AN INVESTIGATION
OF
SOME DUST PROBLEMS IN COAL MINES

submitted by

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CONTENTS.

INTRODUCTION

Coal dust is a potential danger in coal mines. Although our knowledge of the properties of coal dust and of the means of rendering it innocuous have been extended within recent years, the mining industry is still visited from time to time by disasters in which coal dust plays a prominent part.

Coal mining by modern methods results in the production of large quantities of fine coal dust and in our collieries at the present time the general use of incombustible dust is considered to be the only practical and really efficient means of ensuring safety from the danger of coal dust explosions. Experiments at Altofts, Eskmeals and Buxton in this country and at other testing stations abroad have proved that fine incombustible dust, when suitably mixed in sufficient quantity with coal dust, will prevent both the initiation and propagation of coal dust explosions. The treatment of deposited coal dust is governed by General Regulations made under Section 62 of the Coal Mines Act, I9II. These Regulations require, generally, with respect to the use of incombustible dust, that "in every seam, except a seam in which anthracite only is worked, the floor, roof and sides of every road or part of a road which is accessible shall, unless the natural conditions comply with the requirements as regards incombustible dust, be treated with incombustible dust in such a manner, and at such intervals, as will ensure that the dust on the floor, roof and sides respectively shall always consist/

consist throughout of a mixture containing not more than 50 per cent of combustible matter". The Regulations also allow of the dust being treated by water alone or by a combination of both methods. The Regulations regarding the use of water and dust are given in full in Appendix I and the testing procedure for the estimation of combustible matter in the various types of dust mixtures in Appendix 2.

Although compliance with the above Regulations has ensured and still ensures a reasonable measure of safety from the danger of coal dust, it is now well known that the minimum amount of ~~stone~~ incombustible dust prescribed is insufficient to prevent inflammation in some cases and more than enough in others. The amount required depends upon the relative inflammability of the coal, the composition of the incombustible dust, the fineness of both dusts and their moisture contents. Different percentages of incombustible dust are required for different coal dusts and an approximate formula for the amount of dust required, deduced from large scale experiments at Buxton, has been given by Wheeler (1) as follows:-

Percentage ~~stone~~ incombustible dust required $= 100 - \frac{1250}{V}$

where V = Percentage Volatile Matter in the coal dust.
This formula, based on tests with coals of widely different volatile content, has been more recently modified by Mason and Wheeler (2) to take account of the nature of the ~~stone~~ incombustible dust used. A small laboratory apparatus has also been designed, (3) which, on proper/

proper standardisation is said to give results approximately comparable with those obtained from explosions in the large experimental gallery at the Buxton Testing Station.

Although research has shown that the ulmin content, and hence for all practical purposes the volatile content of the coal, is the criterion of its inflammability, the exact properties of the incombustible dust by virtue of which it suppresses inflammation are not known. The earlier conclusion drawn by the Explosions in Mines Committee (4) was that fineness was of more importance than chemical composition. More recent researches, however, have shown that chemical composition is also important when considering the effectiveness of an incombustible dust. Other factors may also be influential. Whether the quenching action is mainly dependent on chemical or physical properties or on both and to what extent has not been definitely proved.

The Function of Incombustible Dusts.

As already stated, although some roadway dust mixtures may comply with the Statute in regard to percentage of incombustible matter, this is not always a criterion of safety. A still higher percentage of incombustible dust is no greater criterion of safety as no action takes place with the dusts at rest in the roadways. It is the percentage of proportions of the various dusts which rise and form a cloud in an explosion which is the all important feature. The condition and intimacy of mixture of the dusts are of great importance.

Incombustible/

Incombustible dust is said to be effective in preventing the initiation or propagation of an explosion by reason of its capacity for absorbing heat and screening the suspended coal particles from the heat source or other ignited particles. Briefly stated, coal dust can be made safe if sufficient suitably conditioned incombustible dust is raised into suspension in a cloud with it to extract and /or screen enough heat to prevent its inflammation. The ~~stone~~ incombustible dust, although spread about on the surface of the mine roadways, is not expected to lay or keep down the coal dust, although this may actually happen, for this reason it is an advantage to have the incombustible dust as the surface layer.

The formation of a cloud in intimate mixture with the coal dust is the action expected of the stone or other incombustible dusts used in mines and it is evident that, apart from its capacity of absorbing heat, the dust must be capable in the first place of rising and dispersing easily and intimately with the coal dust under the same disturbing forces. Although the stone dusting principle has been in operation for close on 40 years, the fact of the ~~stone~~ incombustible dust being present in sufficient quantity on the roof, floor and sides of mine roadways but failing to rise in a sufficiently dense cloud to be effective at the critical moment was, until comparatively recently, rarely questioned. That this actually did happen was the important fact which emerged from the enquiry held by Sir Henry Walker, C.B.E., L.L.D., H.M. Chief Inspector of Mines, into the Causes and Circumstances attending/

attending the Explosion at the Haig Pit, Whitehaven Colliery, Cumberland, on 29th January, 1931. The finding, after complete examination of all circumstances, was that "the explosion was spread throughout the district because of the dampness causing the limestone dust to bind and not rise and intermingle with the fine coal dust which lay upon it".(5)

It is quite conceivable that an ~~stone~~ incombustible dust applied in a mine, although efficient at the time of application, may sooner or later become useless for the purpose originally intended. Depending mainly upon the nature of the dust, a change may be brought about in its physical and chemical properties by variation of atmospheric temperature and humidity; or, because of the addition or absorption of excessive moisture from wet strata and other sources, the dust may ball up and cake on drying out again after being thoroughly wet, and thus become incapable of being easily raised into suspension to form a dust cloud.

Although the tendency of these dusts to ball up and cake has only comparatively recently been realised by mining engineers in this country, it has been recognised for some time in the Dortmund area of Germany where rough tests for looseness of the dusts used in the mines are prescribed by Regulations.

Object of Research

Mainly as a result of the finding of the enquiry into the Whitehaven Colliery Explosion (1931), the present research was commenced to investigate the reasons for the incombustible dust/

dust binding in the mine and the circumstances in which a similar condition might exist.

The general physical properties and characteristics of the more common incombustible dusts used in coal mines were therefore examined and their reaction to changes of temperature, humidity, and added moisture investigated. Since there is a difference in the looseness of dusts, as well as a marked balling tendency in some dusts, methods of measuring their cloud forming properties were studied together with the effect of fineness and moisture content on these properties.

Other problems directly connected with incombustible dusts and their use in mines were also investigated and the results are presented in the following series of papers.

PAPER I.

SOME IMPORTANT PROPERTIES OF INCOMBUSTIBLE DUSTS.

PHYSICAL PROPERTIES.

To assess the value of an incombustible dust for use in combating coal dust explosions, it is necessary to have some knowledge of its fineness, chemical composition, specific gravity, particle shape and size. In general, its more important physical and chemical properties must be known.

For the determination of these properties numerous samples of dusts commonly in use were obtained and these were assumed to be representative of the typical materials in use throughout the country. It was anticipated that slight differences in chemical composition and fineness would occur in succeeding samples even from the same source and this was actually found to be the case . To obviate this difficulty and as far as possible to carry out all the tests on the same dust, fairly large samples were obtained in the first place. Additional dusts were from time to time added for special tests or as they became available.

Specific Gravity.

The specific gravity of a dust is probably one of its most important properties when considering its possible efficiency in the quenching of a coal dust explosion. The more nearly this approaches the specific gravity of coal dust(I.3-I.5), the more readily will it behave like coal dust in rising into a cloud when subject to the same disturbing forces.

True specific gravity was found by the standard laboratory method for powders using a pyknometer of 50 c.c. capacity. Alcohol was used as the liquid medium, thus obviating any wetting and solution/

TABLE I.

Showing the more important Physical Properties.

DUST	True Specific Gravity	Bulk Density.	True S.G. / Apparent S.G.	Specific Heat cals./ gm.
SHALE (Murton)	2.732	0.7036	3.87	0.2148
Fullers Earth	2.569	0.6474	3.98	0.2890
Pixie Powder	2.3335	0.7293	3.20	0.4244[x]
Gypsum	2.2040	0.7103	3.10	0.4244[x]
Anhydrite	2.717	0.8654	3.14	0.1961
Softener Product	2.274	0.5404	4.21	0.2321
Lime Pulp	2.31	0.4540	5.08	0.2457
Limestone (Lugton)	2.68	0.9507	2.83	0.2094
Limestone (South Wales)	2.662	0.8477	3.14	0·2034
Limestone (Cults)	2.813	0.8494	3.32	0.2078
Limestone (Charlestown)	2.668	0.9465	2.82	0.2070

[x] Calculated Values.

solution difficulties.

Apparent specific gravity or bulk density was determined by weighing a large volume of each dust under the same conditions. The values obtained give a measure of the looseness of packing of the dusts or the amount of void space in a given volume, and they are influenced by the shape and size of particle and by the distribution of the various sizes. As shown by Greig(6) however,the relationship between bulk density and fineness is not linear and although a finer dust may give a lower bulk density the method is not to be recommended as a type of fineness measurement. Certain dusts, although alike in true specific gravity have an entirely different consistency to the touch. This is generally attributed to their difference in composition,but more especially to differences in their fineness and size grading. This is shown by the bulk density and true specific gravity values in Table I.

The values of the ratio of true to apparent specific gravity vary from 2.82 to 5.08, the high values denoting dusts which even to the touch appear to be most loose and open; the synthetic materials, lime pulp and the mixture of carbonates from a water-softening plant are best in this respect. The remainder of the dusts have nearly similar ratios, which, considering the differences in specific gravity,would appear to show a similarity in fineness. This however is not the case.

As already mentioned, this test cannot be relied upon too much as it is difficult to compare the dusts under identical conditions. The results given in the table were obtained under the conditions of most loose packing - a condition difficult to obtain with all the dusts.

<u>Specific Heat.</u> So far as research into coal dust explosions has gone the main properties by virtue of which incombustible dusts are considered to be effective are those of heat capacity and fineness. It is only within comparatively recent years however that specific heat has been proved to be an important factor. Previously, the fineness of the dust was considered to be more important and although it is probable that the rate of heat absorption and heat capacity are the important properties, information on this point is scanty.

The values of specific heat given in Table I were determined by the method of mixtures a number of times for the range 20-IOO degrees Cent. and the average values taken. Values for the hydrated gypsum dusts were calculated. The range of temperature for which the values are given is low and perhaps provides but little guidance in the question of specific heat values at much higher temperatures. Decomposition of the dusts at higher temperatures complicates the experimental determination of these values.

With the exception of gypsum all the dusts have more or less equal specific heat values and it is significant at this point to note that gypsum has been proved at Buxton to be the most effective dust. The relative efficiencies of the dusts tested at Buxton (2) recently are as follows:-

Fullers Earth.....	IO
Shale............	II-I2½ (depending on the type)
Anhydrite.........	9
Limestone..........	8
Calcium Carbonate..	7½
Gypsum...........	4

The numbers denote the relative amounts of each dust required to

TABLE 2.

Wet Screen Analyses.

Percentage Weight left on	Shale (Murton)	Limestone (Lugton)	Limestone (So. Wales)	Limestone (Cults)	Limestone (Charlestown)	Pixie Powder	Gypsum	Anhydrite	Fullers Earth	Lime Pulp	Softener Product.
80 - mesh	4·32	0·82	1·96	0·30	14·52	0·50	1·34	9·50	0·04		21·40
100 - "	2·68	3·00	2·28	0·50	3·86	1·22	1·28	4·40	1·24	1·41	3·28
120 "	1·84	3·68	2·94	1·00	3·08	1·54	1·00	3·90	2·08		2·94
150 "	2·92	4·66	4·30	2·14	5·22	3·48	1·90	6·30	2·76		2·26
200 "	3·62	6·08	7·00	5·30	3·92	5·10	3·46	8·90	5·40	2·94	4·56
250 "	2·52	5·24	5·14	5·22	3·24	3·18	2·20	7·20	3·98	1·36	2·18
Through 200 - mesh	84·62	81·76	81·52	90·76	71·40	88·36	91·02	68·00	88·48	95·65	65·56

prevent an explosion under standard test conditions.

A glance at the specific heat values shows the above relationship to hold only in the case of gypsum, anhydrite and limestone and that other factors must play an important part, as the marked differences in efficiency between certain dusts cannot wholly be attributed to difference in specific heat.

SIZING AND FRACTIONATION OF DUSTS.

Screening

The complete specification of a powder or dust necessitates a mechanical or screen analysis. This consists of separating the particles into groups lying between certain limits of size and for coarse granular powders,screening or sieving is quite efficient and effective and is the method generally adopted.

With much fine material, especially when fine sieves are used, dry sieving is generally unsatisfactory: fine material or material slightly damp clogs up the finer mesh screens and precludes any accurate analysis of sizes being made. A much more accurate analysis can be obtained by screening the dusts wet. This has the disadvantages that some material may be soluble in or very easily disintegrated by water. It has the advantages however in the case of most stone dusts that it is quicker, more efficient in the separation of fines from the surfaces of the larger particles, and causes less abrasion and degradation of the dust in the process.

Table 2 records the result of a wet screen analysis of the various dusts under test. The results clearly show that all the dusts easily comply with General Regulations, requiring that 50 per cent by weight of the material shall pass a 200-mesh sieve.

