

CARBONIC OXIDE IN MINES

By

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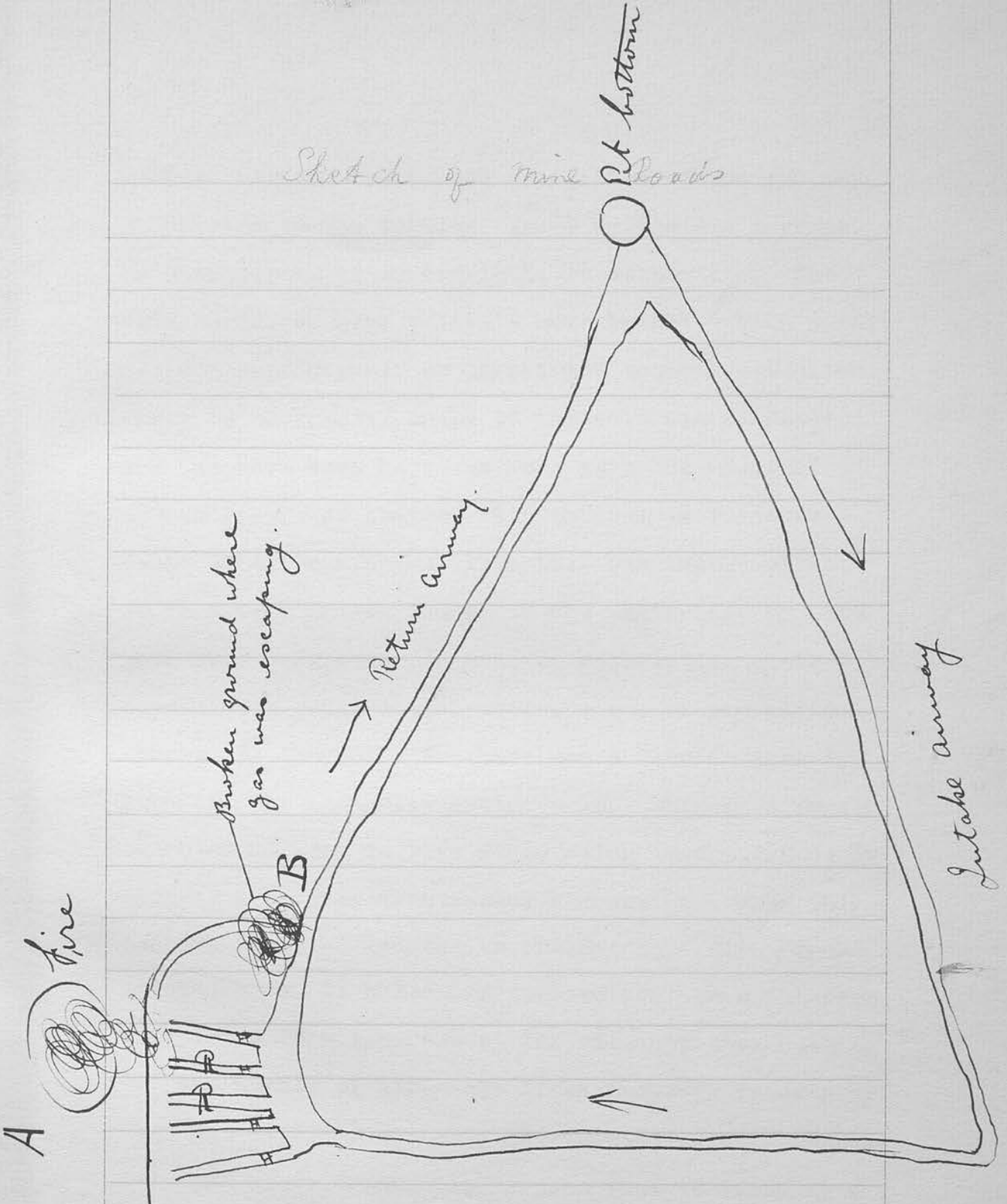


CARBONIC OXIDE IN MINES

Even under the most favourable conditions, there is a considerable amount of danger attached to the occupation of the coal miner. A very common cause of accidents is a fall of stones from the roof. But with ordinary care a man can make his working place secure, by using the necessary props for supporting the roof. In a fiery mine the use of the Davy lamp or some modification thereof enables him to detect the presence of inflammable gases in his neighbourhood, and he forthwith takes the necessary precautions to insure his own safety. The presence of carbonic acid gas in quantity sufficient to be a source of danger is at once detected. A lamp will not burn. Sulphuretted hydrogen and sulphurous acid fumes are at once detected by the sense of smell, and a man would at once take the precaution of quitting a place where the air was so polluted. With carbonic oxide, however, the case is different; there is often nothing to indicate its presence. In the immediate neighbourhood of a fire, of course, there is smoke, sulphurous acid and other gases. But



Sketch of mine Pit Roads



Broken ground where gas was escaping.

Return Airway

Intake Airway

Pit bottom

A fire

H. stoppings
P. Roads leading to the fire

minute, although poisonous quantities of the gas may be carried to the working places by the air current. In this event, it is difficult to detect it. The lamp burns, perhaps a little more brightly than usual, but not sufficiently so to attract special attention. There is no special smell to indicate its presence, and men have been known to walk into the midst of an atmosphere so charged with the gas as to cause death in a few minutes. This fact was impressed upon me in a very tragic manner in the beginning of the year 1901. In order to make my description clear I have made a rough sketch of the scene of the catastrophe. At the point A., there was a fire in what is known as the Lochgelly splint seam. This is a very troublesome seam in Fife mines owing to the frequency that it undergoes spontaneous combustion. When this happens the plan adopted to prevent the fire from spreading is, to build off the section where the fire is burning from the rest of the pit. By thus cutting off the supply of air, this often succeeds in damping down the fire. Sometimes, however, it is not successful, and there frequently happens what is known as a burst. The gases behind the masonry gradually accumulate and finally reach a stage at which they can be pent up no longer. They burst through some weak

point in the building or some neighbouring part. The supply of air being very small there is always a large percentage of carbon monoxide present, and if the fire happens to be in an ingoing air course, the result is disastrous, the gas being carried to all parts of the mine. In this particular instance the current of air was on its way to the upcast shaft, and the road it had to traverse was not in everyday use. The seat of the fire is marked A. The burst took place at the point B. The ingoing and outgoing currents of air are shown by arrows. *X*

*see addl.
matter.*

What happened was as follows : An underground manager accompanied by another man went to the seat of the fire, after most of the men had finished work, to see in what condition the stoppings were, as the air in the upcast shaft had been impure for some days. Those men never returned. Their bodies were afterwards found in the return air course. That of the oversman was discovered some distance from the fire, showing that he must have attempted to get to the pit bottom by the shorter way.

