically impossible to bore these cylinders to the required and exact diameters and obtain exact duplicates of the same, and I had to construct hydraulic apparatus to make these cylinders correctly.

I found that I could not get these cylinders correctly drawn, even by men who made tubes for telescopes &c., and I was compelled to construct machinery for that purpose, otherwise I could not make two machines that would measure the per cents. alike and the same difficulty was encountered in laying out the scale of percentage upon the beam of this instrument. I have all the degrees calculated and laid out on that beam so that the party who is testing is not required to do any figuring. The degrees are all laid out ready for him to read off in the scale beam. In order that you may understand the principles upon which that instrument is constructed and operated in testing of gases of low percentage, or below the igniting line, I will explain the same ; for example, the gas of the street main here which I will now use, has a definite igniting line; if the igniting line of the gas of our street main is 8½ or 8.6 per cent. for example, how am I going to measure one per cent. by the line referred to, using this street gas as a standard. I can illustrate that feature and possibly make it clear to you by citing a parallel—and, if you choose, an imaginary parallel. Suppose for example, that 6 per cent. of alcohol in water would make that water a bright red color, we would then have a brilliant test for 6 per cent. of alcohol in water. But how would we test for one per cent. ? By adding one per cent at a time to the solution until we arrive at 6, and finding that we only added 5 per cent. it would be evident that 1 per cent. was there before. This is similar to what I do in this case here. This large cylinder of the instrument has a capacity of 800 cubic centimeters.

[At this point the lecturer illustrated practically from the machine the method of doing it and showed how to establish the standard line and how to measure from that point.]

You will find in testing gases in that manner that you have certain valuable information always to compare with. That is, if you have a pure carburetted hydrogen, take a rich gas that will ring at about 4 or 4½ per cent., take water gas and diluted gas and it will ring in the neighborhood of 8½ per cent., whilst mine gas, pure marsh gas, CH_4, will ring at about 6 per cent. [Gong rings.] That is 9. It will ring at a lower point. It is now moved ½ of 1 per cent. at a time. When we are moving closely for exactness we will move the one-thousandth part at a time, that is about the one-fiftieth of an inch on that bar and in doing so you will find that the difference between ringing and not ringing the gong lies in the one-thousandth part. My assistant, Mr. Fitts, will now retreat or go forward, and in whichever direction he goes he will only move the one-tenth of one per cent. and you will notice that when it ceases to ring, that the ringing and not the ringing line lies in that one-thousandth part. That makes the line of demarcation about as sharp as exists in the test tube between oil and water, and gives us a point of measurement and performs in this instrument the same office that the freezing point does in the thermometor, gives you a line to measure from.

It is now at 8.3 per cent. You have evidence of it but it does not ring. We will now return to the ringing point. Of course you who are at a distance, do not know whether we move the distance that I state or not, but those on the platform can observe more closely and know that that is the distance that we move and I am going to give a private test with some of the professors of the Ohio State University, where they can stay close by and watch the fine degree of this instrument at work. There, you notice that the gong rings this time, and the movement he made was the one-fiftieth of an inch, or the one-thousandth part. So I give here practical evidence that the line of demarcation lies in that very narrow limit. Now that instrument is in condition for testing gas present in the air in any fraction or per centum and to give that a practical illustration I can reverse this instrument so to speak—that is, set it so as to pump a bag full of air with any desired percentage of gas. For example, we will pump up one-half of one per cent. for illustration, that is, we will pump up 199 inches of air to which is added one inch of gas equalling ½ of 1 per cent. of gas. Now this is the only instrument extant that is competent to perform this act, and I make this bold declaration that there is no other instrument in God's world that is competent to measure that percentage of gas in air. In that bag he has one-half of one per cent. of gas. Now there are other means of filling that bag with gas and air for testing gas independent of the instrument we have just operated. Suppose you are suspicious of the instrument and we wanted another means of filling the bag with air and gas, we could take the means I adopted on the other table [explaining from instrument] using from inverted jar with colored water. In this way you can measure gas as accurately as any liquid or solid. So if at any time we are suspicious of the accuracy of the exact measurement of the new instrument we can take this means of determining its correctness. Now we have here in this bag ordinary air and in every one hundred inches of that air we have one-half of a cubic inch of gas. There is only one cubic inch of gas in two hundred inches of air present.