Andrews' Kinetic Elutriator

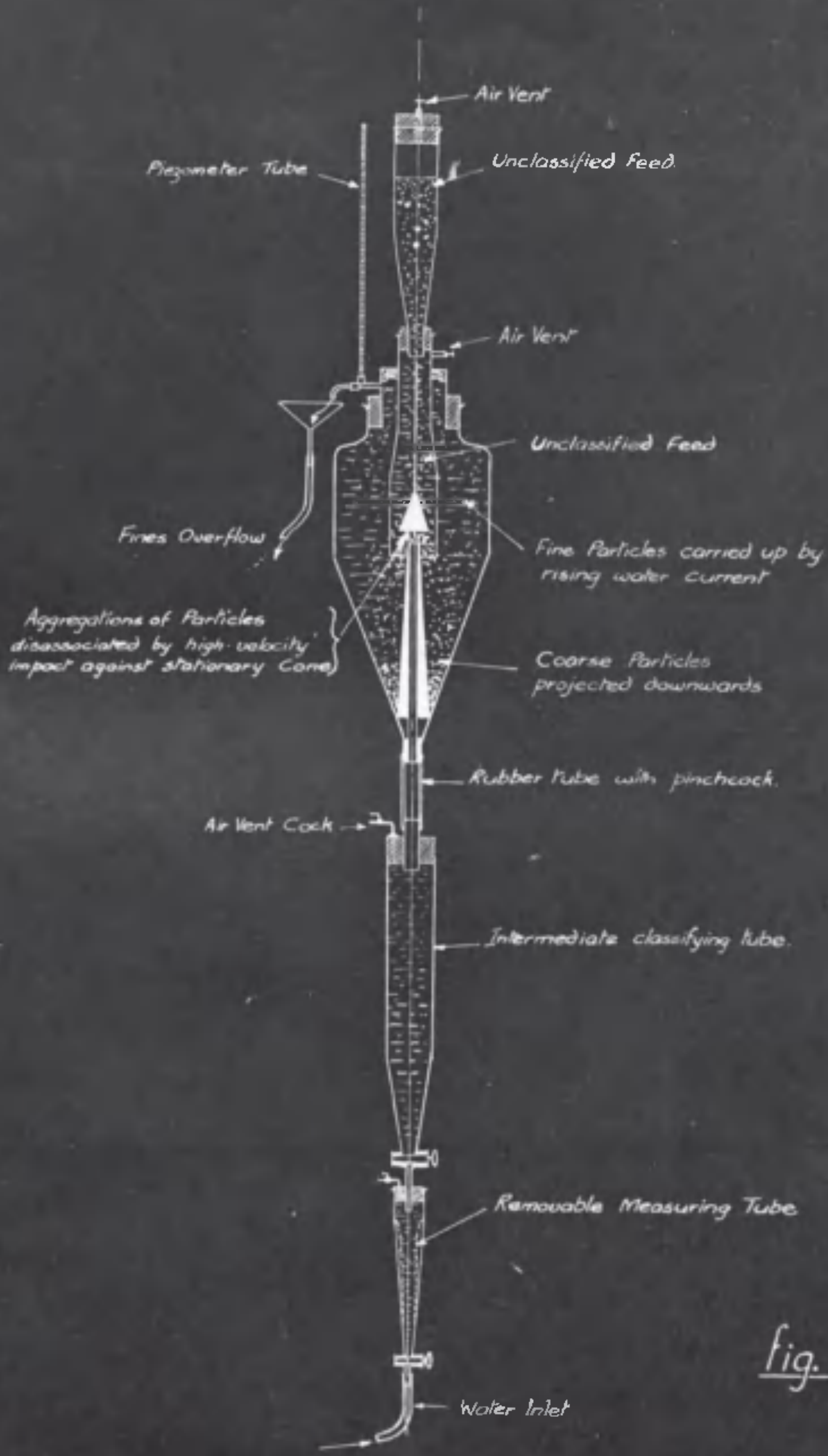


fig. 1

The analyses also show that the bulk of the dusts pass through the finest mesh used (250-meshI.M.M.). This is the important fraction of the dust,since it contains the material likely to be most efficient as well as the particles which are likely to be physiologically dangerous.

Wet Elutriation

To obtain a more complete analysis of the portions passing thro' 250 mesh , sieving was replaced by elutriation methods. The method adopted was that of elutriation by water, whereby the dusts were classified by upward water currents. By alteration of the velocity of the upward current particles of different size ranges were separated. The samples obtained in this way were small,but, although weighable, could not be weighed or sized until dry. As solution again may cause a small error and also slight disintegration the analyses obtained may not be considered true in every case.

It was decided however that wet elutriation was the most accurate method of making a complete size analysis of a sample although of little use for providing bulk samples of sized fractions for further experiments. The degradation difficulties mentioned are disadvantages in any accurate sizing process but are inherent to some extent in all apparatus where a bulk sample is subdivided in this way.

Apparatus. An Andrew's Kinetic Elutriator (fig.I) was used in this work and was designed normally to give three sizes:- coarse, intermediates, and fines, the size range of the latter being capable of considerable variation. A modified method of working the apparatus was adopted to allow of a series of fractions being

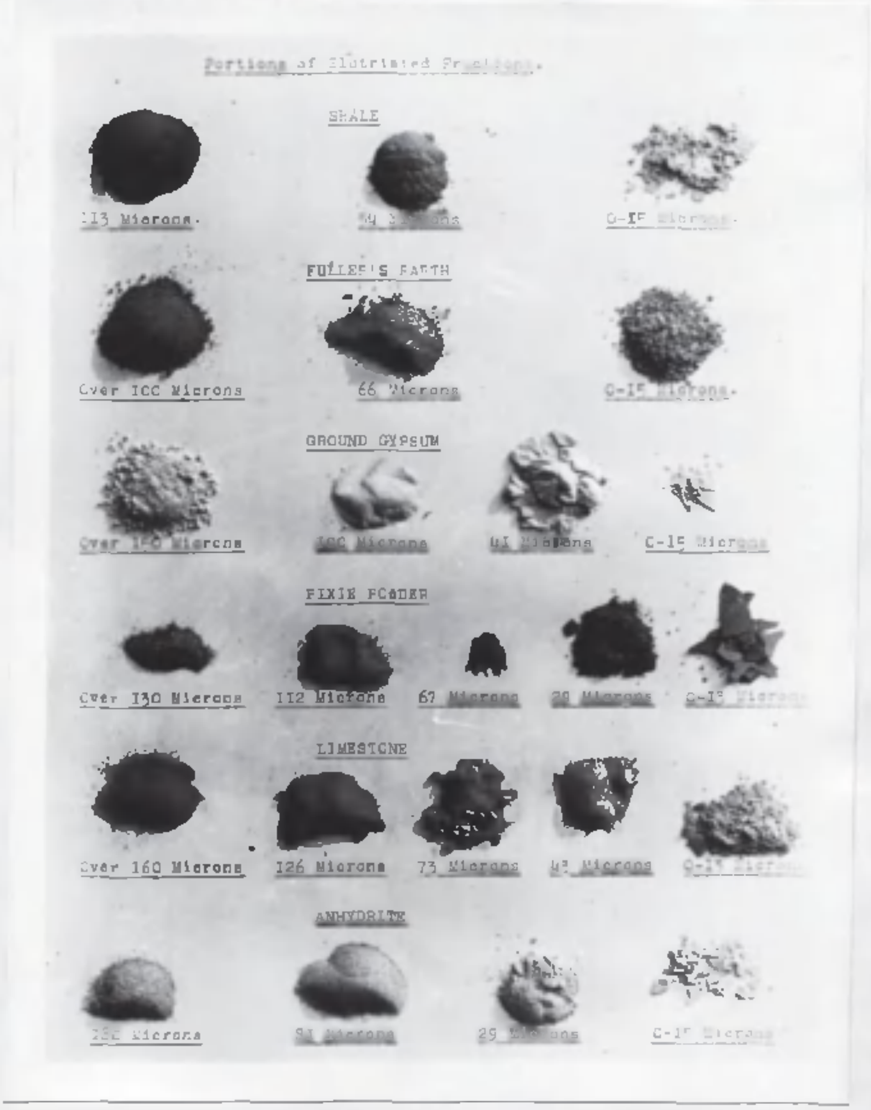

Portions of Elutriated Fractions.
SHALE
113 Microns.
54 Microns
0-15 Microns.
FULLER'S EARTH
Over 100 Microns
66 Microns
0-15 Microns.
GROUND GYPSUM
Over 150 Microns
100 Microns
41 Microns
0-15 Microns
PIXIE POWDER
Over 130 Microns
112 Microns
67 Microns
28 Microns
0-15 Microns
LIMESTONE
Over 160 Microns
126 Microns
73 Microns
48 Microns
0-15 Microns
ANHYDRITE
130 Microns
91 Microns
29 Microns
0-15 Microns

fig. 2.

obtained, and a complete analysis of each dust on 20 gm. samples. As the finest size came over with the overflow, it was obtained by collecting the overflow, settling, decanting and filtering. All the fines were not collected, but only sufficient for a few examinations. The remaining fractions were all collected and weighed and the amount of fines estimated by difference.

Fig.2 shows portions of the various sized fractions obtained with this apparatus.

Sizing of the particles was done microscopically using an eyepiece filar micrometer; the predominant shape of particle in each fraction was also noted when sizing. The shape of particle is considered again at a later stage.

Analyses. The results of the elutriation analyses are given as follows:-

SHALE(Murton)

Range of size in microns.	Shape of Particle.	Percentage by weight	Remarks
Above I20	Rounded to Subangular	9.25	
I20 - 90	-do-	5.42	
90 - 65	-do-	2.23	
65 - 35	Subangular	8.84	
35 - I5	-do-	8.05	
I5 - 0	-do-	66.2I	

GROUND GYPSUM.

Ab ove I50	Subangular to Rounded.	I5.20	A few angular particles
I50 - 60	-do-	I0.4I	-do-
60 - I5	-do-	35.00	-do-
I5 - 0	-do-	39.39	-do-

LIMESTONE (Lugton)

Range of size in microns	Shape of Particle.	Percentage by weight.	Remarks.
Above IIO	Subangular to Rounded	IO.24	
IIO - 80	-do-	IO.6I	A few angular Particles.
80 - 45	-do-	7.84	Many angular particles.
45 - I5	Subangular	I5.I6	-do-
I5 - 0	-do-	56.I5	

LIMESTONE (South Wales)

Above I40	Rounded	4.46	Few subangular particles.
I40 - I00	-do-	II.85	-do-
I00 - 75	Subangular	4.86	
75 - 55	Subangular to Rounded	7.34	
55 - I5	Angular to Sub angular	I9.34	
I5 - 0	Subangular to Rounded	52.I5	

LIMESTONE (Cults)

Above I40	Angular to Subangular.	4.02	
I40 - I00	Subangular	I.72	
I00 - 70	Angular	I2.39	A few very sharp particles.
70 - 45	-do-	8.5I	
45 - I5	Angular to Subangular	7.50	
I5 - 0	Subangular	65.86	

LIME PULP

Above 250	Irregularly Rounded	0.70	
250 - 70	-do-	3.80	Many aggregates
70 - 30	-do-	II.20	-do-
30 - 0	Rounded	84.30	-do-

Limestone (Charlestown)

Range of size in microns	Shape of Particle	Percentage by weight.	Remarks.
Above 200	Subangular to Angular	I3.02	
200 - I40	Rounded to Subangular	6.62	
I40 - 90	Angular to Subangular	7.44	
90 - 50	Subangular	6.66	
50 - 35	-do-	2.80	
35 - I5	Rounded to Subangular	II.28	
I5 - 0	-do-	52.I8	

SOFTENER PRODUCT

Above 300	Subangular	I4.37	Many large aggregates
300 - 200	Rounded and Irregular	5.67	-do-
200 - I40	Irregularly Rounded	8.79	Smaller Aggregates
I40 - 80	-do-	3.06	
80 - I5	-do-	42.77	
I5 - 0	Spherical	25.35	Very small aggregates

PIXIE POWDER

Above I40	Rounded	4.77	
I40 - 90	Rounded to Subangular	3.83	
90 - 50	-do-	8.43	Many rhombs.
50 - 30	Sub-crystalline	8.29	
30 - I5	Subangular to Rounded	7.89	
I5 - 0	Sub-crystalline to Rounded	66.79	

ANHYDRITE

Range of size in microns.	Shape of Particle	Percentage by weight	Remarks.
Above I50	Subangular to Rounded	5.9I	
I50 - I00	-do-	5.75	
I00 - 50	Angular to Subangular	6.49	
50 - 25	-do-	I2.89	
25 - I5	-do-	6.29	
I5 - 0	Subangular to Rounded	62.67	

FULLERS EARTH

Above I40	Subangular to Rounded	0.83	
I40 - 90	-do-	I4.44	
90 - 60	-do-	8.98	
60 - 35	Subangular to Rounded	5.I0	
35 - I5	-do-	34.36	
I5 - 0	-do-	36.29	

These analyses are expressed by histograms(fig.3) which show at a glance the percentage weight of dust between the size limits stated.

Compared with the results obtained by wet screening there are discrepancies in some cases. These can be attributed to degradation and solution of particles in the process of elutriation and also to the influence of particle shape. Shape of particle plays an important part in elutriation where the particles are carried upwards in the water current. This is not so important in screening.