After the lapse of two hours, the under manager, suspecting that something must have gone wrong, descended the shaft with six other men. About three-quarters of a mile from the pit bottom they came to

the dangerous region, and they were all quickly overcome by the gas. The manager and another man succeeded in getting back to a purer atmosphere, over the bodies of their comrades, but they unfortunately felt quite powerless to assist them in any way. The manager had penetrated furthest into the poisonous region, still he was able to get out of it, while his less fortunate comrades, with one exception, perished. I saw him shortly after he was brought to the surface, and he described his experience to me. This will be given later.

There were now seven men in the pit, five of whom were rescuers, and it was impossible to get near them. Possibly they had all died from the effects of the gas. But this did not deter others from risking the same fate, on the off-chance of finding someone living. I had by this time arrived at the pit head, and the scene there can be more easily imagined than described. Surrounding the pit mouth were the anxious relatives and friends of the men who were below. The painful silence was only broken by an occasional monotonous signal from below to the engine driver, indicating to him that someone was ready to be brought to the surface. Then the suppressed excitement of the onlookers would become apparent as the cage was slowly raised

to the surface, and a rush would be made to the pit mouth to get a glimpse of the occupants. A couple of men would be seen to step from the cage supporting between them someone who had been overcome by the gas while endeavouring to rescue his fellow workmen. Those men recovered in a short time, but it was observed that they got worse after being brought to the surface and a man who might be able to walk to the cage, below ground, would be unable to leave it without assistance at the surface. The night was very cold and frosty, and that no doubt would have a very injurious effect upon the men. It was quite evident that they ought not to be hurried up the shaft, and I accordingly decided to descend the pit and attend to them at the bottom of the shaft. The air in the downcast shaft was, of course, good but in the upcast it was very foul. I was told by the bottomer that a rescue party lead by Mr Rowan, general manager, to the Fife Coal Company, had just set out for the seat of the fire. Mr Rowan had taken the precaution of taking with him a canary in a cage, the idea being that a small animal like a canary would be affected by the gas much sooner than a man. When it showed signs of distress that would be sufficient indication that the party had got into a dangerous place and had better retire. There

being no one at the bottom requiring special attention I got a man who knew the pit to show me the road, and we started to follow in the steps of Mr Rowan and his party. For the first few yards the air was very bad and was laden with smoke fumes. The smoke was seen issuing from the outgoing air course to find its way to the upcast shaft, and the smell was very disagreeable. I could not have inhaled very much of the vile mixture, but the little I did inhale was sufficient to cause a severe headache and slight giddiness. We soon got into purer air and continued our journey for a short distance, when we were suddenly left in darkness. A current of air had blown out our lights and neither of us had a match. This was an effectual termination to the journey so far as I was concerned, and all I could do was to sit down and "wait for something to turn up". My conductor might find his way back all right, but I had no ambition to knock my head about on projections from the roof, or trip over sleepers and such like obstacles. The situation was not an enviable one, but luckily we were not kept waiting for any length of time. A light soon became visible in the distance, and was quickly followed by others. These were carried by some of the rescue party who had succeeded in recovering a body which

they were conveying to the pit bottom. I examined the body and came to the conclusion that life had been extinct for some time. Artificial respiration had already been tried by some ambulance men. All hope of finding anyone alive was now abandoned, and I devoted my attention to those of the rescue party who were suffering from the effects of an overdose of the poisonous fumes. Mr Rowan now gave orders to reverse the air current. This had the effect of clearing the air in that part of the mine where the bodies were lying, and they were all ultimately recovered. This briefly is an account of the catastrophe which directed my thoughts to the subject of carbonic oxide gas in mines.

The questions which occurred to me were :

(1) What are the best practical tests for CO in mines?

(2) What precautions can miners adopt when working in the presence of CO ?

(3) What is the best treatment to adopt in CO poisoning in mines?

We shall consider those questions later. In the mean time let us consider the symptoms produced by CO upon the rescuers, and the appearances presented by the bodies of those who died from the effects of the

gas. The first man I saw was Richardson the manager of the pit. He led the first rescue party, and just escaped with his life. I saw him in his house, on my way to the pit. He was in bed, and had been up the shaft about an hour. He was quite conscious, but complained of severe headache, and was very sick. His pulse was going at the rate of 110 beats per minute. The heart was excited but the heart's action was feeble. Nausea was a prominent symptom and vomiting was frequent. I had no time to get the history of his case then, but next day he gave me the following description of his symptoms.

He was the leading man of the search party and was only conscious of being in danger on feeling a "heaviness" in the chest, and a difficulty in breathing. The respirations increased very much in frequency, and there was great muscular weakness. He did not have a feeling of dizziness, although that is often a prominent symptom. The muscular weakness came on very suddenly, and he had only sufficient energy to retrace his steps a short distance, when he lost consciousness. Luckily for him, he had succeeded in getting into a safe atmosphere. Only one man of the party escaped along with him. All

the others collapsed, and were unable to retreat. Richardson ascribes his escape to his strong constitution. I am more inclined to believe that he was more fully alive to the danger he was in than the rest of his party, who were only working miners, and, attributing the initial symptoms which he experienced to their proper cause, he would instinctively try to control his breathing so as to inhale as little of the gas as possible. The action of the gas is so insidious that the rest of the men might think that they were in no danger until it was too late, the limbs being affected long before consciousness is lost.

Richardson regained consciousness while he was being conveyed to the pit bottom. This was immediately followed by sickness and vomiting. These symptoms soon disappeared, and next day his only remaining symptom was a severe headache.

It was evident that those men had walked suddenly into an atmosphere containing a large percentage of carbonic oxide. As a matter of fact, an analysis of the air coming from the fire not long after the catastrophe, showed about 5 per cent

of CO present. By this time, however, the fire had extended and the air was much worse than it was at the time of the accident. It was evident, from his rapid recovery, that Richardson had not be a sufficiently long time in the poisonous atmosphere, for the blood to absorb a very large quantity of CO.

Besides Richardson's case, I had an opportunity of observing the effects of the gas upon men who had inhaled only a small quantity, sufficient to cause muscular weakness, but not unconsciousness. The chief symptoms were weakness of the legs, dizziness, palpitation and increased frequency of respiration, sickness and vomiting.

It was observed that men, on being brought into a pure atmosphere, lost consciousness. I noticed this in several cases. Dr Haldane, in his report to the Home Office, on explosions in coal mines refers to this fact. He says that men who were quite conscious in an atmosphere containing a small percentage of carbonic oxide, became unconscious when they were removed to fresh air.

