METHODS FOR DETERMINING THE DUST IN MINE AIR, AS PRACTISED ON THE WITWATERSRAND

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To the best of our knowledge the first determinations of dust in mine air on the Witwatersrand were carried out for the Miners' Phthisis Commission of 1902, with the following results:

Place	Dust in milligrams per cubic metre
Face of drive	424
do. do.	192
do. do. behind spray	42
100 ft. from face after blast	83
End of drive 5½ hours after blast	43
Stope	14
Stope	32
Raise	164

In 1910 the East Rand Proprietary Mines found as much as 1,500 milligrams in a drive.

In 1911 the systematic determination of dust was begun by the Consolidated Gold Fields Group. The method adopted was a gravimetric one, a known quantity of the mine air being drawn through a column of pure sugar, the sugar being then dissolved in distilled water, and the dust filtered off, ignited and weighed. The dust-laden air was aspirated through the sugar (which was contained in a tube) by various methods, the one generally adopted being to use a double-acting suction pump.

The capacity of the standard pump is about 3 litres per double stroke, the pump being calibrated against a standard wet meter. The tube used to contain the sugar is made of thick walled glass tubing, 5 inches in length by $1^1/_4$ inches in diameter, fitted at the top with a solid rubber cork, and at the bottom with a one-holed rubber cork, through which passes a piece of glass tubing $^1/_2$ inch in diameter. At the bottom of the sugar tube is placed a small piece of cotton wool, this being used to prevent the sugar being drawn out in sampling. The sugar used is of such a size that it will pass a ten-mesh sieve and remain on a twenty-mesh sieve, and 40 grammes of the sugar is used per tube.

In taking a sample the tube is connected by a length (usually 6 feet) of pressure tubing to the inlet of the suction pump, and the required volume of air aspirated. This volume depends on the dustiness of the air, but is usually $^1/_3$ to $^1/_2$ cubic metre.

The tube is held at about the height of a man's mouth, and the sampling is done to windward of the pump, the tube being moved about so as to obtain a representative sample. After sampling, the tube is recorked, numbered, and a record made of the place sampled and the work in progress. The tube is then returned to the laboratory for analysis.

Up to 1913 all the dust found in a sample was regarded as dangerous, and was returned as total dust. The research of Dr. J. McCrae, however, proved that in the ash of a silicotic lung it was only the very fine dust that was found, the particles ranging in size from 12 microns downwards.

As the sugar tube determinations were of all the dust in the air, it became necessary, therefore, to devise some method of separating the coarse from the fine dust.

In 1915 Dr. J. Moir published details of a method for the separation of large and fine quartz particles. The method consisted of allowing dust in suspension to settle in water for a period of time, calculated from the size of the particles and from the rate of fall of quartz particles when suspended in water. The formula is as follows:

$$V = \frac{7D^2}{100000}$$

where V = velocity of fall in cm. per second.
D = diameter in microns.

In practice, the procedure to settle out particles above 12 microns in size was to allow the well-mixed suspension of dust to settle for four minutes for each centimetre of height of the liquid in a straight-sided beaker, siphon off the supernatent liquid (containing the fine dust in suspension), make up the residual liquid to the original bulk, allow to settle for two minutes for each centimetre of height, siphon off, mix the two siphoned-off liquids, filter and weigh the dust.

In dealing with large numbers of samples, the time involved in this process was very great, and recourse was made to a mechanical method. It became possible to obtain very fine screening of some 350 mesh. A small truncated cone was made, the screening forming the base of the cone, and the sugar solution containing the dust was filtered through the cone on to a fine filter paper. The cone is then washed free of sugar solution, removed, and the filter paper containing the dust is then incinerated in a crucible, cooled, weighed, and the weight of dust determined.

As all sugar contains a certain amount of inorganic dust, it is necessary to make an allowance for this as well as for the weight of the filter ash. This is done by running a number of blank sugar tubes, which are treated in the same way as the tubes containing dust and the weight of dust found is taken as the weight of dust in the sugar plus the weight of the filter paper ash, the amount usually being about 0.7 milligrams per sample. The amount of dust found in mine air is returned as milligrams per cubic metre.

The method described above gives the weight of dust in a given quantity of air. It is, however, necessary to have a knowledge of the number of particles of dust in the air. This can be determined in a gravimetric sample by counting the dust in an aliquot part of the solution by means of a Haemocytometer or similar instrument; but this is a tedious method.