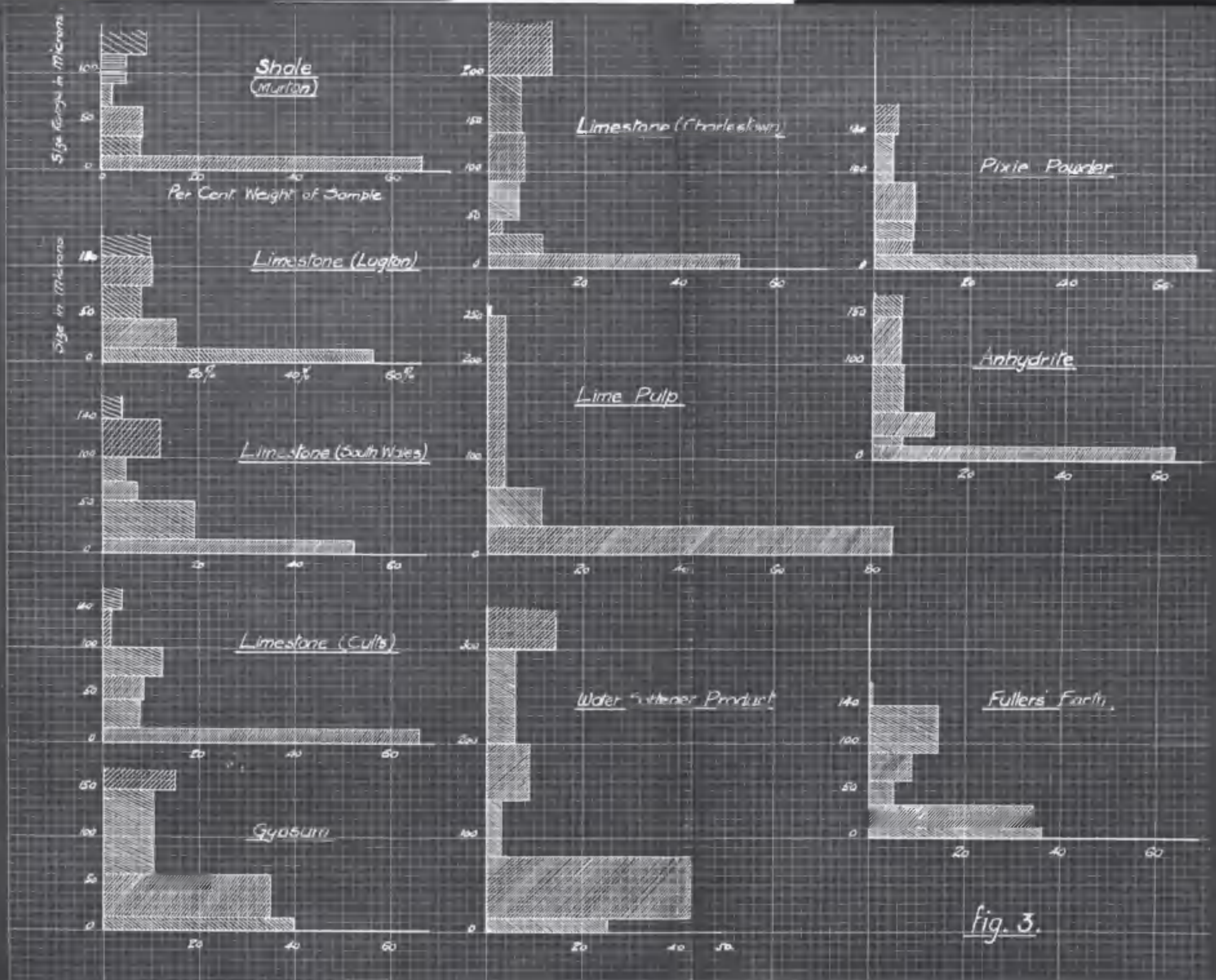
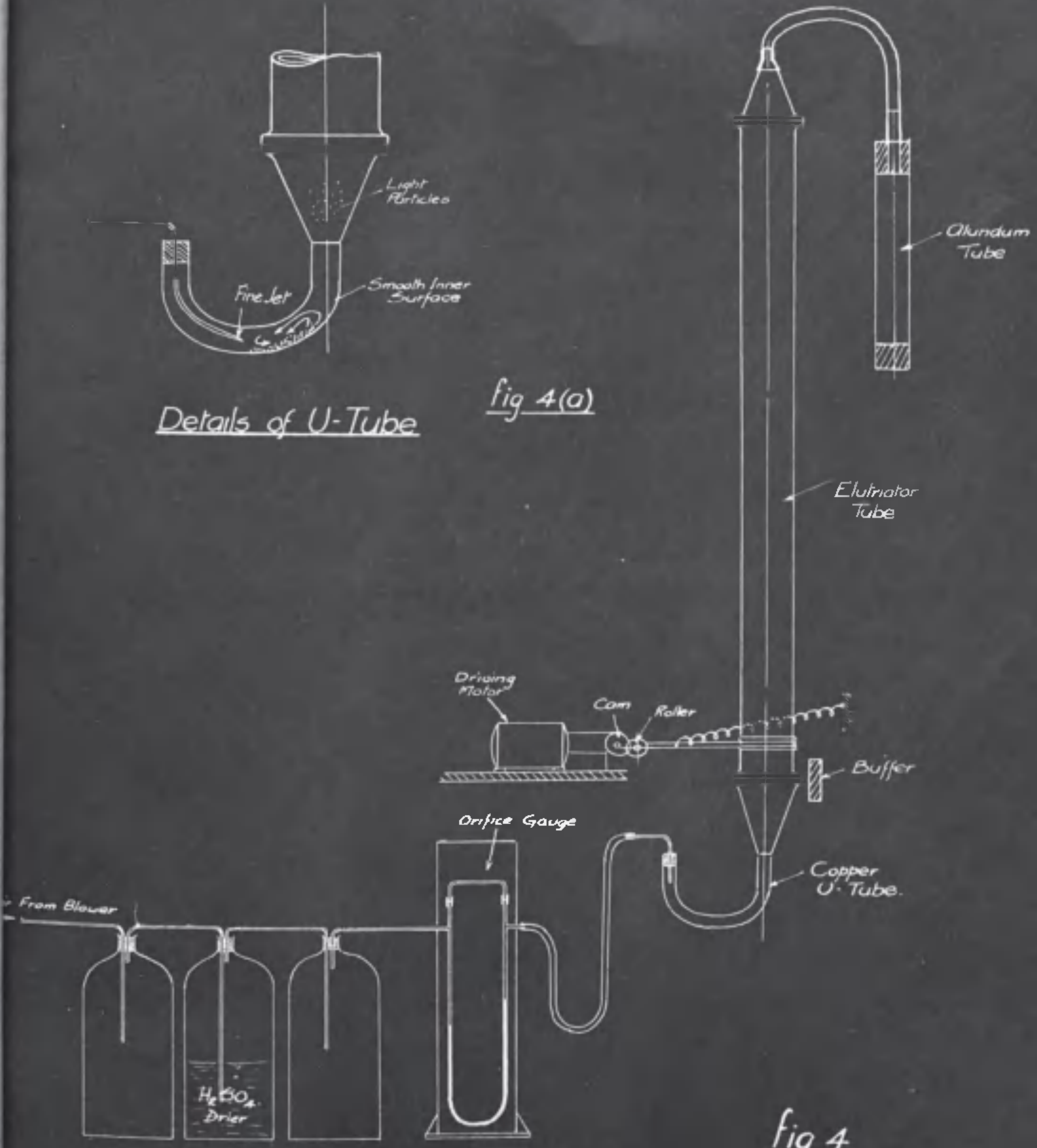

Shale (Murton)
Size Range in Microns
Per Cent Weight of Sample
Limestone (Charlestown)
Pixie Powder
Limestone (Lugton)
Size in Microns
20% 40% 60%
Lime Pulp
Anhydrite
Limestone (South Wales)
Limestone (Cults)
Water Softener Product
Fullers' Earth
Gypsum
0 20 40 60 80

fig. 3.



Details of U-Tube

fig 4(a)

fig 4

Arrangement of Air Elutriation Apparatus.

Air Elutriation

Separation of fractions by means of an air current was carried out to obtain bulk samples of the finest fractions unaffected by wetting. No accurate size analysis however was carried out by this method.

Apparatus. The elutriator (fig.4) was based on the principle that if the mixed particles were suspended in an air current of regulated speed,the stream of airwould carry the finer particles along with it, whilst the heavier particles would fall back to the bottom of the elutriator tube. As the speed of the air stream passing through the apparatus was capable of fine control within wide limits, particles of any size range could be separated.

The apparatus consisted essentially of a brass elutriation tube 4 ft. long by 3 ins. internal diameter, fitted at the upper end with a dust filter and at the lower end with a means of dispersing the dust into the tube. The method of dispersion was similar to that used by Roller,(7) a I-inch diameter copper U-tube containing the dust and the dispersing jet. An air supply,obtained from a small rotary blower and dried by passing through sulphuric acid was admitted to the U-tube by means of a fine glass jet. This jet projected into the middle of the U-tube and thoroughly agitated and dispersed the dust. The finest dust was carried up the elutriator tub e while the heavier particles slid back into the U-tube for a repetition of the process.(fig.4a).

Dust laden air passed to the alundum filter tube where dust and air were separated. Special paper filter bags were later used for this purpose but too much dust was always lost by adhering to the inside of the bag. Ultimately, mantle-shaped parchment filters were used and found to be highly satisfactory.

During elutriation, fine dust adhered and built up on the walls of the elutriator tube and to prevent this the 'tapping' mechanism shown was introduced. A small motor, driving a small cam through a worm reduction gear, transmitted to the long tube a series of sharp blows which prevented much of the fine dust from adhering to the tube sides.

As found by Roller (7) and later by Graham (8), attrition of the dust in the U-tube prevented the absolute determination of the percentage of fine material in any sample. Due also to aggregations of fines and their cohesion to the larger particles, all the fine material was seldom separated at its correct elutriation velocity. Certain proportions came over with larger material and prevented very closely graded fractions being obtained. The advantage of the method in preparing bulk samples of fine fractions lay in the fact that the samples were recovered unaffected, apart from any slight absorption of moisture and, in the case of coal dusts, oxidation.

PARTICLE SIZE AND FINENESS NUMBER

For comparatively coarse powders it is sufficient to express the size in terms of the mesh through which the dust passes. With the dusts under test this method can be employed down to screen sizes of 300-mesh but below this limit other methods must be employed.

In the elutriated fractions particle size was measured microscopically. By adjustment of the hairs of the eyepiece micrometer the dimensions of the particles were readily obtained in microns. Theoretically, for a completely accurate size measurement, the particles should (unless cubical or spherical) be measured in three dimensions. For most of the particles examined, however, it was found that the shape factor did not vary greatly and it was considered sufficient to measure the particles on their greatest dimensions only. A more complete treatise on the measurement of particle size and shape is given by Greig(6) and by Green.(9)

In the analyses already given, the sized fractions have been grouped between definite upper and lower size limits as it is obviously incorrect to assign a specific size to any fraction. These limits were determined by measuring the largest and smallest representative particles. With coarse particles the adherent fine material, if present, was always excluded when making the size measurements. In the tests carried out it was generally found that in any microscopic field the ratio of largest to smallest particle was between 3 and 4 to I.

In certain circumstances it is advantageous to know the "average diameter" of the particles in any fraction and since this cannot be obtained by measurement directly or by experiment, a mathematical derivation of this value must be used. The following derivation of average diameter is due to Mellor(IO) and is based on the assumption that all particles are sperical in shape.

<u>Average Diameter of a Fraction</u>

Let d and d_s denote the largest and smallest diameters measured in a fraction and let the variable x denote the size of any intermediate particle.

Also if V_1, V_2, V_3, etc....V_n denote the volumes of the groups of particles of diameters $d_1, d_2, d_3 \dots d_n$ and if <u>n</u> denote the number of particles present then

Average volume of the particles is $\dfrac{V_1 + V_2 + V_3}{n}$ ------------(I)

By dividing $d - d_s$ by n particles we obtain dx

Therefore $n = \frac{d - d_s}{dx}$ and by substitution in (I)

$$\text{Average volume of particles} = \frac{1/6\pi d_1^3 + 1/6\pi d_2^3 + 1/6\pi d_3^3 ---- dx}{d - d_s}$$

$$= \frac{\pi}{6(d - d_s)} \int_{d_s}^{d} d^3 . \, dx.$$

$$= \frac{\pi (d^4 - d_s^4)}{24(d - d_s)}$$

$$\text{and hence } \frac{\pi d^3}{6} = \frac{\pi (d^4 - d_s^4)}{24(d - d_s)}$$

$$\text{Average Diameter}(d) = \sqrt[3]{\frac{(d^2 + d_s^2)(d + d_s)}{4}}$$

Surface Factor

When the histograms of a number of dusts are given, it is difficult to grasp the significance of large percentages (of) of different sizes, especially if the limits of these sizes are not quite the same. A single quantity or number expressing the effect of these fractions is more appropriate and direct and enables the fundamental idea of fineness to be instantly grasped. The average diameter of a dust sample is not so suitable in this respect as the "surface factor" or the surface exposed by the particles in I gm. of the material. Also, since chemical and physical action between particles takes place at the surface of contact of the particles themselves, a knowledge of the surface factor is (very) essential. The surface factor of a dust is easily found when the average diameters of the various fractions are known.

Surface Factor $= \frac{6}{S}\sum\frac{w_1}{d_1}$ sq. cms. per gm.

where w_1 = Percentage weight of dust of average diameter d_1 cms.

d_1 = Average diameter of fraction of weight w_1 in cms.

and S = Specific Gravity of substance.