^{after}
~~Often~~ an explosion there is a large amount of CO

generated, and a considerable proportion of those who were found dead, had been poisoned by this gas. According to Dr Haldane "the explanation of the bad effects of the current of cold air is not altogether clear. Possibly the cold in some way diminishes the blood supply to the brain, or perhaps the temperature of the body is reduced owing to impairment of the heat producing or heat regulating functions".

Dr Haldane is thus of opinion that it is the cold air which has an injurious effect. I have no doubt it is so in many cases. Still, I have seen men become unconscious in fresh air, the temperature of which was only a slight degree lower than that of the poisonous atmosphere from which they had just been removed. Of course, in those cases, the unconscious condition must be directly due to the prolonged deficient supply of oxygen to the brain. In less severe cases, however, we can well conceive how cold air will have a very injurious effect upon the patient.

Whatever the cause may be, it was a common experience to find that men who had been able to walk a considerable distance would suddenly become

unconscious. The natural process of oxydation usually going on in the body is considerably interfered with by the presence of that very stable compound carboxy-haemoglobin, and a lowering of the vitality of all the internal organs, including the brain is a result.

Another symptom which has been described in connection with CO poisoning is the occurrence of convulsions or epileptiform fits. I failed to see this symptom in any of the cases which came under my observation. One man, however, showed symptoms which might easily have been mistaken for convulsions. He was carried out to the pit bottom, became unconscious, and when he was regaining consciousness began to throw his arms and legs about in a most erratic manner. It required several men to hold him down and prevent him from injuring himself. Those symptoms only came on after I had been performing artificial respiration for about ten minutes. He presented the appearance of a person in the excitable stage, during chloroform administration. There were no true epileptiform movements. He very soon became sick, vomited, and then felt

much better. He was taken up the shaft, and complained chiefly of severe headache and weakness of the limbs. He was able to walk home and quickly recovered.

Dr Haldane in some experiments which he made upon mice, observed the occurrence of convulsions in those animals when they were placed in pure coal gas, which contains a large proportion of carbonic monoxide, (5 per cent.) This happened just before the death of the animal. Possibly in man, the same result would follow immersion in coal gas. With small quantities of CO, however, diluted with ordinary air, such as we find in mines where a fire is going on, the evidence tends rather to show that unconsciousness alone is the precursor of death, and I was unable to detect any signs upon the bodies which were recovered later on, that death had been preceded by convulsions or epileptiform fits. These, however, are very frequent symptoms after an explosion of fire damp. But in this case the conditions are very different. There is not only a large quantity of CO present, but there is also a deficiency of oxygen. The nervous shock in those cases must be very great, and there

is also the effect of the flame upon the body, to be considered. It is not surprising, therefore, to find in published reports of explosions of CH_4 in mines, that many men recovered consciousness and were able to be removed to their homes, but died some time afterwards, some of them having severe epileptiform fits. In the Hill of Beath catastrophe however, all the men recovered who were living when carried out to pure air, although some of them were unconscious for a considerable length of time.

I have referred to the case of the man who showed considerable nervous excitement upon regaining consciousness, but I do not consider that this symptom is one peculiar to CO poisoning. I have frequently observed it to occur in men who have been exposed to considerable danger, especially if they are naturally of a nervous temperament. After the Donibristle disaster (which happened in August of last year) where so many men were entombed owing to a subsidence of the moss, one of the men who volunteered to descend the temporary shaft after the sides had shown signs of giving way, presented very similar symptoms when he got home. When I saw him he was in bed and it took three powerful

men to keep him there. He was partly unconscious, although he had received only a few trifling bruises.

Post Mortem Appearance of the Bodies.:

This was very characteristic especially as regards their life-like appearance, and the bright red colour of the skin and mucous membranes. This red coloration was most pronounced in the case of Birrell and his companion. Possibly they had lived for a considerable time in an atmosphere containing a small percentage of carbonic oxide, before the second burst took place behind them which would prove rapidly fatal. The bodies of these men were recovered thirteen hours after death. Rigor mortis was well marked and there was considerable difficulty experienced in getting them into the hutch in which they were to be taken to the surface.

The others (rescuers) had been dead for about seven hours before their bodies were recovered. Rigor mortis in these cases was not well marked.

We now come to consider the treatment of carbonic oxide poisoning. The first thing of course to be done is to remove the patient to pure air. This, as we have seen, is often followed by

unconsciousness, possibly due to the effect of cold air upon the body. It is therefore important to apply warmth to the body. If there happened to be an engine below ground the heat given off from it, and the steam pipes connected with it, could be utilized for that purpose.

Artificial respiration is essential in many of the more severe forms of poisoning. The respiratory centre is affected at a very early stage as is shown by the fact that one of the first and chief symptoms is increased frequency of respiration. This is soon followed by paralysis of the muscles of respiration. It is therefore a matter of the first importance that those muscles should be kept working in order to get rid of the very stable and poisonous compound which CO forms with hæmoglobin. The use of compressed oxygen has been found to be of great service, and may be employed along with the artificial respiration. The difficulty, however, is that cylinders of oxygen are not often kept about a coal pit. I have no doubt that the time is not far distant when it will be compulsory to have at every pit, a supply of oxygen. The remarkable affinity which the hæmoglobin of

I had other experiments performed in order to see the difference of results obtained by using air and oxygen.

30.8 cc air taken (6.4 cc oxygen present)

32 ?
22.0 cc = vol after $\frac{1}{2}$ hour shaking with blood containing CO.

31.5 cc = vol after K O H

26.0 cc = vol after pyrogallate.

26.0 cc = vol after Cu Cl.

0.5 cc CO₂ obtained No CO

0.9 (6.4-5.5) cc i.e., 14.1% oxygen used.

Experiments with 97.6% oxygen.

30.5 cc of 97.6% oxygen taken (29.8 pure oxygen present).

30.3 cc = vol after $\frac{1}{4}$ hour shaking with blood containing CO.

28.8 cc = vol after K O H

21.1 cc = vol after pyrogallate

1.4 cc = vol after Cu Cl.

1.5 cc, CO₂ and 1.5 cc CO obtained.

3.1 (29.8-26.7) cc i.e., 10.4% oxygen used.

Other two experiments performed on the same lines with 97.6% oxygen gave the following results:

With 30.0 cc O present in 30.8 cc there were obtained:

1.5 cc CO₂ and 1.5 cc CO and
13% of oxygen was used.

With 30.4 cc of 97.6 % oxygen (29.7 cc O present) there were obtained

1.9 cc CO₂ 0.5 cc CO, and
11.1% of oxygen was used.