Now the question is, will this instrument recognize the presence of this small amount of gas that is in the air? And we will again endeavor to discover if our established standard line has altered in any respect, and in doing that we will go back again to the line of demarcation where it just rings that gong, and then retreat from this point a quarter or a half or one per cent., or whatever we deem necessary for the gas we are testing. We retreat from here until that gong ceases to ring, any distance, a quarter of a per cent. or a half per cent., and then we apply the air in this bag to the large cylinder, which has heretofore taken pure air alone, and connect with rubber tube the pipe on the large cylinder and we know that this bag contains some gas because we put the gas in. We now just have it at the point and no more, and if we retreat downwards on the scale and get the point where it ceases to ring, the proper standard line I want to say is just where it rings and no more. Now we have it at the ringing point, and if we retreat the thousandth part, it will cease to ring. Now we move a fraction [illustrating]. You see it does not ring. The only change we now make is that we connect this bag of air and with its fraction of gas on the pipe. That connects with that large cylinder, and and the air, instead of being taken from this room is now taken from the bag. That is the only change we make. [Gong rings]. Now you will observe that the gong rang on testing the air in the bag. Now let us see if the air in this bag is the cause of the gong ringing. I will remove it by disconnecting the rubber tube. [Illustrating]. You will observe the gong does not ring. Now I will apply it again in order that you may have proof that this is the cause of it, and that this test is recognizing that small fraction. [Gong rings]. Now, observe, there is the half of one per cent. shown in the scale beam, and I repeat, that there is not another instrument in God's world that is competent to measure this fraction of gas in the air, but with this instrument a blind man would know it across this room, the test being of such positive character. Of course you could take any other fraction, smaller or larger.

Suppose, that instead of being one-half of one per cent., that a person had brought gas to me in a bag of unknown quantity and larger per cent. of gas, and wanted me to test it. In that case, if this gong would ring sharply, I retreat from the standard line with the small cylinder until it ceases to ring or is just at the ringing line. Then the measure of ignitible gas in the bag is the per cent. that is between these points, that is, the point established as a standard and the point, moved to. Now, the standard may vary considerably, without any alteration in the result, for the reason that the standard is always established before tests are made; between here and some other town they may vary four or five per cent. as a standard, but it gives you no alteration in the result. I have provided tables running from 6 per cent. up to 12, jumping ½ a per cent. at a time, but it is scarcely necessary to use the same, for with this beam, if you have the standard, you take your measure between these points provided, in the clamp on the beam and the point shifted to in the beam. Now, coming back to these fractions of per cents again, I propose that the Professors who are present shall take an hour or two to-morrow, to carefully test different mixtures of gases where they will be in close contact with the instrument. I know that you gentlemen being at a distance that it is impossible for you to see much of the finer movements of this instrument, and that you have to take much from my statements which you cannot witness, but our Chief Inspector of Mines is here to-night, and he, together with the Professors, will be present to give this instrument a critical test to-morrow. I referred, in the early part of my lecture, to the slow velocity of these gases at the low or first igniting point, and I want to illustrate that feature to you. I now, with this instrument, am able to give you accurately any per cent. you desire, and at the same time I am enabled to show you one or two tests here with reference to the effect of the silent current, which "ozonizes" the oxygen and shows the wide range of temperature required to ignite the gases under different circumstances, and I will light a cigar to give you the illustration.

I have here an ordinary Holtz machine which will give me the regular static current, or switching off the condensor will give the silent current. The reason I employ this machine is that it is more continuous and more evident at a distance, and those who know this machine know when I have the silent current. I have thrown the switch off here so that we have the simple silent current. I don't think any of you gentlemen doubt the fact that the silent current will ignite these gases. No doubt many of you have made the test that young men often make rubbing their slippers over the carpet, and lighting the gas with their fingers, and that is all I am doing here except I have more of it, in having it continuous. I am smoking this cigar for a purpose and not for comfort. Now I want to give you evidence first that the gaseous mixture with air will ignite with the silent current. Now you will observe that it has ignited in the blue flame traveling back the long glass tube. You have positive evidence there of its ignitibility with the silent current, although it is a pretty high per cent. (nine per cent). You have evidence of the velocity of the gas, which is quite low, and that is the character of the gases that the fire bosses sometimes light in the gangway, to see it roll along, but it is a pretty dangerous experiment, because if the per cent. present be 7, 8, or 9, it may be all right, but if it is up to 10, he will never live to tell the tale of the disaster he will produce from presumed innocent mixtures. Now I have shown you that the gas does ignite with the silent current by repeated ignitings.

There is no trouble to get that current. You can get it by friction on this glass or a change in atmospheric condition will produce it and conduct it in a long wire. That is one reason why it is perilous to put a wire in fire-damp mines for telegraphing or telephoning, or any other purpose.

It is important that the mines shall be free from these gases in such portions that they would refuse to ignite before you do that, because they surely will ignite under the conditions I have shown you.