For the finest sizes given in the histograms of fig. 3 the lower limit has been set at 0 and a mathematical derivation of an average diameter cannot therefore be made. From the results of a number of counting and measurement tests an average size of from 3-5 microns was found to be most nearly correct for all the fine fractions and was assumed in all calculations. Calculation of fineness numbers for coarse dusts simply from the average of the mesh sizes of the sieves compares favourably with the present method but there is a distinct difficulty in estimating the fineness of the fraction passing through the finest screen. This difficulty has been overcome in certain cases by the use of an arbitrary value for this fraction. Mason and Wheeler(II), in their work on the fineness of coal dust use a fineness factor of I.0 for the I00-200 mesh fraction and adopt an arbitrary value of 2.0 for the fraction passing the 200-mesh sieve. Their figure appears to be remarkably low for the fraction it represents and it is considered that a much higher value should have been used.

Using the formulae and methods outlined the surface factors of the dusts tested were calculated and found to be as follows:-

Dust	Surface Factor
Shale(Murton)........................	3049 sq. cms. per gm.
Limestone (Charlestown)...............	2430 " " " "
Limestone (Lugton)....................	2690 " " " "
Limestone (South Wales)...............	2540 " " " "
Limestone (Cults).....................	2930 " " " "
Pixie Powder..........................	3635 " " " "
Gypsum................................	2220 " " " "
Anhydrite.............................	2880 " " " "

Dust	Surface Factor
Lime Pulp	2225 sq. cms. per gm.
Softener Product	I395 " " " "
Fullers Earth	I8I0 " " " "

PARTICLE SHAPE

In making the detailed examinations of the various dusts the general shape of particle was observed to vary in a marked degree from one dust to another and often between different sized fractions of the same dust. Chemical composition, hardness of material, method of grinding, initial and ultimate size have all a bearing on the shape of particle produced.

As with size, the shape of particle varied greatly and a classification allowing some latitude had to be adopted, as it was impossible to define any particular fraction as being composed entirely of one definite shape of particle. For this reason, in the report on particle shape and size, the shapes have been classified as follows:-

<u>Angular Particles</u> Particles of this shape had irregular outline but well defined corners and edges. These particles had resisted abrasion more than the others and as a general rule were found to be composed of the more resistant materials. In the case of angular particles of soft material the shape had been preserved on account of size alone.

<u>Sub-angular Particles</u> These particles were slightly less angular in outline than the first group. The shape was a common one for the average stone dust particle over a large size range.

<u>Rounded Particles</u> Soft materials such as shale were found to have this shape in the larger sizes of particle. All sharp corners and edges were entirely absent.

fig. 5 x 93

fig. 5(a) x 35

fig. 5(b) x 93

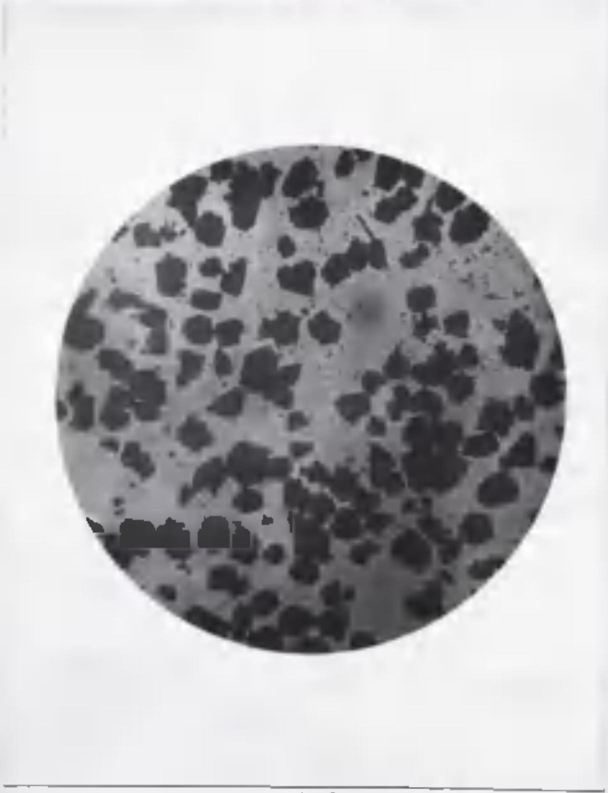


fig. 5(c) x 35.

fig.6 x 93

fig. 6(a) x 35

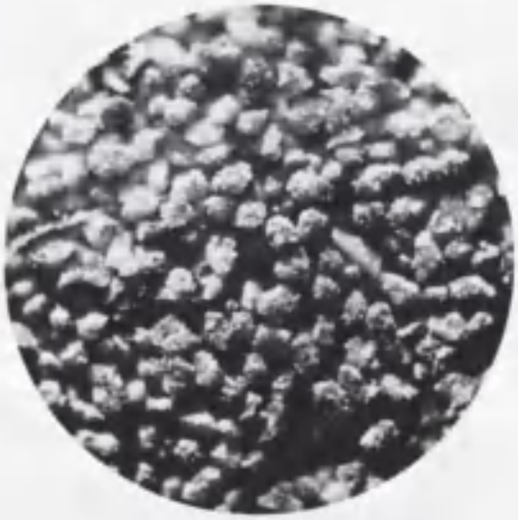


fig. 6(b) x 35

fig. 6(c) x 35.

Crystalline Particles These were common only in gypsum and anhydrite dusts, although the majority of these were found to be somewhat degraded and rounded. Laths and rhombs were predominant in the crystalline forms.

Irregular Particles The irregular shape was peculiar to the synthetic dusts such as lime pulp and was due to the large particles being aggregates of much smaller spherical particles.

Fig.5 shows typically angular to sub-angular shapes. The photograph shows a fine limestone fraction which, due either to its size or hardness, has resisted degradation. Fig 5(a) is typical of most of the coarse fractions of shale and limestones. The particles are classed as sub-angular to rounded, the gently rounded shape predominating.

Fig.5(b) shows a preponderance of crystalline rhombs of gypsum. The particles are from a fine fraction and the preservation of shape is possibly due to size alone.

Irregular particles from the product of a water-softening plant are shown in fig. 5(c). The extreme irregularity in outline is evident and the fine material degraded in the process of preparing the specimen.

Nature of Surface Examination under reflected light showed extreme differences in the nature of the particle surfaces and this must certainly have an effect on the tendency of the particles to adhere and cling together.

Gypsum dusts (fig.6) were found to have comparatively smooth surfaces and the roughness increased in anhydrite(fig.6(a) and shale to limestone (fig.6(b). Softener product had the roughest and most irregular surface of the dusts examined (fig. 6(c).

TABLE 3

Important Chemical Properties.

Dust	Percentage Loss of Weight on Ignition at 700°C	Percentage Loss of Weight on Ignition at 940°C	Moisture per cent. 1hr. at 212°F.	Moisture per cent. till constant in weight at 212°F	Percentage CO_2.	Total Combustible and Organic Matter + Residual Water of Hydration.	Material Insoluble in HCl. per cent.
Shale (Murton)		26·81	1·56	1·56	–	25·25	89·85
Limestone (Lugton)		30·76	0·618	0·618	30·50	0·26	28·85
" (So. Wales)		43·58	0·13	0·13	44·82	–	4·25
" (Cults)		43·50	0·15	0·355	43·04	0·46	9·47
" (Charlestown)		41·25	0·17	0·20	39·99	1·26	12·84
Fullers Earth		18·98	4·37	4·96	11·45	7·55	94·16
Pixie Powder	19·50	60·00	6·97	13·85	–	5·65	13·62
Ground Gypsum	22·10	64·42	5·87	13·98	–	8·12	14·14
Anhydrite	2·91	57·35	0·82	0·82	–	2·09	4·18
Softener Product		42·31	1·485	1·495	37·07	5·24	9·03
Lime Pulp		45·03	1·62	2·18	39·56	5·47	1·988

CHEMICAL PROPERTIES

The chemical properties of the dusts have for the most part been investigated by Haldane, Graham(8), Sinnatt(I2) and others, both from the physiological standpoint and from the point of view of relative efficiency. Much work has also been done in regard to the silica content of such dusts and on methods of analysis generally. As a consequence, this investigation of chemical properties was confined to the estimation of carbon dioxide and combustible matter mainly, as properties being directly connected with the efficiency of the dusts in the suppression of explosions.

The results are arranged in Table 3.

Insoluble and Siliceous Matter This was determined by treatment of the dusts with dilute HCl, the undissolved residue on filtering giving the insoluble and siliceous matter. Although the percentage of insoluble material in shale is high, the percentage of free or physiologically dangerous silica seldom exceeds 50 per cent.(8) and at this figure is considered by same physiologists to be above suspicion.(32,33)

Carbon Dioxide Estimation of CO_2 was made by the Schrodter apparatus in which a known weight of dust was treated with dilute HCl and the loss in weight after complete evolution of CO_2 determined. Although gypsum and anhydrite generally contain traces (up to 2 per cent) of CO_2, no estimation was found possible with this apparatus.

Tests recently carried out at Buxton indicate that the CO_2 contained in a dust has a definite quenching effect. It is now stated(I3) that, weight for weight, the CO_2 has an efficacy of I.4 times that of an anhydrous CO_2-free dust and hydrated water an efficacy of 6 times.

Loss of Weight on Ignition

The loss of weight test, on ignition of a dust sample is designed to furnish the amount of combustible matter present. But the loss in weight, after constancy in weight is obtained, is a variable quantity depending on the ignition temperature and on the nature of the dust. This is important in the case of dust mixtures containing hydrated water or carbonates where loss on ignition does not represent the true combustible matter. Special tests for such dusts (Appendix 2) overcome this difficulty to a certain extent.

In the case of gypsum dusts Regulations allow of the moisture being reckoned at a temperature not exceeding 275 degs.Fah.

This is to ensure that most of the hydrated water is reckoned as moisture and not as combustible matter. About 75 per cent. of the combined water is evolved fairly readily (but see later) leaving the hemi-hydrate $CaSO_4\frac{1}{2}H_2O$. Various workers have from time to time given different ranges in which the water of hydration is given off and M.le Chatelier (14) gives the lower range as 248-266 degs.Fah. and the upper range 320-338 degs.Fah. At the higher range the hemi-hydrate is broken down to leave $CaSO_4$ - the anhydrite.

In the experiments it was found that the loss in weight of approximately 75 per cent. of the combined water could be obtained by prolonged heating of gypsum for about 6 hours at 103 degs.Cent. The breakdown to the hemi-hydrate was gradual at this temperature.

Another point noted in the investigation was the loss of weight occurring with gypsum dusts at the incineration temperatures. The testing Regulations presume that the dusts, at a dull red heat in an open vessel, are reduced to $CaSO_4$.only. With a bunsen flame this is the case; after 690 degs. Cent. is reached the gypsum is

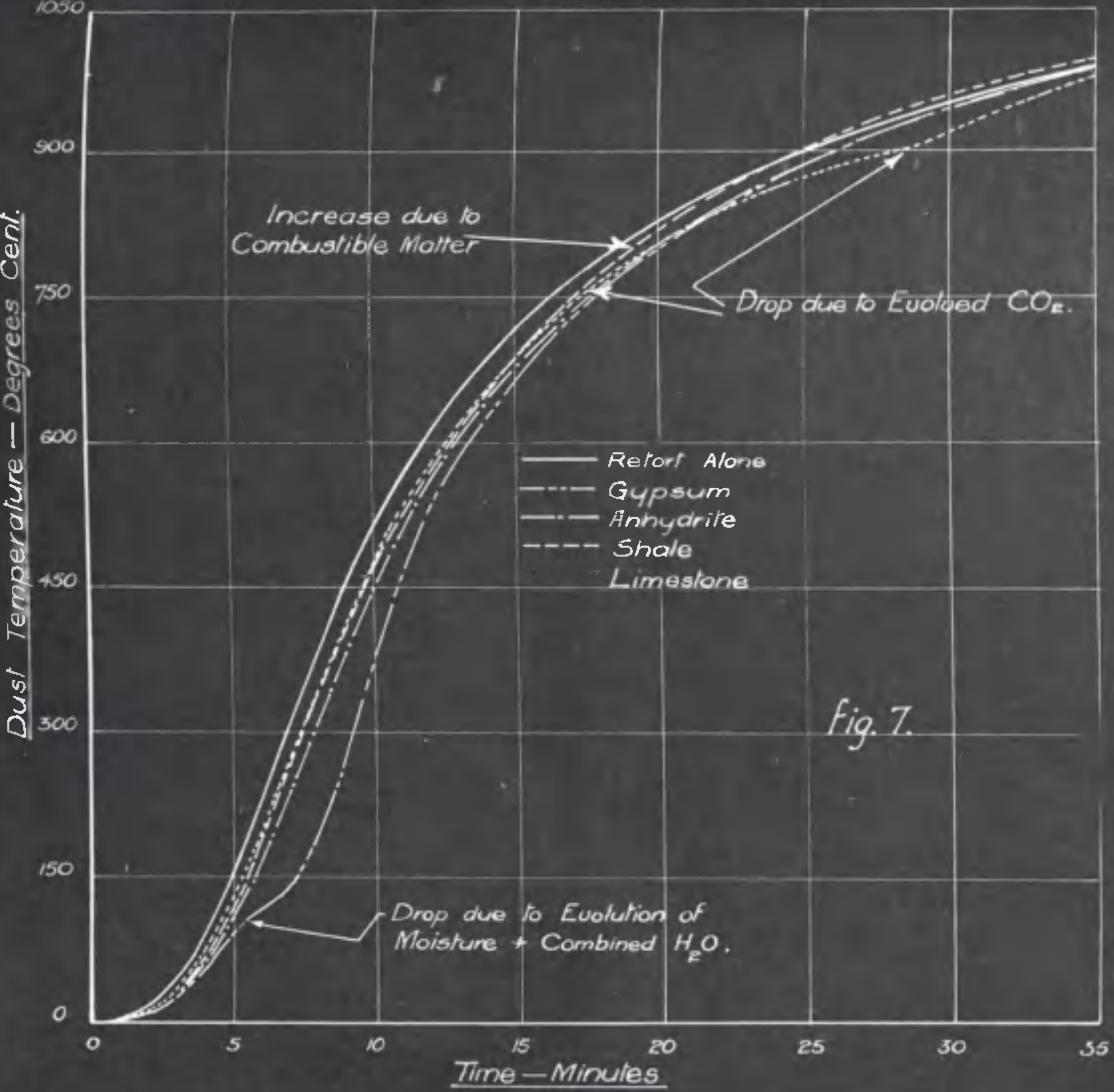
1050
900
750
600
450
300
150
0
Dust Temperature — Degrees Cent.
0
5
10
15
20
25
30
35
Time — Minutes
Increase due to Combustible Matter
Drop due to Evolved CO_2.
Retort Alone
Gypsum
Anhydrite
Shale
Limestone
Drop due to Evolution of Moisture + Combined H_2O.