These experiments show that while a larger amount of CO₂ is produced by oxygen than by air, the percentage of oxygen used is about the same in all cases.

rid of it.

Blood was heated to the temperature of the body and was made to absorb a large quantity of CO. I wanted to see the effect of air upon this.

30.5 cc of air free from CO₂ was taken
 30.9 cc = vol after $\frac{1}{4}$ hour shaking with the blood.
 30.2 cc = vol after standing over KOH
 24.6 cc = vol after standing over pyrogallate.
 24.4 cc = vol. after standing over Cu Cl.

Showing 0.2 cc of CO liberated and 0.7 cc of CO₂ produced, not a very great result.

Seeing, therefore, that carboxy-haemoglobin is such a stable compound it would seem advisable to treat cases of poisoning with CO, with pure oxygen. I felt at the time of the accident that a cylinder of oxygen would have been of great value, but as it could not be procured I had to be content to do without it. Luckily all the men recovered.

When they were able to swallow, a little stimulant was given to help the heart's action which, in most of the cases, was found to be feeble. They were kept at the pit bottom in a warm place, and were not allowed up the shaft until they had recovered the use of their legs.

Blood letting and transfusion have been recommended as means of treatment. With regard to the former I do not see what good it can do except in a mechanical way. Theoretically, I am inclined to think it would do harm, because although the amount of blood in the body is diminished by bleeding, still its capacity for carrying oxygen to the tissues is not in any way increased. The injurious compound still exists, although diminished in quantity. If the compound formed by carbonic oxide with haemoglobin were of itself poisonous, one might see the force of removing some of it from the circulation. But, as it acts simply by preventing the formation of oxyhaemoglobin the benefit to be derived from the practice of blood letting is not so very apparent. When the patient is removed to fresh air the CO begins gradually to leave the blood in the form of CO and CO₂, and one would think that the greater the volume of blood in the body the greater would be the amount of oxygen which could be absorbed. Transfusion, on the other hand is more likely to be beneficial. It might be performed at the home of a patient who was lingering on in an unsatisfactory condition. It would not be an easy

operation in a coal pit. Still, theoretically, it is the best treatment which could be adopted.

Tests for Carbonic Oxide :

Ignorance regarding the dangerous properties of this gas is not confined to miners. In the neighbourhood of Manchester on Christmas day of last year a man lost his life in attempting to rescue a fellow workman from the interior of a gas holder which contained CO. He did not know that the gas was dangerous, and it even appears from the evidence that he was allowed to enter the gas holder by his superiors, who ought to have known better, and who ought at least to have taken some precaution to ensure the man's safety.

If such ignorance exists among the managers and men employed at manufactories where a large quantity of poisonous gases is produced, it is not surprising to find the same ignorance displayed by miners. A man will not work a moment longer than

he can help in air in which his lamp will not burn brightly, yet he will continue to work in air polluted with carbonic oxide to such an extent as to show a cap on the flame of his lamp. Of course the reason for this is that carbonic acid occurs frequently while carbonic oxide is only occasionally met with. That is all the more reason why men working in mines should be made aware of the dangerous properties of the gas, the conditions under which they are likely to meet in with it, and if possible some simple and reliable test for it. They should be on their guard, after an explosion of fire damp, and in places in the neighbourhood of underground fires. I could well imagine the reception which a statement like that would receive from an old miner. He would tell you that he had known that fact ever since he began to work in a pit. The men who lost their lives would have told you the same thing, before the accident. The fact of the matter is that miners do not fully appreciate the dangers of CO in the air. In the Hill of Beath disaster there were no precautions taken until Mr Rowan, the general manager, arrived on the scene and made use of the canary to show when the dangerous

point was reached. When the canary dropped from its perch it was considered advisable to retire. This test is a very simple one and can be appreciated by anybody. More especially is it of benefit to rescue parties. Of course it only proves the presence of a dangerous gas or gases. It does not indicate either the kind of gas or its amount. Dr Haldane in his report to the Home Office regarding explosions in coal mines, recommends the use of small animals for the detection of dangerous gases. The animals which he made use of were mice. I think, on the whole, that a canary is even better than a mouse. The limbs are affected at a very early stage and the bird drops from its perch, and this is a symptom of poisoning which can be mistaken by no one. When a mouse is used it requires a little closer observation to detect the primary symptoms. Rats and mice are frequently met with in mines, and if one or two of these animals are found dead in the morning at any particular place in the mine that should be a sufficient warning that the place is dangerous. I have, on several occasions examined the blood of the rats and mice which have been found lying dead in the pit, and it presented

the appearance which one would expect to find in cases of poisoning by carbonic oxide. These examinations were made after the accident in order to see if the efforts of the manager to get rid of the gas were being successful. Of course, the simple fact of the animals being found dead was of itself a sufficient proof that the place was not fit for men to live in. Still it was more satisfactory to know that death was due to the presence of carbonic oxide in the air. The blood is tested by taking a drop or two from the body of the poisoned animal, placing it in a test tube and diluting it with water, and a comparison is made between the colour of this blood and the same quantity of normal blood which has undergone similar treatment. The pink colour of the blood saturated with carbonic oxide is at once recognised. This test cannot be used in a mine, as the difference in colour cannot be distinguished in lamplight.

Then there is the flame test, which, as devised by Dr Clowes, is both practical and accurate, as it indicates by the size of flame produced, the proportion of inflammable gas present. He recommends the use of a hydrogen flame, and he has

Cap heights over standard Hydrogen flame, with coal gas.

| Percentage of coal gas in the air | Cap height - in mm. over Hydrogen flame | | | Cap height - in mm. over oil flame reduced until the cap is at its maximum. |
|-----------------------------------|---|------------------------------------|------------------------------------|---|
| | Standard 10 m.m. flame | Flame raised to 15 m.m. in the gas | Flame reduced to 5 m.m. in the gas | |
| 0.25 | 15.7 | 27.6 | - | - |
| 0.5 | 18.4 | 37.0 | - | - |
| 1.0 | 25.3 | 60.0 | - | - |
| 2.0 | 40.6 | - | - | - |
| 3.0 | 60.0 | - | 11.5 | 15.3 |
| 4.0 | - | - | 30.0 | 20.0 |
| 5.0 | - | - | 60.0 | 34.0 |
| 6.0 | - | - | enters top | 65.0 (over) |