In 1916 Sir Robert Kotze, Chairman of the Miners' Phthisis Prevention Committee, devised an instrument to enable the particles of dust in mine air to be counted. This instrument, known as the *Konimeter*, consists of a valveless cylindrical suction pump of a cylinder capacity of 5 to 10 cubic centimetres. In this instrument a piston is depressed and held by a catch, and when it is released a volume of 5 cubic centimetres of air is sucked in through a nozzle, which is tapered and smoothly bored, with an orifice diameter of 0.6 millimetre. The air sucked in impinges on a glass slide which is placed 0.5 millimetre from the nozzle. The slide is made by cutting an ordinary microscope slide in half, and is held in position over the nozzle by means of a spring, the jet itself being surrounded by a rubber ring about 16 millimetres in diameter. This forms, with the slide in position, a small air-tight chamber. The slide may be moved over the chamber so that samples of dust may be taken. The slide may be coated with a very thin coating of vaseline or glycerine jelly, or, if the sample is being taken in moist air, may be uncoated with any adhesive. The velocity of the air when it leaves the nozzle should be not less than 30 metres per second. To count the particles of dust in the spot, the slide is examined under a microscope, using a 16-millimetre objective, and an eye-piece of high power. An eye-piece micrometer ruled in sectors is used, the most usual sectors being either 9° or 18°. The spot is counted vertically and then the eye-piece is rotated through 90° and the spot counted again, the sum of the two counts giving the number of dust particles when 5 centimetres of air has been impinged.

A modified form of Konimeter is also used. In this instrument the glass plate on which the dust is caught is made circular and fitted into a toothed wheel which engages a pinion. By means of this device the plate is made to revolve under the jet and as many as sixty spots can be taken on the one slide. When the plate is removed from the Konimeter it is fitted into a special holder on the stage of the microscope, and by means of a toothed pinion is revolved under the objective so that each spot in turn comes into focus and can be counted.

When the Konimeter was invented, counting was done by means of ordinary reflected light, but it was soon found that, as the particles of dust are extraordinarily minute, they could not all be counted by this means. After much experimenting a method was evolved which is a modification of dark ground illumination. The method has for its object the securing of contrasts, and therefore a spot is used which allows the maximum illumination. In practice this is obtained by placing a dark ground spot of 10 millimetres diameter immediately below the condenser. This cuts out the central portion of the light pencil and allows the particles of dust to stand out clear, bright and easily countable. Illumination is obtained by using a 100 candle power $^1/_2$-Watt ground glass bulb, which is placed about 9 inches from the mirror.

Just as the gravimetric sugar tube collects all the dust in the air, irrespective of size, so does the Konimeter collect the dust irrespective of kind, and irrespective of its nature.

It has been pointed out by Dr. Mavrogordato that all instruments delivering air at a high velocity through a narrow jet bring in the condensation principle, and that the resultant spots are not only precipitation spots but also condensation spots, so that if the moisture in the air contains salts in solution, these will materialise as visible particles when the spot on the Konimeter is examined under the microscope. This does happen in the sampling of mine air by the Konimeter, and has been a source of error and of great trouble in Konimeter work on these fields.

Water used for dust allaying almost invariably contains soluble salts, and, as the air underground is more or less saturated with moisture, a Konimeter spot contains salts of sodium, calcium and iron. The Konimeter appears to exert a selective action in its collection of dust particles, and these are always of very small size. The soluble salts in the moisture in the air crystallise out in very minute crystals, and are nearly always indistinguishable from the quartz particles. Here then we have a source of very considerable error.

In addition, the illumination of the underground workings is by means of acetylene lamps and candles. Acetylene, as is well known, burns with a smoky flame, and large amounts of carbon in a very fine state of division are liberated, so much so that the gravimetric or sugar tube sample is often stained black by the carbon. The carbon particles by semi-dark ground illumination appear bright and shiny like the silica particles, and it is impossible to differentiate the one from the other. As far as our knowledge goes, carbon particles are not dangerous when breathed into the lung, and as in some places they are present in very large quantities in mine air, if counted in the Konimeter sample with the silica dust, an entirely wrong idea of the dangerousness of that particular sample of mine air would be obtained. Here there is another source of error in counting dust particles.