Fig. 7.

"dead-burned" or anhydrite. Samples were tested in this manner first of all and were later subjected to the same incineration temperature (940 degs.C.) as the carbonate dusts when a further and much greater loss in weight took place. The loss was equivalent to the reduction of $CaSO_4$ to CaO with the following suggested reactions:-

$$CaSO_4 + 4C \rightarrow CaS + 4CO$$
$$2CaS + 3O_2 \rightarrow 2CaO + 2SO_2$$

The reduction in the case of gypsum alone was assisted by the impurities present but the same reactions take place readily with Coal-gypsum mixtures, subjected to a muffle furnace temperature of 940 degs.Cent. It is felt that this point is not made sufficiently clear in the special testing Regulations and errors might easily arise by incinerating gypsum and carbonate mixtures together under the impression that excess of temperature will have no effect. This results in a positive error of approximately 40 per cent in the combustible matter of the gypsum dust.

For a further investigation of the temperature of decomposition of the dusts and the relative cooling effects of combined CO_2 and combined water, 5 gm. samples of each dust in turn were heated up at a uniform rate in a Lessing coking furnace. Temperature readings of a thermo-couple embedded in the dust, plotted against time are given in fig.7.

A marked departure of the curve from its normal heating rate denotes either cooling or heating: cooling is due to the evolution of CO_2 and water vapour and heating, in the case of shale, to the evolution of combustible gases or combustion of the shale itself.

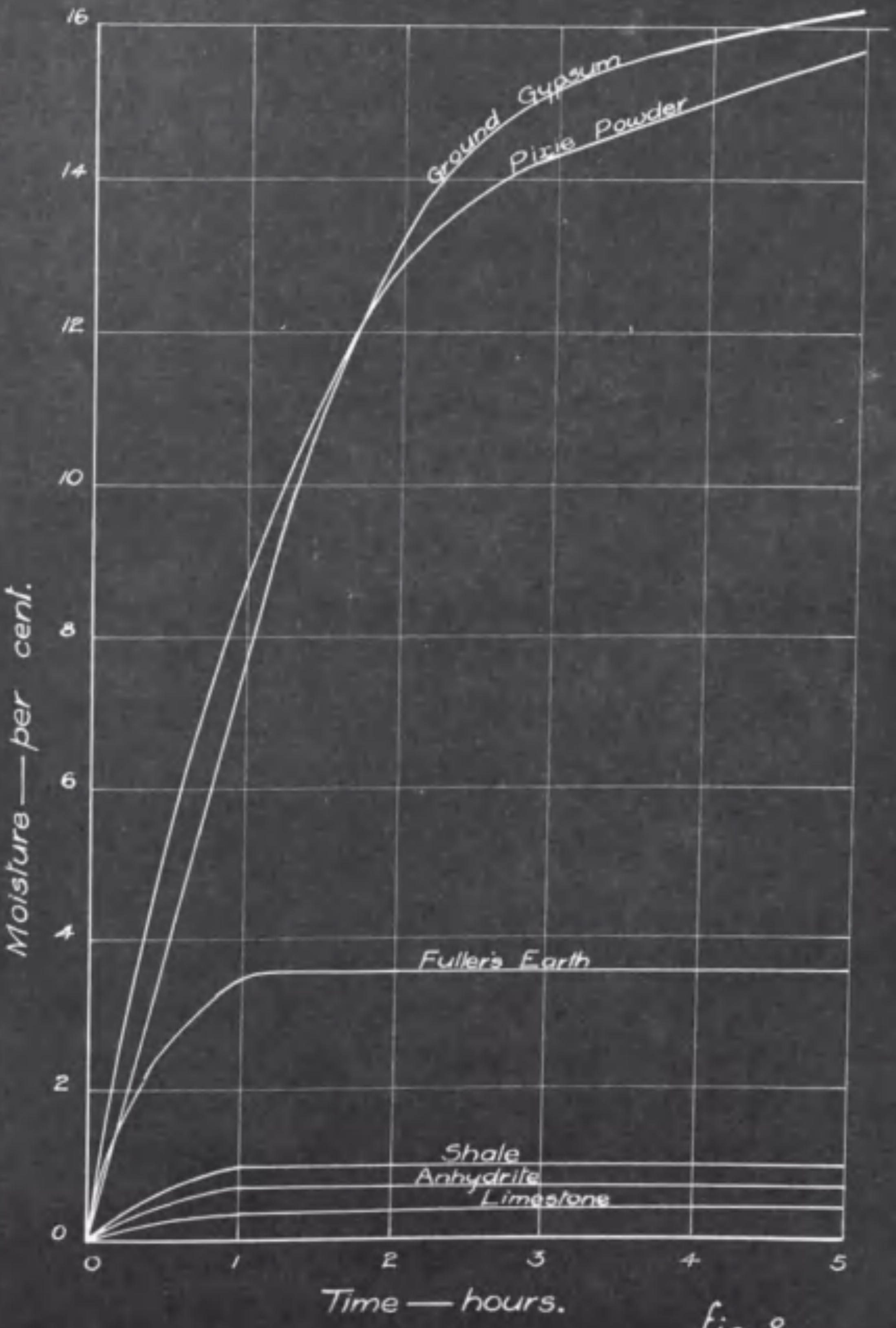
PAPER 2

THE ABSORPTION OF MOISTURE BY INCOMBUSTIBLE DUSTS.

THE ABSORPTION OF MOISTURE BY DUSTS.

Normal Moisture Content. Each dust holds a certain percentage of moisture at ordinary atmospheric temperature and humidity which can be driven off by heating at IOO degs.Cent. Dusts such as gypsum, however, contain water of hydration which is only driven off at higher temperatures and which, for the purposes of this section cannot be classed as mechanically held moisture. For dusts such as coal,shale,and limestone, containing no chemically combined water, heating for I hour at IOO degs. Cent. is sufficient to drive off completely all the mechanically held moisture present in normal amounts.

The rate of loss of moisture and the effect of prolonged heating on samples of each dust were found for the temperature mentioned. The results are shown graphically in fig.8 and indicate that for dusts containing no chemically combined moisture one hour of heating at IOO-IO3 degs. Cent. is sufficient for the moisture determination. The continued loss of moisture with prolonged heating in the case of the hydrated dusts indicates that in experiments dealing with moisture content, care must be taken to distinguish between mechanically held moisture and combined water. Although, as already mentioned, the lower limit of decomposition of $CaSO_4.2H_2O$ is said to be 248 degs.Fah. the water is given off at IOO degs.Cent. Fig.8 shows that the major portion of the water is evolved in the first three hours and that nearly all can be driven off in about 6 hours. This results in a loss of weight of approximately 20 per cent to leave the hemi-hydrate.



16
14
12
10
8
6
4
2
0
Moisture — per cent.
0
1
2
3
4
5
Time — hours.
Ground Gypsum
Pixie Powder
Fuller's Earth
Shale
Anhydrite
Limestone

fig. 8.

Although for the purpose of estimating the volatile combustible matter under the General Regulations it is desirable to include as much of the combined water as possible under the heading of moisture, it was decided that for moisture experiments this procedure was wrong,as the chemical composition of the dust is altered. Consequently the moisture in gypsum and hydrated dusts was estimated in the first place on one hour of heating only. The results nevertheless still include a high percentage of combined water as moisture.

Variation in Moisture Content If the dust samples are exposed to the atmosphere the moisture contents vary considerably from day to day and show appreciable differences from samples extracted from closed bottles or tins. Calculated on the loss of weight on drying for I hour at IOO degs.Cent. the limits of variation in normal moisture content of the dusts as found in one series of experiments were as follows:-

	Moisture per cent
Shale..............	0.89 - I.32
Anhydrite...........	0.40 - 0.86
Pixie Powder........	3.20 -IO.00
Fullers Earth......	3.50 - 6.75
Ground Gypsum......	2.50 - 8.90
Limestone..........	0.I9 - I.00

The losses are high in the hydrated dusts due to the loss of some of the combined water.

Variation of Moisture Content with Temperature and Humidity

A number of samples were placed over water in a large bell-jar, and by weighing daily the change in moisture content was observed over a period of 22 days. Fig.9 shows the results of this experiment, the hygrometer and temperature readings being those taken at the time of weighing the samples. As no attempt was made

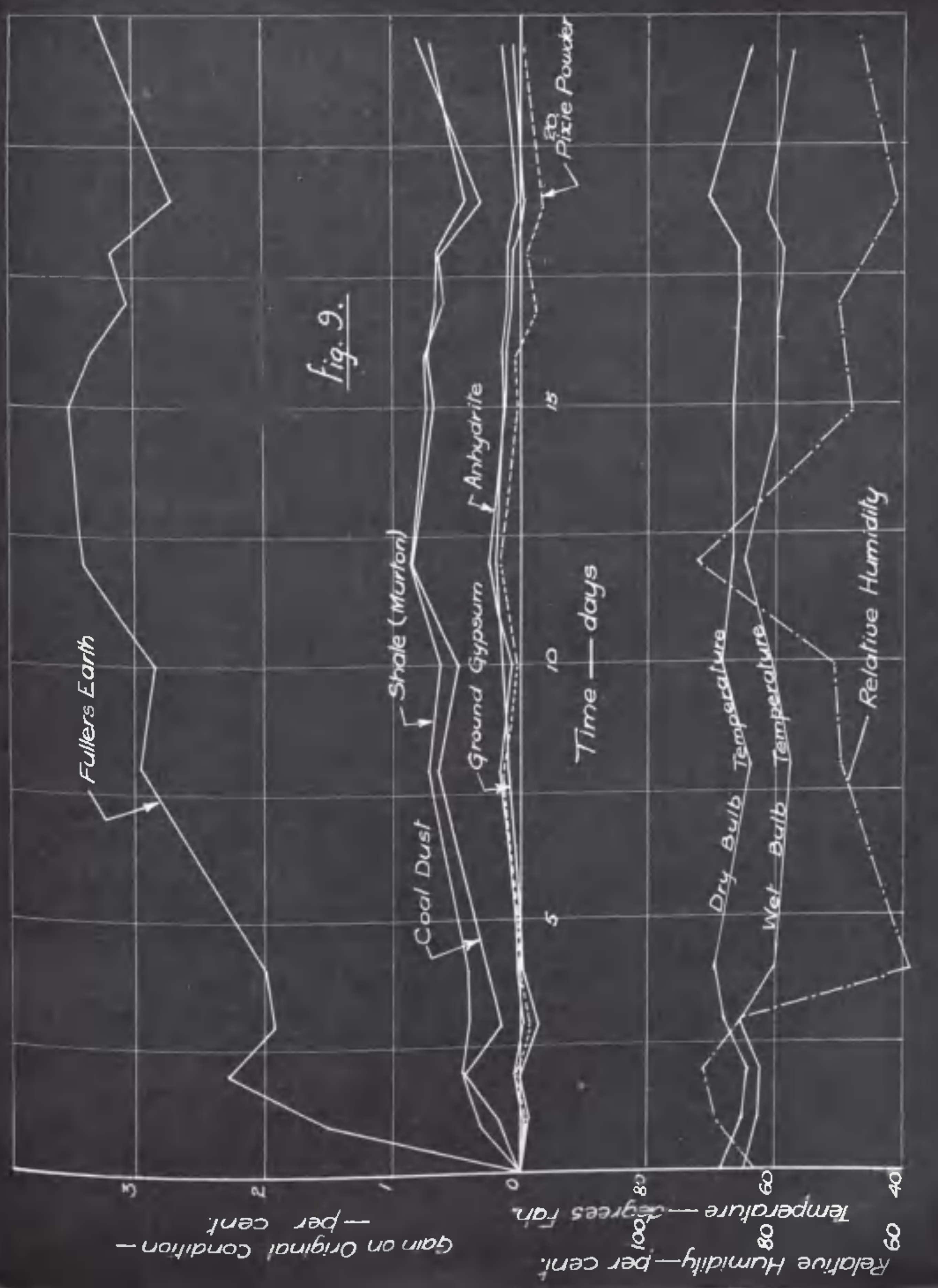


Fig. 9.