Cap. heights over standard Hydrogen-
flame with water gas

| Percentage of Water-gas in the air | Hydrogen-flame | | | Colya-petroleum flame. maximum size — |
|--|----------------|-----------------------|----------------------|--|
| | 10 m.m. | 15 m.m. in the gas | 5 m.m. in the gas | |
| 0.25 | 10 | 25.3 | Nil | Nil |
| 0.5 | 14.5 | 33 | " | " |
| 1.0 | 17.2 | - | " | " |
| 2.0 | 28.7 | - | " | 8 |
| 3.0 | 31.4 | - | " | 8 |
| 4.0 | 36. | - | " | 9 |
| 5.0 | 40. | - | 11 | 14.5 |
| 6.0 | 50.6 | - | 26 | 20. |

succeeded in fixing on to an ordinary Davy lamp, a cylinder with the necessary supply of that gas. A full description of the lamp and his reasons for adopting a hydrogen flame are given in a paper published by him in 1894 entitled, "Cantor Lectures of the Detection and Estimation of small quantities of Inflammable Gas or Vapour in Air". His experiments were mainly performed to demonstrate the amount of CH_4 present in fiery mines, but he also shows the effect produced on a hydrogen flame by coal gas and water gas which contain a large quantity of carbonic monoxide. I give his tables, from which it will be seen how much greater is the sensitiveness of the hydrogen flame as compared with that of a more luminous flame. The ordinary tallow lamp used by miners in this district is not a safe guide. The gas may be present in poisonous quantities and yet not show any effect upon the flame; whereas if a blue cap does become visible the danger to life is so imminent that it may be impossible to escape. It would seem that it requires two per cent of CO to be present in the air to make any appreciable difference upon an ordinary flame, while the hydrogen flame can detect the presence of 0.25 per cent of CO.

Palladium chloride has been suggested as a test for carbon monoxide, metallic palladium being thrown down and the gas changed to carbon dioxide. This test is carried out by saturating filter paper with palladium chloride and allowing carbonic oxide to come in contact with it, when a black colour is produced. I got this reaction very distinctly by using a mixture of carbonic oxide and air, but it took some time for the black coloration to appear. The value of the test is also diminished by the fact that palladium chloride is also decomposed by many organic substances which may be found in mines along with carbonic oxide. The black colour produced upon the filter paper was seen very distinctly in one of the experiments where a 5 per cent mixture of CO in air was used. After the experiment it was observed that 80 per cent of the carbonic oxide had been converted into carbonic dioxide, a result which might be made of practical use if it were not for the cost of the palladium chloride. Other tests for CO have been described, but none of them seem to be of any practical use. Berthelet, in the Journal of the Society of Chemical Industry, 1891, p.662, gives the following :

"If a few bubbles of carbonic oxide are passed into a weak and cold solution of ammoniacal silver nitrate, the liquid immediately assumes a brown colour, and at the boiling point the silver is quickly reduced, etc."

In the same Journal, 1897, p.561, Merinet describes a reaction of carbonic oxide, a weak solution of K_2MnO_4 acidified with HNO_3 being decolorised by it.

Having now determined that CO is present in poisonous quantities in a mine, what precautions ought to be taken to protect those men who have to work in the midst of it?

In Fife mines there is no apparatus in general use by any of the coal companies. After the Hill of Beath disaster, I discovered in one of the workshops in Cowdenbeath, a pneumatophone, but it might just as well not have been there, as there was nobody in the district who knew how to use it. In order to work it properly one requires to have a special training and if employed by an unskilled person it would be a source of great danger. Still if it, or some similar apparatus had been available at Hill of Beath, many lives might have been preserved.

A full description of the various appliances at present in use for rescue work, etc., is given in a book published in 1901 entitled, "Recovery work after pit fires, A description of the principal methods pursued, especially in fiery mines, and of the various appliances employed, such as respiratory and rescue apparatus, dams, etc." This work is by Robert Lambrecht, and has been translated from the German by Charles Salter. After reading this book it was evident that our continental neighbours were far in advance of us in Fife so far as the use of those safety appliances in mines was concerned. I understand, however, that in many parts of England and the west of Scotland their use is common, the reason being, of course, that explosions and fires are of more frequent occurrence in those districts, than in the east of Scotland. As if to contradict this statement I see in the evening paper an account of an explosion at Glencraig, only a few miles from here, at 9 o'clock this morning where four men are supposed to have lost their lives. I will not be astonished to hear later on that there were no rescue appliances at the pit, or that more men have lost their lives in trying to recover the bodies.

It is unnecessary to describe the various forms of rescue appliances now in use. Suffice it to say that no form of respirator is known which is of any use in an atmosphere of carbonic oxide. Some such arrangement as that used by divers and firemen might be used in some cases where the operations have to be conducted at a place in the proximity of a pure air supply. It is very seldom that the conditions favourable for the employment of such an apparatus are to be found in a pit after an explosion or fire. The best form of apparatus to use is one in which a supply of oxygen is carried. Of this there are two main types. In one the oxygen is taken in through the mouth, a mouth piece being used and a clamp is fixed on to the nostrils.

The other is in the form of a helmet which completely covers the head and upper part of the body. In both the supply of oxygen is carried in cylinders, and an alkali is also carried for the absorption of carbonic acid. Of the two the helmet arrangement seems to be the better for most purposes. For rescue work either of them is of the greatest value. The latest improvement is the

addition of an extra cylinder of oxygen. When the first one becomes exhausted the man knows that he has still the reserve one for use on the return journey^{ed}. The best of those appliances labour under the disadvantage of being very expensive, and it also requires a considerable amount of training before a man is qualified to make use of them. Their weight also is considerable, and it is important that men should have as little to carry as possible when working under conditions which necessitate their use.

It occurred to me that it would be of the greatest benefit to miners if some simple form of respirator could be devised which could absorb carbonic oxide or convert it into carbonic dioxide, which in its turn could be absorbed by an alkali. With this object in view I had a number of experiments performed with various chemical combinations. These in many cases were very unsatisfactory. Others again gave results which encouraged the hope that it might be possible to convert a large percentage of Co into CO_2 . Especially was this the case on using a mixture containing permanganate of potash, weak nitric acid, and a little nitrate

of silver. This mixture was first used in solution, the gas being shaken up with it. The amount of CO converted into CO_2 was then estimated. The results varied according to the percentage of CO present, the temperature of the mixture, and the length of time allowed for the change to take place. For instance a 17 per cent mixture of CO with air showed on analysis that 75.5 per cent of the CO had been converted into CO_2 , after standing over the mixture, slightly warmed, for 15 minutes. A 7.2 per cent mixture of CO with air showed that 95.5 per cent of the CO had been converted into CO_2 after standing over the warm solution for 20 minutes. These experiments were, so far, satisfactory but there was the considerable disadvantage of working with the permanganate in solution. This difficulty was overcome by the use of glass wool. The wool was packed loosely in a glass tube and into this was poured the permanganate solution, any excess of liquid being allowed to drain off. This tube was fixed on to the gas apparatus, and a known quantity of CO and air was drawn through it, and thence into the caustic potash solution. The results obtained upon subsequent analysis were, to