Experiments were conducted for some time in an endeavour to eliminate the soluble particles from the Konimeter samples, and a method devised by Mavrogordato, Moir and Ray proved satisfactory. These investigators found that most of the soluble particles could be removed by the action of hydrochloric acid vapour, which did not touch the silica.

The method adopted was to insert a watch glass over the spot, the watch glass having in its centre a small segment of filter paper saturated with a 15 per cent. solution of hydrochloric acid. In the case of spots on circular slides a rubber ring is placed round the periphery of the slide and a spare glass slide with the saturated filter paper in the centre placed on top of the ring, thus forming a small chamber with an atmosphere of hydrochloric acid gas. By this means most of the soluble salts were dissolved, but, unfortunately, not the carbon particles.

In 1927 McEwen and Thompson tried immersing the whole slide in a dilute solution of hydrochloric acid, washing in distilled water and drying. Instead of this somewhat drastic treatment removing the whole spot, they found that on examination under the microscope the particles on the spot shone up clear and bright with no trace of contamination by either carbon or soluble salts; the silica in fact looked clean and polished.

Many experiments were made to see if there were any loss of silica particles, but the results in many cases showed an increased count after treatment, as if some of the silica particles had been masked by carbon in the original count.

In 1925, on my suggestion, an attempt was made to eliminate carbon from the spots by ignition, using heat-resisting glass in the slide, but unfortunately it was not then possible to obtain a sufficiently transparent glass.

Recently it has been found possible to obtain a glass with heat-resisting properties which is also transparent under the microscope and free from flaws. McEwen and Thompson have made a large number of experiments with encouraging results. The slides are made of Chance's heat-resisting glass. On to the centre of the slide is poured a few cubic centimetres of the acid, and this is allowed to spread all over the slide covering the spots. The slide is then immersed in a basin containing distilled water, the washing being repeated twice, and finally the slide is immersed in hot distilled water and allowed to dry. The slide is then placed on a smooth fireclay tile in a cold gas muffle, and the gas lit. The mufflle is kept at a dull red heat for thirty to twenty-five minutes, then the gas is turned off and the slide allowed to cool in the muffle. The silica particles when examined under the microscope after this treatment are clear and bright, and in many cases show a much larger count than before treatment.

This new method represents a very great advance, and enables more reliance to be placed on the accuracy of Konimeter samples.

Systematic Dust Sampling on the Witwatersrand

Previous to 1913 no attempt had been made to determine systematically the amount of dust in the air of the mines of the Witwatersrand. In December of that year the Miners' Phthisis Prevention Committee, which had been appointed by the Government, caused the first dust survey of the mines to be carried out.

The samples were all taken by the gravimetric method, and gave the following results:

	Milligrams per cubic metre
General average	5.4
Drives	6.1
Raises	9.1
Winzes	5.0
Ore bins	5.5
Stopes	4.2

In May 1914 the Chamber of Mines established a department to investigate the dust conditions of the mines, and to suggest methods of preventing the formation of dust and its dissemination into the air of the mines. Visits were paid to each mine, and samples taken in as many of the working places as possible. Tests were made of various kinds of work likely to produce dust, and suggestions made for bettering conditions.

Since 1914, fifty-eight systematic dust surveys were made, showing the following results:

	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
General average	4.9	3.9	3.8	2.9	2.4	2.6	1.6	1.6	1.3	1.1	0.9	1.2	1.2	0.8	1.0
Development	6.9	5.8	5.4	4.4	3.5	2.9	2.3	2.4	1.9	1.2	1.0	1.1	1.2	0.8	0.8
Stopes	3.4	2.8	2.9	2.1	1.9	1.6	1.2	1.2	0.9	0.7	0.7	1.0	0.9	0.6	0.7
Ore bins	4.4	4.0	4.2	3.7	2.9	2.7	2.1	2.2	1.8	2.0	1.6	1.8	1.9	1.3	2.0
Percentage over 5 mg.	27.0	23.0	20.0	13.0	10.0	8.0	4.0	4.0	3.4	2.5	1.7	1.1	1.2	1.2	1.9

It will be noticed from the above table that there is a steady diminution in the quantity of dust found in the various sections into which mine work is divided. Taking 5 milligrams per cubic metre as the danger mark, it will be noticed that whilst in 1915 27 per cent. of the samples were above that limit, it had fallen in 1928 to 1.2 per cent. and in 1929, owing to some high samples at ore bins, was 1.9 per cent.