I also made the statement to you that this same silent current was not competent to ignite gun-cotton. I want to give you some evidence of that fact. This is ordinary gun-cotton, and I have placed the gun-cotton between the points of the conducting wires and run the current through it. Now this gun-cotton will ignite at 270 degrees centigrade and it refuses to ignite there with a continuous silent current. Now there you have that demonstration, and if any person sees any error, or wants any part of this test repeated, I will repeat it with pleasure. I now want to show you that a bright lighted cigar in the same gases that ignited here with the silent current, will refuse to ignite, although the temperature, when I draw that cigar rapidly [in the act of smoking] in, the hottest portion runs up to 1000 degrees. You might smoke it there for an hour and it would not ignite the gas, because the oxygen is in a passive state and not in the active state, induced by the silent current.

I will ignite it here again to show you that the gas is present, and flowing through the large tube. You will observe that it is ignited.

That is the same per centage of gas that I tried to ignite with the cigar.

It is very important to know that fact, because it tells you that there are times when your safety-lamp places you in greater peril than at other times.

When we have one of the blizzards from the north-west, and you are pumping a large amount of air highly ozonized into the mines, that is the time when it will ignite at a low temperature when combined with $C\ H_4$, in ignitible proportions. I believe that I am alone in this discovery of wide range of temperature of point of ignition. At all events I have worked it out myself, and have never been contradicted or challenged on this point.

I will now place the gun-cotton where I can ignite it with gas and show you that it is gun-cotton. [Explosion]. We have opportunity now to put the lamp to a crucial test, which I propose to do. In making this test of the lamp I am enabled with this glass jar which covers the lamp, and by means of the combined pumps that I have here, to pump gas over the lamp having a predetermined or any desired per cent., and in doing so I want to ask some of the gentleman in the audience who are skilled in handling the lamp to come up here and observe the lamp closely. I see Mr. Rae sitting in the audience, and I know that he is well posted on the lamp tests. Mr. Rae, will you please come up here?

Mr. Rae. There is a gentleman here who has been in the habit of working with lamps; here is a gentleman who has had considerable experience.

Mr. Shaw. Chief Inspector Haseltine will also watch it and report to the audience. Now, in the first place, you will please set the flame of the lamp to suit your judgment. Prof. Lord, who is close to the instrument, will watch the per centage, and our friend who has volunteered to hold the lamp, will make the test. I am going to put this glass cylinder over the lamp, and give you different per centages of gas, and I want you to tell the audience whatever change you see in the flame of the lamp. (As this lamp test is a test of the change of flame of the lamp, and as the audience cannot see it, I would like to have this gentleman tell you just what he sees). I regard this test, gentlemen, as one of the highest importance, one on which you would not sacrifice any time if you were to sit here a week, on this subject. I don't believe that there is a gentlemen here, unless I have shown it to him, who has ever put his lamp to the crucial test. If it is otherwise, I wish that he would come up and convince us of the fact. This is a crucial test of the most perfect character, and I can make affidavit that the per centage state to you is the per centage of gas that is delivered by that instrument as accurately as we can weigh or measure anything.

Now it is declared in our text-books that 2½ per cent. puts the first cap on the flame. The lamp, of course, is now in pure air. When I put this glass dome chamber down, covering the lamp, I place the lamp in a different atmosphere. This chamber contains air carrying 2½ per cent. of gas. I want you to notice what difference there is. The flame should elongate. I find that the fire-bosses all have their own way of testing.

The majority of our fire-bosses, however, test with very low flame, a very small flame. Now I will lift this glass cover exposing the lamp to the pure air again. I want this to be a plain, honest test, conducted with every care possible, and we will make note of the observation. This gentleman thinks that there is a difference of four apertures. We will take it for granted that there is a difference of four apertures. If we were making that test as I now do between pure air and air carrying a per cent. of gas, the sharp lines and quick change between air and the air carrying this gas we might discover that fraction. But bear in mind that the man carries this lamp several hundred yards before he gets to the gas, and we must bear in mind also that the flame of the lamp will increase by reason of the heat of the lamp before he gets there, and when he examines the lamp at this period, and elongated a slight fraction, he is at a loss to know whether it is the heat of the lamp that increases his light or the presence of gas, permitting only a guess work conclusion. From my own experience in the testing of this lamp, I believe that it is best to carry a very small flame, because you can measure the fraction of alteration easier in a short than in a long flame.

You are satisfied there is a difference to the flame, here?

Mr. ——. Yes, but it would be almost imperceptible.

Mr. Shaw. It would not be such a difference that you could make an affidavit to it?