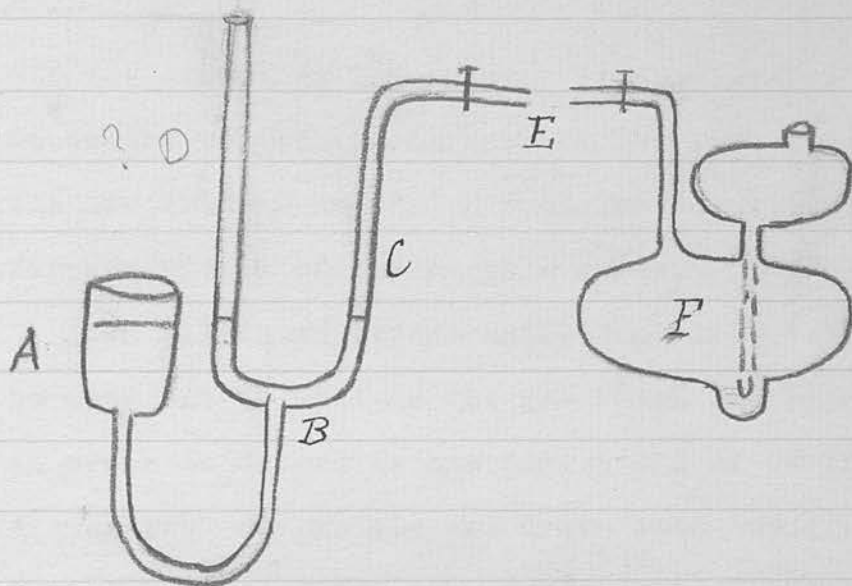
a certain extent, satisfactory, but they varied considerably. It was clearly shown, however, in all the experiments, that the permanganate solution was capable of converting a considerable proportion of the CO present into CO_2 .

The first experiment was performed with a 6 per cent mixture of CO with air. This was passed into the permanganate solution which was at the ordinary temperature, and it was allowed to remain in contact for five minutes. The result was that 55 per cent of the CO was removed. Next, air containing 2.3 per cent of CO was passed once slowly through the glass tube which was still at the ordinary temperature, and it was found that 71 per cent of the CO was removed. When air containing 1.5 per cent of CO was passed once through the solution the temperature of which had been slightly raised, it was found that the whole of the CO had been removed. This result was highly satisfactory. In fact, it seemed to me to be too good to be true. I repeated the experiments, therefore, but altered the proportions of CO in the gas mixture to be analysed, and the results obtained were still satisfactory. They varied a little however and

this no doubt was due to the difference in the amount of CO present, the temperature, the time allowed for the oxidation to take place, and possibly also to the way in which the experiments were carried out. Still even by using a mixture containing 81 per cent of CO, it was possible to remove a very considerable proportion of the gas. Possibly by using a larger quantity of permanganate and glass wool, thereby giving a greater surface for the gas mixture to pass over, the results obtained might be more constant.

Sulphuric acid with the permanganate, was also tried and it was found that 82 per cent of the CO had been removed, when a mixture was used containing 13 per cent of CO.

A great many other chemical combinations were tried, but they did not give so good results, although many of them were capable of converting a considerable amount of CO into CO₂. Many however gave quite negative results.



This is a rough sketch of the gas apparatus used in the experiments. A, is a glass receiver filled with mercury. Attached to the bottom of this is an indiarubber tube which is connected at B with a U-shaped tube. The limb of the tube, C., is used as a measuring burette, and is graduated to the 10th of a cubic centimeter. A is raised or lowered by means of a weight attached to a cord which works on a pulley. By raising the level of the mercury in C., tube all the air can be expelled, and by lowering its level after shutting the stopcock a vacuum can be made into which the gas to be experimented upon can be sucked. Before reading

off the amount of gas present in the burette it is necessary to get the mercury at the same level in the two tubes D and C. F contains the solutions for absorption of the various gases.

In all those experiments, the first thing to be done was to analyse the gas which had been made, in order to determine the percentage of CO present. A quantity of the gas was drawn into the graduated burette and was then passed successively over the caustic potash, pyrogallate, and cuprous chloride solutions in order to absorb carbonic acid, oxygen, and carbonic oxide, respectively, and after each of these processes the gas was drawn back into the measuring burette and any change in its volume was observed. The percentage of carbonic oxide present in the gas to be experimented upon could thus be ascertained. The same process was gone through in all the experiments performed, after the gas had been acted upon by the oxidising agent. When glass wool was used, it was packed loosely into a glass tube narrowed at each end, and this tube was fitted on to the gas apparatus at the point E, by means of elastic tubing. Asbestos was also used, but it did not work so well as the glass wool.

The solutions of caustic potash, pyrogallate and cuprous chloride were prepared according to the instructions given in Hempel's gas analysis.

It will be unnecessary to give details of all the experiments which I had tried, nor will it be necessary to record the preliminary failures before satisfactory results were obtained. My idea was that some absorbent might be found, or some oxidising agent which, when used in a respirator, would be capable of removing any CO in air. Taking into consideration the affinity which blood has for CO, it occurred to me that it might be tried.

24.4 cc of gas was taken in which
19.5 cc CO were present.

After standing a quarter of an hour over the blood the volume was reduced to 24 cc.

After 16 hours it was reduced to 22.2 cc.

Vol. I. 24.4 cc 19.5 cc CO present.

After $\frac{1}{4}$ hour 24.0 cc

16 hours 22.2

Experiment with a mixture of H Cl and K ClO₃ solution.

Vol. I. 31.7

2. 31.7 after standing over the mixture

for one hour and shaking up with KOH. No result.

There is recorded in the Journal of the Society of Chemical Industry, 1897, p.561, a reaction of CO by Mermet. A weak solution of $KMnO_4$ acidified with dilute HNO_3 is decolorised by CO. I thought this solution might be tried to see if it would oxidise CO.

Experiment with 5.3 per cent of CO present in gas mixture.

- Vol.1. 30.2 cc (1.6 cc CO present)
2. 31.9 after standing for two hours over mixture.
 3. 31.0 after standing over KOH for a few minutes.
 4. 36.4 after standing 10 minutes over warm $KMnO_4$
 5. 36.4 after standing over KOH.
 6. 39.8 after standing another 10 minutes over $KMnO_4$.
 7. 39.8 after standing over KOH.