Fullers Earth
Coal Dust
Shale (Murton)
Ground Gypsum
Anhydrite
Pixie Powder
Dry Bulb Temperature
Wet Bulb Temperature
Relative Humidity
Time — days
5
10
15
20
Gain on Original Condition — per cent.
0
1
2
3
Temperature — degrees Fah.
80
60
40
Relative Humidity — per cent.
100
80
60

to control the temperature or humidity, fluctuations of both took place between the successive readings and yet the results do not appear to be influenced by these variations to any marked extent. They show quite clearly the interdependence of moisture content on humidity and temperature and show that the dusts do not all have the same avidity for moisture: some are more susceptible to changes in relative humidity than others.

These preliminary experiments showed that in every case it would be necessary first of all to determine the moisture content of each dust at the time of use. In the case of the absorption tests to be described this procedure was adopted, all samples being dried at IOO degs.Cent. for I hour before use.

ABSORPTION TESTS

(a) In Saturated Atmospheres In these tests all dust samples were first dried at for I hour and then subjected to a saturated atmosphere at a definite temperature for 3 hours. Four different temperatures were used for each test but the humidity was kept constant at saturation point. The tests were carried out in a small electric oven, the temperature and humidity being controlled by thermostats.

The results of the tests are summarised in Table 4.

Following the drying procedure already described and bearing in mind the variation in moisture contents of the dusts from time to time, the results are as regular as one might expect under the circumstances.

The dusts show a decrease in the amount of moisture absorbed with increase in temperature. This is to be expected due to the greater molecular activity of the materials with increase in temperature. Another interesting fact is the large moisture absorption by Fullers' Earth and it would appear at first sight that this material would not be very suitable for use underground. It will be shown later however that this is not the case and despite its high moisture absorbing power its efficiency as regards its dispersability, even when containing a large percentage of moisture, is only very slightly reduced when compared with other dusts having much smaller quantities of moisture.

Table 4

Temperature	23°C.		30°C.		40°C.		47°C.	
	Percentage		Percentage		Percentage		Percentage	
Dust.	Loss at I03°C.	Gain	Loss at I03°C.	Gain	Loss at I03°C	Gain	Loss at I03°C.	Gain
Shale	I.005	2.67	I.I0	2.43	I.205	I.I9	I.32	0.848
Anhydrite	0.755	0.76	0.75	0.46	0.637	0.069	0.859	0.08
Fullers Earth	6.75	I0.50	6.53	9.76	6.55	8.35	5.I9	5.00
Ground Gypsum	6.99	2.87	8.98	3.I8	8.09	I.26	7.I8	0.90
Pixie Powder	9.90	3.43	3.32	I.86	I0.20	I.38	8.92	0.94
Limestone	0.47	0.63	0.44	0.38	0.53	0.2I	0.497	0.I5

(b) In Varying Humidity Similar tests to those already made were carried out at constant temperature(40 deg.Cent.) but with humidities lower than the saturated condition. Again the exposure was of three hours duration.

Table 5

	Percentage		Percentage		Percentage	
Dust.	Loss at I03°C	Gain at R.H. I00%	Loss at I03°C	Gain at R.H. 77%	Loss at I03°C	Gain at R.H. 43%.
Shale	I.205	I.I9	I.28	0.8I5	I.I2	0.37
Anhydrite	0.637	0.069	0.785	0.23	0.565	0.057
Fullers Earth	6.55	8.35	2.97	7.89	8.35	5.I7
Ground Gypsum	8.09	I.26	5.75	0.608	6.45	0.064
Pixie Powder	I0.20	I.38	8.98	0.893	6.52	0.337
Limestone	0.53	0.2II	0.285	0.II9	0.334	0.I25

The results of Table 5 show conclusively that the amount of moisture taken up by each dust decreases with decrease in humidity at constant temperature.

Another series of tests was carried out at normal atmospheric temperature (60-65 deg.Fah.) with varying humidities. Each dust was dried at 100 deg. Cent. till constant in weight and then exposed to the test atmosphere. With the hydrated dusts the procedure was altered and the dusts in their normal condition submitted to the test atmosphere, duplicate samples being dried till constant in weight. After exposure the test samples were dried till constant in weight and the differences in the losses of weight so determined taken as the gain or loss of moisture in the tests. This procedure was adopted because it was assumed that drying even for one hour before the test would alter the dust properties considerably.

A preliminary test at 90 per cent R.H. showed that most of the moisture was absorbed in the first few hours and that after 8 hours the increase was very slow and after 24 hours, imperceptible. The dusts were therefore exposed to the various atmospheres for a period of 48 hours to ensure complete and maximum possible absorption.

Mixtures of water and H_2SO_4, calculated to give the required humidities, were used. The vessel covering the solution and the dust samples was designed to enclose the minimum volume of air, thus ensuring that the required humidity was reached as early as possible. The vessel was also closed some time before commencing the test to ensure this condition and that the dusts were introduced into an atmosphere as near the required humidity as possible.

TABLE 6.

Moisture Absorption with varying Humidity

Exposure — 48 hours. Temperature 60 – 65 °Fah.

Dust	Relative Humidity — per cent.							
	100	90	75	65	50	35	25	10
Shale (Murton)	3·31	2·51	1·805	1·348	1·13	1·235	0·83	0·63
Limestone (So. Wales)	0·52	0·55	0·339	0·32	0·265	0·452	0·467	0·468
Limestone (Lugton)	0·995	0·903	0·80	0·502	0·552	0·353	0·393	0·304
Softener Product	7·12	4·65	2·57	1·735	1·38	0·96	0·902	0·65
Lime Pulp	3·79	2·79	2·15	1·655	1·62	1·23	1·025	1·08
Fullers Earth	15·80	9·10	6·18	4·54	2·73	1·173	0·388	−1·53
Ground Gypsum	1·80	0·394	0·07	-	0·049	−·0375	−·0397	−·058
Anhydrite	2·93	1·303	0·482	0·265	0·54	0·54	0·278	0·631
Coal Dust	3·67	5·93	3·095	2·36	2·31	1·925	1·395	1·405

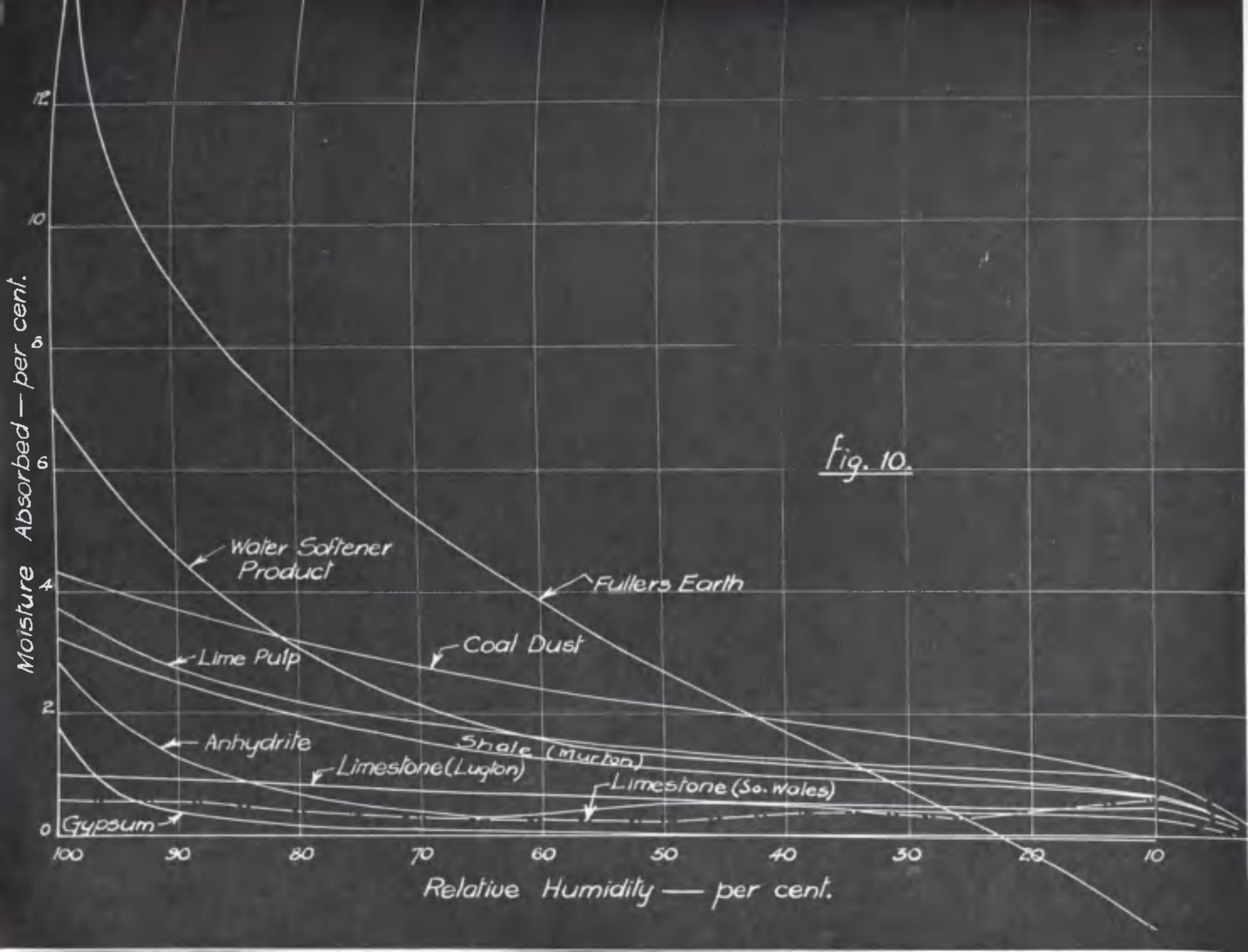


Fig. 10.
Moisture Absorbed — per cent.
0
2
4
6
8
10
12
Relative Humidity — per cent.
100
90
80
70
60
50
40
30
20
10
Water Softener Product
Fullers Earth
Coal Dust
Lime Pulp
Shale (Murton)
Anhydrite
Limestone (Lugton)
Limestone (So. Wales)
Gypsum

The results (Table 6) show that while the dusts absorb moisture to different extents the amounts absorbed are not unexcessive. Fullers Earth absorbs most of all while gypsum, unaffected by previous heating, absorbs practically nothing. Allowing for slight differences in chemical composition between samples and slight temperature variations throughout the 48 hour test, the results are uniformly consistent. The same results are plotted as absorption isotherms in fig.IO.

(c) Tests in Mine Atmospheres To confirm the results so far obtained some samples of dust were left in an underground airway for a period of 23 days where the temperature was 76 deg.Fah. and the air fully saturated. The results were as follows:-

Dust	Moisture per cent before exposure.	Moisture per cent after exposure.
Lime Pulp	I.I9	4.29
Shale(Murton)	I.29	3.02
Limestone(Lugton)	0.40	I.23
Limestone(South Wales)	0.I6	0.48

Another sample of the last-named dust taken from a return airway where it had been lying for two months in a temperature of 60 deg.Fah. and R.H. I00 per cent showed a moisture content of only 0.829 per cent. As supplied for use to the mine the dust had a moisture content of 0.322 per cent.

The practical significance of the results obtained will be appreciated when one considers the relation of temperature and humidity in the air currents underground. It is well known that, as a general rule, temperature and humidity rise towards the face and reach a maximum at that point. Thus it would be natural to expect the dusts near the face to take up more moisture. But this is not so, since the experiments have shown that temperature is more important than humidity and consequently, with increase in temperature(even at saturation point), the dusts will still become drier. In other words the increase of temperature in the region of the coal face more than counteracts the increased humidity of the ventilating current.

The effect of Particle Size on the Moisture Content.

For this investigation three typical dusts were elutriated and the sized fractions tested for moisture in the usual way. Each fraction was then subjected to a saturated atmosphere at 30 deg.C. for three hours. It was observed that after elutriation a marked difference in the colour and consistency existed in the various fractions and that a difference in chemical constitution between the fractions was also probable.

The following table gives the results obtained.

Shale		Pixie Powder		Fullers Earth	
Ave. diar. of fraction in microns	Moisture per cent	Ave.diar. of fraction in microns	Moisture per cent	Ave.diar. of fraction in microns	Moisture per cent
0 - 5	0.555				
7	0.708	0 - 10	4.50	0 - 7	9.00
14.5	0.678			20	2.25
21	0.70	28.3	6.75	36.4	8.37
50	0.965	52.3	7.12	55	7.61
90	0.915			90	8.20
Normal Dust	0.955			Normal Dust	7.58

With shale and Pixie Powder the larger sizes contain most moisture but with Fullers Earth the reverse is the case. Despite the fluctuations and variations, a fair deduction from these tests would be that a difference in moisture content does exist in the different fractions of the dusts and will affect the resulting moisture content of the dust as a whole.

The Mechanism of Atmospheric Absorption.

In considering the manner in which moisture may be held by a dust, note must be taken of the chemical constitution and surface factor of the dust, as these are important. The various ways in which the moisture may be held in a dust are:-

(I) As a film of water vapour molecules on the outer surfaces of the particles.

(2) In chemical combination with the substance to some extent - i.e. adsorption

(3) In the interstices between particles, held by surface tension.