Mr. ——. No, sir.

Mr. Shaw. Now, mark you, here is a gentleman who is skilled in this matter. Personally a stranger to me, (but Mr. Rae referred him to me, and I know that Mr. Rae is skilled), but he is in doubt at 2½ per cent., and could not make affidavit of his observation, it being so much in doubt, whereas you could make affidavit to one-half of one per cent. on this new instrument of test. Now we have 3½ per cent. of gas in the air flowing over the lamp. I lift it up in order that you may notice the difference between the sharp line of pure air and the air that contains this per cent. of gas.

Mr. ——. I notice that there is considerable gas, but there would not be danger of it exploding.

Mr. Shaw. If you had no knowledge that I was pumping gas over it, could you make affidavit that there was any gas?

Mr. ——. By noticing that light before I went into the gas and afterwards, I would notice that there was gas in that place, that is, taking the light before it is covered, and then looking at it after it is covered, I would discover that there was gas there, but not dangerous.

Mr. Shaw. I am now going to run a higher per cent. Now we have 4½ per cent.

Mr. ——. The light is lengthened.

Mr. Shaw. We have a good many observers here, but I guess that there are few who could make affidavit to that.

Mr. ——. How much oxygen is there in that?

Mr. Shaw. That is the pure air in this room with 4½ per cent. of gas.

Mr. ——. Does not the light consume the oxygen?

Mr. Shaw. Yes, there is a consumption of oxygen, but with the amount we pour over it, it really would not effect it. Now I propose to take a higher per centage, 5½. I think this is the only time that I have met a person who uses the large flame for measuring presence of gas with the lamp. Now you can see that there is an evident lengthening of flame, of course, as we have a very high per centage, 6½; and I desire to state, that if there is any gentleman in the audience that sees any error or fault of any kind, in the tests that we are participating in here, I will be pleased to have him mention it.

Mr. ——. I think, Mr. Shaw, that the same conditions are not there that would be in a mine. I think that the light consumes the oxygen in this glass or tube, and consequently that light wont burn as freely or indicate the presence of gas as readily as it will where there is a sufficient amount of oxygen along with the carbureted hydrogen.

Mr. Shaw. Well, this is the first time that I have met any man who claims to know anything about the subject who did not put the flame down to the lowest point possible where it consumes the least amount of oxygen. I want to say, that if there are any gentlemen who would prefer to come up here on the platform, they can do so. Now we have 6½ per cent., that is a very high amount, and I will remove this so that those who are near can all see it and replace it. Here is Mr. Rae, and I would like to have him see this. Mr. Rae, please step around here. We now have 6½ per cent., and I am removing this in order to show what difference there is in the air and in the air containing 6½ per cent. Now, I want to say as a fact, that the measure of gas in the air pouring over that lamp is 6½ per cent., and it does not make any difference in its effects, whether it is there or in the mine.

Mr. ——. Is there any pressure there?

Mr. Shaw. No, sir; because it is open at the bottom. There is no pressure.

Mr. ——. I can detect it by the blue haze around the light without the tail on the top of the light.

Mr. Rae. You will see that it is not so much the tail on the light as the haze around it.

Mr. Shaw. Now, I will give you 7½ per cent., and go on in this way until the flame will ignite. What I wish you to notice is, that with all the tests with the lamp, you almost require a microscope to observe any alteration, and you are obliged to have a very wide range of per centage to see anything, whereas on the new instrument, a mere fraction is shown in a positive manner, and it measures the fraction for you. Now, we have 7½ per cent. That is very high. I want to say to those who have to use the lamps that the more they make this test the less confidence they have in the lamp as a means of testing. Now there is a blue flame burning up in the center.

We have now 9½ per cent. It is very prominent, and anyone would know that the gases are present. Now I will take the current off the lamp and turn it on the new instrument in order to make the contrast. We do that by simply turning a disc valve one-sixth of a revolution. Here you have to watch with the lamp closely and with guess work results, and in the other instance with the new test instrument you have tests of the most positive character and of the highest degree of accuracy.

Mr. ——. I notice, Mr. Shaw, that gas don't make the same indications as gas in the mines.

Mr. Shaw. No; there is a difference, a slight difference, but the difference is not enough for you to tell. If I were to give you those gases and change from one to the other, the difference would be so slight that you could not tell whether I gave you one or the other. The mine gases will ring that gong at 6½, whereas this gas here rings at 8½ per cent.

Our friend here suggests that we adjourn the meeting and let those who desire come up front and examine the machine, and so we will adjourn at this point, thanking the audience for their kind and careful attention.