In 1916 it was decided to appoint an official on each mine to investigate and report on the dust conditions, as it was recognised that the staff of inspectors appointed by the Chamber of Mines could not be expected to pay sufficient attention to all the working places on the mines. These inspectors were expected to pay surprise visits to see that things generally were in good condition.

The mine officials took samples in the same way as the Chamber's officials, and all the samples were analysed in the Chamber's laboratory. The following table shows the more important of the results obtained:

	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929 (6 mths.)
General average	5.2	3.4	2.8	2.0	1.5	1.6	1.2	1.2	1.0	1.1	1.1	0.9	0.8	0.8
Development	6.0	4.4	3.6	2.5	1.9	2.1	1.6	1.5	1.1	1.2	1.1	0.9	0.8	0.8
Stopes	4.8	2.9	2.2	1.6	1.2	1.3	1.0	0.9	0.8	1.0	0.9	0.8	0.7	0.7
Ore bins	5.5	3.9	3.4	2.3	1.9	2.0	1.6	1.8	1.6	1.6	1.2	1.2	1.1	1.1

It will be noticed that the improvement in dust conditions indicated by the samples taken by the Chamber inspectors is corroborated by those taken by the mine inspectors.

Konimeter Samples

Since 1919 Konimeter samples have been taken as a matter of routine at the same time as the gravimetric samples.

Until June 1923, all the samples were counted by light ground illumination, with the following results:

	1919	1920	1921	1922	1923
Development	490	320	211	270	390
Stopes	270	165	130	110	180
Ore bins	240	160	150	150	190
General average	318	190	160	150	230

As before stated, dark ground illumination was introduced in July 1923, and the following results were obtained:

	1923	1924	1925	1926
Development	620	480	350	310
Stopes	360	390	260	250
Ore bins	280	350	250	250
General average	380	410	280	270

In 1927 the McEwen-Thompson method of treating the slides for the removal of soluble particles and particles of carbon was introduced, with the following results:

	1927	1928
Development	132	78
Stopes	119	62
Ore bins	142	105
General average	125	73

In 1929 the ignition method of treating the slide was introduced and in addition the spots were counted by using the full reflectors of the microscope instead of subdued light.

Results	1929 Particles per c.c.
Development	165
Stopes	135
Ore bins	247
General average	159

Conclusions

The figures given show that there has been a vast improvement in the amount of dust present in mine air in 1929 as compared with 1914.

It may be asserted that neither of the two methods of sampling dust in mine air used on the Witwatersrand are methods which can claim any scientific accuracy. The errors which can be, and are, introduced through no fault of the operator are such as to render any claim to real accuracy untenable. The gravimetric method, sampling as it does all sizes of dust in the air, can easily be made to show very serious dust conditions by the presence of a few large (in the microscopic sense) particles of dust, whilst innumerable small dangerous particles of very light weight will not be reflected in the results obtained. The difficulty of separating the gravimetric sample into large (in the microscopic sense) and fine dust is so great that it is not practicable in ordinary routine work. On the other hand, as an indication of the dust conditions, the gravimetric method is useful and has done good work. The vast improvement in underground conditions on the mines of these fields can be traced to the results of gravimetric sampling as showing the condition prevailing.

Despite its faults and errors, the fact that, by the same method as was used in 1914, the average dust content of mine air has fallen from over 5 milligrams per cubic metre to round about 1 milligram, is an indication of the good work performed as the result of using the gravimetric method to call attention to bad conditions.

The Konimeter method has also its faults and errors, some of which have been already mentioned, such as its showing up all dust, whether dangerous or not, and its liability to contamination by carbon particles.

The result of long and painstaking research work indicates that it may be possible in the future to obtain a sample by the Konimeter method which will be a true indication of the amount of dangerous dust in the mine atmosphere.

In the meantime we can say that by using both methods we can obtain results which, if interpretated in a relative manner, give us a good indication of the dustiness, and consequently of the dangerousness from a phthisis-producing point of view, of the air of the mines. By using these methods and remembering that neither give accurate results, but rather results which are only an approximation to absolute accuracy, we can still hope for further improvement in the dustiness and ventilation of the mines.