This experiment shows that in the first two hours 56 per cent of CO was oxidised to CO_2 . The solution was a weak one.

Readings after standing over Pyro and KOH have been omitted

Experiment with a saturated solution of KMnO_4
 in dilute $\text{HNO}_3 + \text{AgNO}_3$.

Vol.1. 30 cc 4.2 cc of CO present.

2. 48.8 cc after standing 8 minutes over mixture.
3. 45.2 after standing over KOH
4. 23.8 after standing over alkaline pyrogallate.
5. 23.2 after standing over Cu Cl.

 .6 cc CO left unchanged.

Therefore there were 3.6 cc that is 86 per cent of CO present, oxidised to CO_2 . The temperature was not raised.

Ammoniacal CuSO_4

Vol.1. 30 cc (4.1 cc CO present)

2. 30.2 after standing $1\frac{1}{2}$ hour over solution
3. 25.1 after standing over pyrogallate.
4. 21 " " CuCl.

 4.1 CO left.

No change has taken place here.

Ammon. Molybdate and Strong HNO_3 .

- Vol.1. 30 cc 4.1 cc CO present.
 2. 30 cc after standing $\frac{1}{4}$ hour
 3. 30 cc after KOH.

No result.

Warm Dilute Ammoniacal AgNO_3 .

- Vol.1. 30.4 cc 4.4 cc CO present.
 2. 30.4 cc after standing $\frac{1}{2}$ hour over mixture
 3. 28.3 cc after standing 16 hours "

At this time the solution was found to have become dark in colour, and a black sediment was present.

Vol.4. 23.4 after pyrogallate.

5. 20.2 after CuCl .

This shows 1.2 cc of CO got rid of or 27 per cent.

This solution has been recommended by Berthelot as a delicate test for CO, see Journal of Society of Chemical Industry 1891, p.662. It gives a dark brown coloration changing to black. Other gases,

however, found in mines give similar colours.

Palladium Chloride.

This substance was interesting from the fact that it is recognised as one of the few tests for CO in mines, but like the previous substance its value is diminished by the fact that other gases besides CO affect it in the same way.

The experiment was carried out by dissolving a very small quantity of palladium chloride in a solution of Na Cl., and soaking filter paper with the solution. This was put into a glass tube and the gas mixture was passed over it into the bulb containing KOH.

5 per cent CO present in mixture.

Vol.1. 30 cc (1.5 cc of CO present)

2. 29.8 after passing the gas for 5 minutes backwards and forwards over palladium chloride into KOH.

3. 28.8 after repeating this for $\frac{1}{2}$ hour.

4. 33.0 after pyrogallate.

5. 22.7 after Cu Cl.

80 per cent CO removed.

There were 1.5 cc CO present in the 30 cc of gas taken, and there were .3 cc left over, showing that 1.2 cc had been transformed into CO₂ or 80 per cent.

Ferrous Sulphate and dilute H₂SO₄.

| | | | |
|--------|---------|----------------|---------------------------------|
| Vol.1. | 30.1 cc | | (4.3 cc CO present) |
| 2. | 30.1 cc | after standing | $\frac{1}{2}$ hour over mixture |
| 3. | 30.1 cc | " | KOH |
| 4. | 25.3 cc | " | Pyrogallate. |
| 5. | 21.0 cc | " | CuCl. |

No change.

Cuprous Iodide (Ammoniacal)

| | | | |
|--------|---------|------------------------------|----------------------|
| Vol.1. | 30 cc | | (4.4 cc CO 4.8 cc O) |
| 2. | 20.8 cc | after standing over solution | $\frac{1}{4}$ hour |
| 3. | 28.8 cc | " | pyrogallate |
| 4. | 28.8 cc | " | CuCl. |

The solution had evidently absorbed both the O and CO present. This will not do for a respirator. After a series of experiments with different substances conducted on the same lines as those which I have narrated, it was seen that the best results

had been obtained by using the permanganate solution. These experiments were therefore continued.

Saturated solution of $KMnO_4 + HNO_3 + AgNO_3$.

- Vol.1. 31.1 cc = vol of air + Co (17.0% CO present)
2. 36.2 cc after standing 15 min. over warm mixture
 3. 35.4 cc " over KOH
 4. 22.3 cc " pyrogallate
 5. 21.0 cc " CuCl.

1.3 cc CO left over, 75.6 per cent of the CO oxidised.

Another experiment.

2.5 cc of 87% CO taken (2.2 cc CO present)

- Vol.1. 30.4 cc = vol. of air + CO (7.2% CO present)
2. 36.7 cc = vol. after standing 20 minutes over warm mixture.
 3. 35.4 cc = vol. after KOH
 4. 22.4 cc = pyrogallate
 5. 22.3 cc = CuCl.

95.5 per cent of CO removed, per cent of CO being reduced from 7.2 to 0.3.

1.4 cc of 87% CO taken (1.2 cc CO present)
 31.8 cc = vol. of CO + air (3.8% CO present)
 42.9 cc = vol. after standing 10 minutes over warm
 KMnO_4 solution.
 46.6 cc = vol. after standing over KOH
 25.9 cc = " " pyrogallate
 25.6 cc = " " CuCl .

showing .3 cc CO left over.

75% CO removed.

Experiment to see if any CO is lost by leakage
 during the working of experiments.

1.5 cc of 87% CO taken (1.3 cc CO present)
 32.5 cc = vol. of CO + air (4.0% CO present)
 32.4 cc = vol. after standing over KOH
 26.0 cc = " " pyrogallate
 24.7 cc = " " CuCl .

1.3 cc found the same amount which was taken
 for experiment.

Experiment with solution containing,

6.2 grms KMnO_4

6cc concentrated HNO_3

1.00cc water and a few drops AgNO_3

1.7 cc of 87% CO taken (1.5 cc CO present)

31.1 cc vol. of CO + air (4.8% CO present)

35.2 cc vol. after standing 15 minutes over slightly warm mixture.

34.0 vol. after KOH.

24.0 " pyrogallate

23.7 " CuCl .

80 per cent of the CO oxidised to CO_2

Mixture of CO and air containing

3.6% CO

1.3 cc of 87% CO taken (1.1 cc CO present)

30.6 cc = vol. of CO + air (3.6% CO present)

33.9 cc = vol. after standing 5 minutes over warm mixture

33.2 cc = vol. " over KOH

24.0 cc = vol. " pyrogallate

23.7 cc = vol. " CuCl .

72.7 per cent of the CO removed.

Another similar experiment with solution which had been standing for some time.

1.3 cc of 87% CO taken (1.1 cc CO present)

30.6 cc = vol. of air + CO (3.6% CO present)

34.0 cc = vol. after standing 10 minutes over solution

34.0 cc = vol. " over KOH

24.0 cc = vol. " pyrogallate.