Tests made with the dusts exposed in various ways showed that the moisture was not held in the interstical spaces and it is therefore highly probable that it is held by adsorption - the amount depending on the physical condition and chemical composition of the particles. According to McBain (I5) adsorption is instantaneous and the lag in time in taking up the full complement of moisture is due to the comparative inaccessibility of the majority of the dust particles. As the property of adsorption is diminished by rise of temperature, this also agrees with the previous results.

Since surface factor alone cannot account for the large differences in the amount of moisture adsorbed, chemical composition must be the important factor.

Conclusions

The general conclusions drawn from the foregoing experiments are that:-

(I) Incombustible dusts vary appreciably in their power to take up moisture from an atmosphere.

(2) In all cases the amount taken up is dependent on the composition of the dust, humidity and temperature.

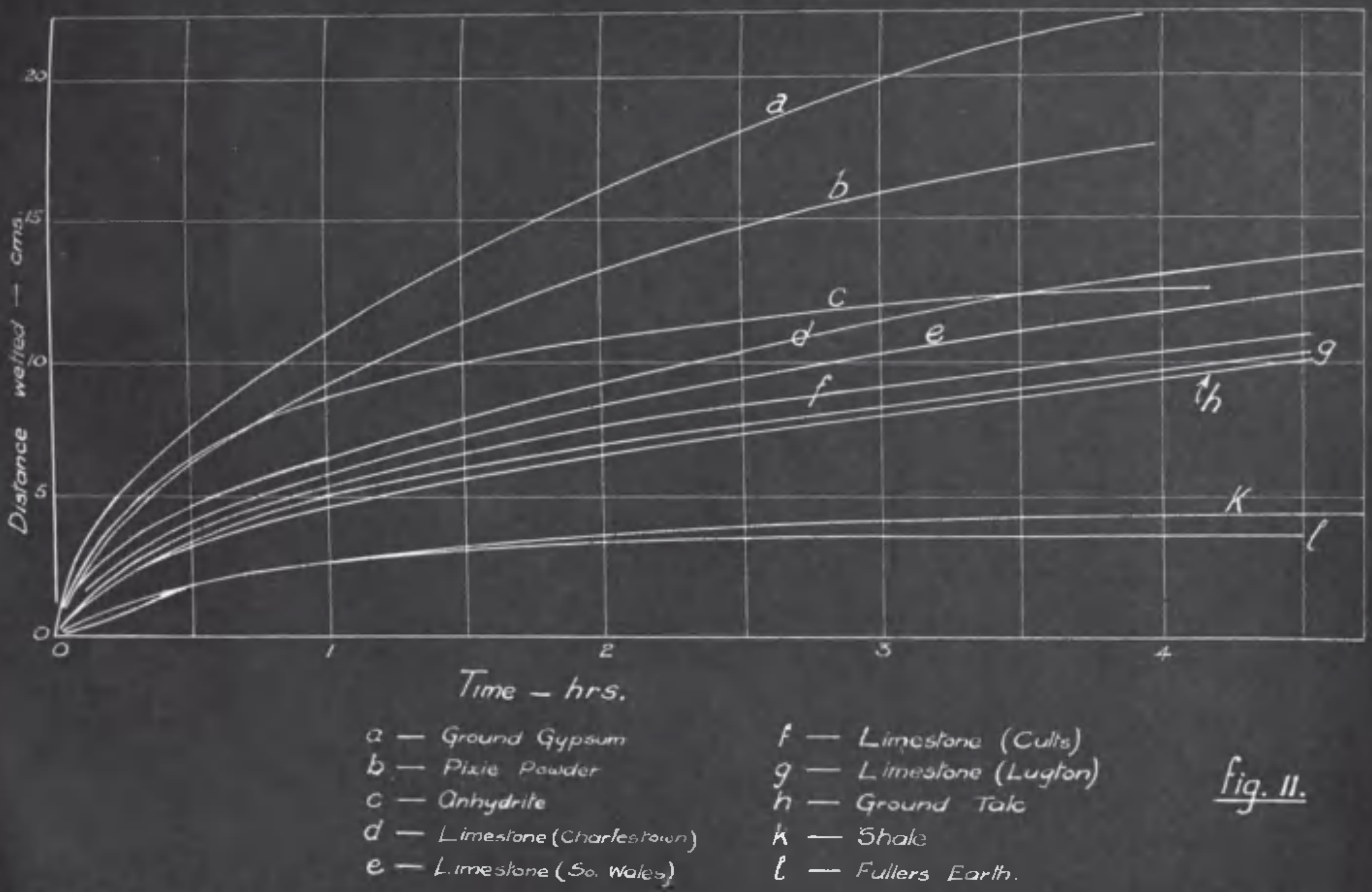

Distance wetted — cms.
20
15
10
5
0
0
1
2
3
4
Time — hrs.
a
b
c
d
e
f
g
h
K
l
a — Ground Gypsum
b — Pixie Powder
c — Anhydrite
d — Limestone (Charlestown)
e — Limestone (So. Wales)
f — Limestone (Cults)
g — Limestone (Lugton)
h — Ground Talc
k — Shale
l — Fullers Earth.

fig. II.

(3) None of the dusts are liable to be materially affected by the amount of moisture taken up from a mine atmosphere.

(4) Size of dust and time of exposure under practical conditions do not appreciably affect the moisture content.

ABSORPTION OF WATER AND ARTIFICIAL WETTING.

Apart from moisture absorbed from the atmosphere, much moisture may be absorbed from damp strata and by water dripping or splashing on to the dust. When the dust is applied in a roadway, due to the natural bleeding of moisture from the rocks and coal, the dust may absorb a great deal of water at once; in fact it may absorb so much as to become absolutely useless. It is necessary therefore to know how much water a dust can absorb without becoming totally inefficient.

Absorption Tests. In order to assess the relative rates of absorption, columns of the dusts 25 cms. long with porous covers over their lower ends, were inverted in beakers of water. The rate of rise of the water, plotted to a time base is shown in fig.II.

From the curves it is apparent that gypsum and anhydrite dusts are the most absorbent, if such a term may be used. That they allow of being wet through a greater distance than the others in the same time is probably the better statement. The limestones come next, followed by shale and fullers earth. Coal dust, tested in the same way did not wet at all during the experiments.

Nature of surface and shape and size of particle are important factors influencing the rate of soaking in the dusts. The nature of the surface of coal dust is the factor accounting for its not wetting. In the case of gypsum dusts solubility will assist in the rapid rate of rise. Swelling and disintegration of particles are assumed to account for the comparatively slow rates of rise with shale and fullers earth.

The main observation from this experiment is that all the incombustible ~~stone~~ dusts easily take up water and if a thin layer is spread on a wet surface it will immediately become thoroughly wet and consequently useless. Coal dust on the other hand, if deposited on this wet surface,will not wet but remain dry and in a dangerous condition.

Artificial Wetting. The case of the dry incombustible ~~stone~~ dust being deposited on wet surfaces has been considered but the case of water being mixed with the dusts prior to their application - in transit to the mine for example - is different. Dusts in this damp condition may quite easily be applied in a hot, dry mine in the expectation that they will function properly when dry again.

As moisture is added to a finely ground dust the substance tends to form small balls or "ball up" at first. Many dusts however have this tendency without the addition of any moisture beyond their normal content. With the addition of water to the dusts under test, they pass successively through the three following conditions:- (I) Damp or mealy condition; (2) Plastic condition; (3) Condition of mud.

As the moisture content is increased a little above normal the dust begins to form distinct balls and becomes less loose. In this condition it cannot be satisfactorily sieved or elutriated. With increasing moisture content the balling increases and a stage is reached,when, by slight pressure of the fingers the balls can be formed into brittle flakes or cakes.


Normal.
Wet.
Dried.
Moisture Content 1%.
Moisture Content 2.4%.
Moisture Content 9.8%.
Moisture Content 27%.
Moisture Content 28.6%

Fig. I2.

These weakly coherent cakes can be shaken down again on a screen to form balls. If the addition of moisture has not been too great these cakes and balls can always be broken down by vigorous movement or a sharp air blast. This condition is referred to as the damp or Mealy condition and is indicated by a slight but distinct darkening in colour.

On drying dusts which have been wet to this damp condition a certain hardening of the aggregations takes place. These again,however, are relatively easily dispersed by a sharp air puff or violent movement.

Fig.I2 shows samples of gypsum dust in the normal, mealy, and dried condition. The balled-up appearance and the darkening in colour are clearly evident with increasing moisture content.

Continued addition of moisture beyond that required to produce a mealy condition ultimately brings the dust to the plastic condition. Cohesion now exists among the particles to such an extent that the substance can be moulded as a pliable mass capable of withstanding a small tensile strain. Every dust, provided it contains a sufficient proportion of fine material, is capable of being brought to this condition. Ceramists term this condition of maximum plasticity and cohesion the "sticky point". The test for the correct point is given as that point at which the moulded masses of dust do not appear brittle and do not soil the fingers when handled.

The further addition of moisture beyond the sticky point produces a mud in which there is sufficient moisture not only to bind the particles but to give them mobility. Consequently the mixture has no cohesion and cannot hold its shape.

The method adopted of wetting the dusts was to spread them in thin layers on sheets of blotting paper of various degrees of wetness. As the layers became wet through they were scraped off and more thoroughly mixed together. Continued addition of water in this way eventually brought the dusts to the sticky point. The average percentages of moisture in the mixtures for this condition, as deduced from a number of tests, were as follows:-

Dust	Percentage of Water in mixture at "sticky point".
Water Softener Product	40.5
Lime Pulp	33.1
Shale(Murton)	21.7
Limestone(South Wales)	15.9
Limestone(Cults)	17.2
Limestone(Charlestown)	17.3
Limestone(Lugton)	17.5
Fullers Earth	37.4
Pixie Powder	20.6
Ground Gypsum	19.1
Anhydrite	17.75
Coal Dust(-250 mesh)	40.15

Conclusions

From the experiments carried out it is proved that all the incombustible dusts are relatively easily wet by water and in thin layers will take up water readily until thoroughly wet. There is a marked difference in the amount of moisture the dusts can hold before reaching the point of maximum plasticity or uselessness and this provides some indication of the fineness of the dust. The water softener product, for example, holds most moisture and has the lowest surface factor of all the dusts. This would appear to show that the presence of a high percentage of very fine material increases the cohesion of the dust and gives a sticky point with much less moisture in the dust. The results also show that equal percentages of moisture will not have the same effects on different dusts. A moisture content of I7.5 per cent will bring the limestones to the sticky point but the same quantity of moisture will only bring lime pulp, softener product and fullers earth to a mealy condition. And it must also be realised that many dusts in the mealy condition can be to a certain extent dispersed and may not be absolutely useless in an explosion wave.

The original fineness and the degree of wetting have an important bearing on the cohesion of the dust when dried out after wetting. The ease with which aggregations are broken up by violence will add to the efficiency of the dust. Generally speaking, the finer the dust and the greater the amount of moisture, the more firmly is the dust caked when dried.

PAPER 3

THE BALLING AND CAKING OF DUSTS

THE BALLING AND CAKING OF DUSTS.

Balling is a phenomenon associated with finely ground dusts and powders and is the tendency of the material to take up the form of spherical agglomerates. With moisture present in abnormal quantities these balls are more pronounced, larger as a rule, and show more cohesion in general.

By the caking of a dust is inferred the formation of a cohesive cake when the dust is dried out after being wet.

As many dusts show balling tendencies in their normal condition, the presence of a great amount of moisture is not essential. For example, fig.I3 shows a sample of balled-up anhydrite dust (moisture 0.58 per cent) - a material noted for its balling tendencies.

Many theories have been put forward from time to time to explain balling, most of them assuming the presence of a high proportion of colloidal material and the presence of minute, adsorbed water films. Of the various theories, that due to Beilby(I6) is the most likely to explain balling in the dry condition, although colloidal material and water films no doubt have an important influence in the cohesion and plasticity of damp materials.

Beilby investigated the cohesion of minute solid particles in their dry condition and concluded the force of cohesion to be the residual of the molecular energy of the substances. For his work he used spheres of zinc and antimony and found that spheres of from 33 - 50 microns could adhere to a dry microscope slide when it was reversed: care was taken to ensure that the film of moisture on the 'dry' glass slide was removed.

In the same manner particles of dust adhere to surfaces and to one another, the cohesive forces acting at the points of contact. This cohesive force varies with the condition and composition of the different substances and consequently a limiting particle size must be reached in every dust, beyond which the cohesive forces will be insufficient to cause two particles to cohere. With most of the ~~stone~~ incombustible dusts examined a fairly large proportion of the particles fall within the range of cohesive force.

Since the experiments of this section were concerned with the balling properties, a few tests on similar lines to those already quoted were carried out. Sized samples of dust were very lightly sprinkled on micro-slides and the slides immediately reversed. The largest average particles of each dust which resisted the force of gravity by cohering to the slide were as follows:-

Dust	Particle Size in microns
Shale	75 x 40
Gypsum	175-210 x 50
Anhydrite	188 x 90
Fullers Earth	100 x 100
Pixie Powder	212 x 95
Limestones	35 x 40
Softener Product	80 x 80
Lime Pulp	106 x 70
Coal Dust	160 x 170

As far as possible care was taken to free the larger particles from adherent fine material but this was hardly accomplished. In each case the slide was simply wiped with a rag, no special cleaning being done.