23.6 cc = vol. " CuCl.

63.6 per cent of the CO oxidised, showing that the best results are got when fresh solution are used.

The next experiment was made with H_2SO_4 instead of HNO_3

8 grms K MnO_4

120 cc distilled water.

5 cc H_2SO_4 concentrated with a few drops $AgNO_3$

1.4 cc CO taken (1.2 cc CO present)

32.0 cc = vol of CO + air (3.8 % CO present)

33.0 cc = vol. after standing 10 minutes over warm solution.

32.4 cc = vol. " over KOH

25.0 cc = vol. " pyrogallate

24.7 cc = vol. " CuCl.

75 per cent of the CO removed.

The next experiment was made with a little more H_2SO_4 added to the solution. The result was disappointing as only 38.4 per cent of the CO was oxidised.

The best results had been obtained from the permanganate solution with HNO_3 and $AgNO_3$ added. The experiments were therefore continued with this difference, that the permanganate solution was poured into a narrow tube filled with asbestos or glass wool, and the gas to be experimented upon was made to pass over this. Several experiments were performed but it will only be necessary to give a few of them.

Gas passed over glass wool into saturated solution of NaCl.

0.9 cc CO taken (0.8 cc CO present)
 30.2 cc = vol. of CO + air (2.6% CO present)
 30.9 cc = vol. after passing 5 times over cold glass wool.
 30.8 cc = vol. after passing over KOH
 24.6 cc = vol. " pyrogallate
 24.3 cc = vol. " CuCl
 62.5% CO removed.

Experiment with tube filled with glass wool
and asbestos soaked in mixture of cold KMnO_4 , HNO_3
and AgNO_3 .

2.1 cc of 85.7% CO taken (1.8 cc CO present)
30.1 = vol. of air + CO (6.0% CO present)
29.7 = vol. after passing 5 minutes over solution
23.7 = vol. after passing over pyrogallate
22.9 = vol. " CuCl.
55.6 % CO oxidised.

0.8 of 85.7 % CO taken (0.69 cc CO present)
30.1 cc = vol. of air + CO (2.3 % CO present)
29.9 cc = vol. after once passing gas slowly through
cold tube into KOH.
23.6 cc = vol. after pyrogallate
23.4 cc = vol. after CuCl.
71 per cent CO removed.

0.65 cc of 85.7% CO taken (0.56 cc CO present)
36.7 cc = vol. of air + CO (1.5% CO present)
36.6 cc = vol. after passing gas once through cold tube
29.0 cc = vol. " over pyrogallate
28.8 cc = vol. " CuCl.
64.3 per cent of the CO removed.

The tube with glass wool and KMnO_4 contained gas mixture used in previous experiment.

0.55 cc of 85.7% CO taken (0.47 cc CO present)
 31.6 cc = vol. of air + CO (1.5% CO present)
 31.0 cc = vol. after passing once through warm tube
 24.5 cc = vol. " over pyrogallate
 24.5 cc = vol. " CuCl .

All the CO removed.

This result was all that could be desired, and to make certain that all the CO had been removed another experiment was performed. Air was passed into the KOH pipette and then sucked through the tube into the burette and analysed, the result being as follows :

47.8 cc = vol. of gas
 47.6 cc = vol. after KOH
 38.1 cc = vol. after pyrogallate
 38.1 cc = vol. after CuCl .

which shows that all the CO in the tube had been oxidised.

I got a similar result on using a mixture of air and CO containing 1.4% of the latter.

It will be unnecessary to give details of all the other experiments; there is one however which may be given in which H_2SO_4 was used.

Concentrated H_2SO_4 was added to a small quantity of saturated $KMnO_4$ solution in water, and the glass wool in tube was moistened with the mixture.

4.6 vol. of 85.7% CO (3.9 cc CO present)
 30.0 = vol. of CO + air (13% CO present)
 28.1 = vol. after passing 4 times through cold tube.
 27.9 = vol. after passing over KOH
 22.0 = vol. " pyrogallate
 21.3 = vol. " CuCl.

82.1 % of the CO removed.

This is very good, and possibly by continuing the experiments with H_2SO_4 even better results might be obtained.

The conclusion I have arrived at is this, that it ought to be quite possible to remove CO from air just in the same way as CO_2 or H_2S is removed. Theoretically it has been clearly shown that at least a very large percentage of CO can be removed and I hope that ultimately, it will be possible to get constant results.

In addition to the reasons already given as to the variations in the results obtained, I think a great deal depends upon the freshness of the solution, and also the extent of surface of glass wool with which it comes into contact. It is difficult to get the whole of the glass wool soaked with the solution.

I have given instructions to the instrument maker to have a light respirator made which can be carried round a man's neck. This is to consist of two chambers one containing glass wool and the other an absorbent for CO_2 . The permanganate solution can be prepared as required and poured into the chamber containing the glass wool. There will thus be a large surface over which the permanganate can be spread.

The air containing CO before being inhaled will have to pass over the permanganate in the first chamber and then through the alkali in the second chamber, when it is to be hoped that the removal of CO by the permanganate will be as effectual as that of CO_2 by the alkali.

The following analysis of air taken from a mine where an underground fire had been ^{shut} off from the rest of the pit, shows how CO, even under those conditions, may find its way to various parts of the workings.

I got three samples of air collected

No. I. 400 yds. from the bottom of the downcast.

No. II 1800 yds. from the bottom of the downcast after passing a section of parrot and one of Lochgelly splint

No. III 2600 yds from bottom of downcast after passing two sections of Lochgelly splint and one of Parrot.

The air had passed the place where the fire had been shut off, No I being taken just after passing it.

The amount of CO present was

No I 0.33 p.c.

No. II 0.17 p.c.

No III 0.01 p.c.

This shows that even when a fire is supposed to be safely shut-off from the rest of the mine, CO must find its way out. Samples II and III were collected in places where men were working.

It is no uncommon occurrence to find strong, able-bodied men complaining of weakness and a feeling of being always "tired". I used to treat those symptoms lightly, and came to the conclusion that the man only wanted an excuse for a holiday. Now, however, it is different, and I generally find, on enquiry, that he has been working in a place where possibly a small quantity of CO has been present.

I am often told by patients that they noticed a cap on their lamp flame while at work. It would be interesting to know if this were due to the presence of CO or C₂H₄. One could hardly believe that anyone could continue

working in an atmosphere containing sufficient C_2 to make a cap on the flame. On the other hand, marsh gas is very seldom found in pipe mines. This is an interesting question which it may be worth investigating on some future occasion.