The sizes given, measured on the longest dimensions to keep a relationship with previous work, provide a measure of the cohesive force between the particles and the glass slide and hence

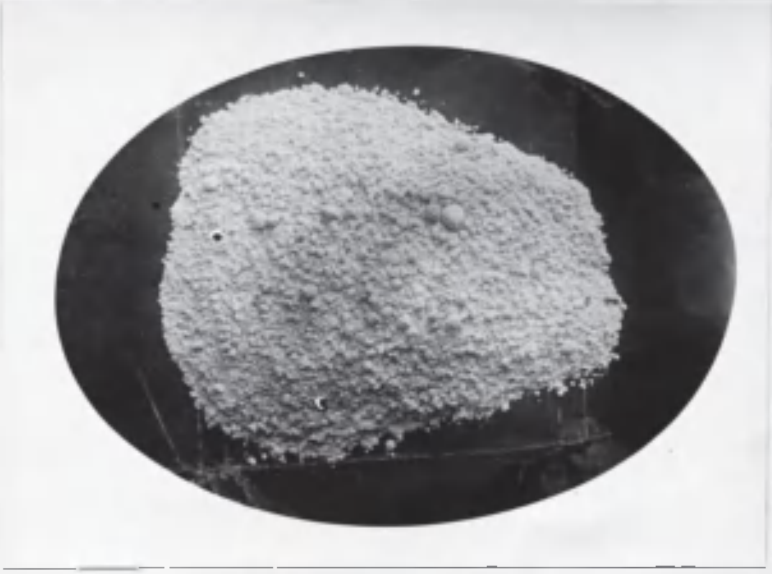


Fig. I3

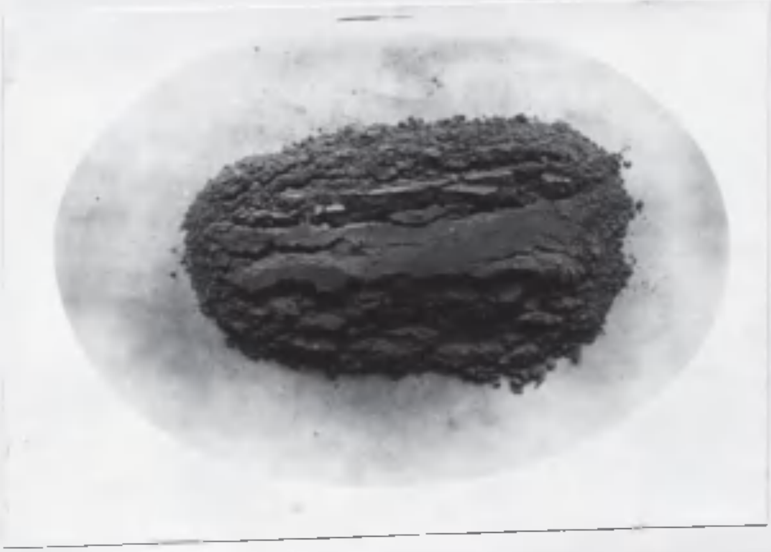


Fig. I4

some indication of the relative tendencies of the dusts to ball or cohere together. Taking into account the masses of the cohering particles it is evident that the greatest cohesion exists in anhydrite, pixie powder and gypsum. Limestones are particularly low. These results lead to the conclusion that for substances of equal specific gravity the cohesive or balling tendency is due to chemical composition and to the shape and nature of surface of particle.

Cohesion and particle grading are features which account for the looseness and compactness of powders. The particles are held in open formation partly by the cohesive forces and also by their size and grading. Closer packing can always be obtained by movement or pressure. With pressure, more particles can be brought into contact and a firmer cake produced. Movement also alters the spacing of the particles and when it causes closer packing, balling results. Similarly, balls produced can easily be shaken down again. A practical example of this movement is well known in the looseness of a bag of stone dust. It may appear very loose at one moment and practically solid at another, simply due to the closer packing caused by pressure and movement.

Where the particles in a dust are all well graded and of greater size than that at which cohesion is possible a definite "angle of repose" is obtained in a heap of the dust. This can be well demonstrated with sized sand grains. It is a criterion of no cohesive force. With very fine dusts, containing only a very small amount of coarse material, the well known cliff effect (fig.I4) is always prominent. This is an early sign of cohesion and on movement such a dust balls up readily, without any addition of moisture.

The Addition of Moisture As moisture is taken from the atmosphere in the form of a vapour, a film is adsorbed on the surface of each particle. It has been shown that there is a limit to the amount of moisture adsorbed in this way by reason of temperature and humidity. Any change in the balling tendencies due to moisture absorbed in this way cannot be detected by visual examination and does not therefore appear to have any marked effect on the cohesion of particles together.

Considering the extreme case of a dust exposed to a supersaturated atmosphere, deposition of moisture takes place and direct wetting of the dust is involved. This water, after filling the pores of the particle(if porous), forms a film around the particle. Surface tension forces cause the particles to adhere together and yet a certain amount of plasticity is given due to the lubricating effect of the water films. The maximum amount of moisture capable of being held by any dust has already been given by the percentage of water at the sticky point: in this condition all dusts are useless.

With the addition of more moisture the mud condition is reached. Dust particles are dispersed completely in the fluid and the finer particles are more evenly distributed among the larger ones.

Caking On drying out, either by natural evaporation or in an oven, the moisture is eliminated. The water films around each particle gradually become thinner and thinner,and,with surface tension forces acting in the thin films, the particles are drawn closer and closer together. Ultimately the particles are left in intimate point-to-point contact and cohesion of dry, solid particles acts as before.

Since the finer particles have been evenly and uniformly distributed among the larger particles, the maximum cohesive force is exerted in the dried out condition.

Particles of colloidal dimensions also assist in cohesion by providing more contact surfaces and probably account for the excessively hard clay formed when wet shale dust is dried out. The friable nature of the shale and its reaction to water are most likely to result in some disintegration, with a consequently greater production of colloidal and excessively fine material.

The Effect of Fine Material

(a) On Balling   In order to determine the amount of fine material to cause balling in the dry condition, various mixtures of coarse and fine elutriated fractions were made up. The fine material in every case consisted of the finest 0 -I5 micron elutriated fraction.

Fig.I5 shows portions of the various mixtures in the dry condition. The balling tendency could only be judged by inspection and was observed to develop with increasing proportions of fine material. Definitely sandy and loose appearances begin to disappear with about 30 per cent.of fines in the case of the coarsest dust and at about 40 - 50 per cent, with the 34 micron size of coarse dust. It is difficult to detect the critical point in each range but the proportions of fines are in the above ratio as nearly as can be estimated. That this is as it should be is known from the surface factors of the coarse dusts. In the case of the 34 micron size there is a greater surface to be covered by fine particles before contact between the fine particle films takes place.

It would thus appear desirable to limit the

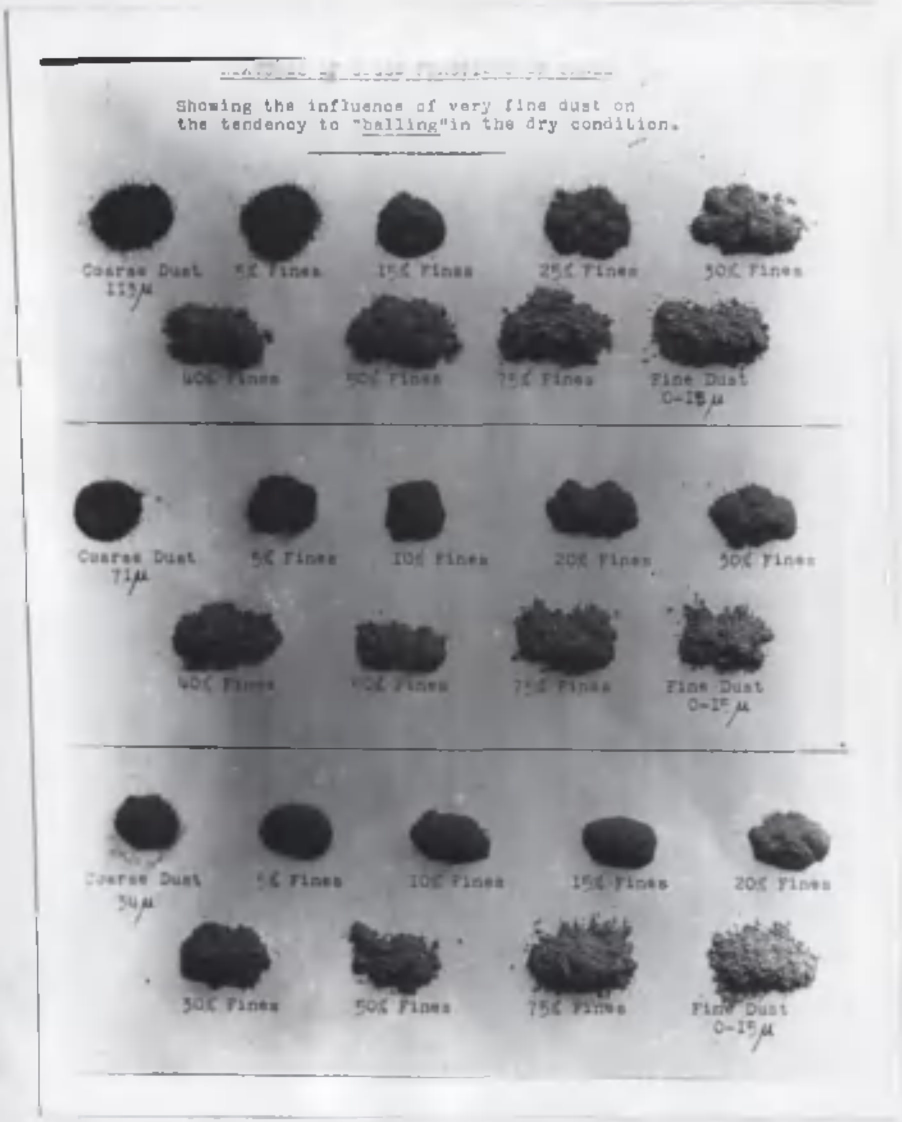

Showing the influence of very fine dust on
the tendency to "balling"in the dry condition.

fig. 15.

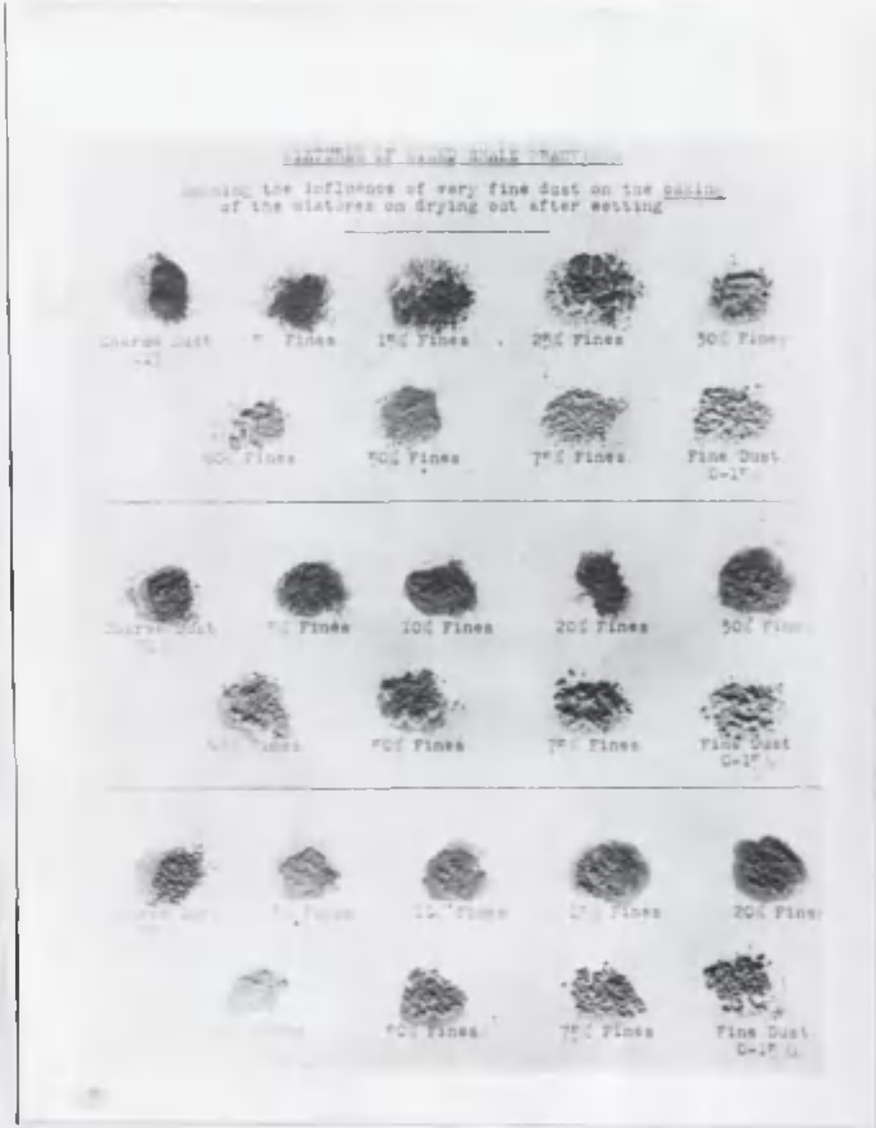

Showing the influence of very fine dust on the caking
of the mixtures on drying out after wetting

fig. 16.

proportion of 0-15 micron size to 30 per cent. Considering the average composition of all dusts examined, any increase in very fine material above this value merely tends to promote balling. Material below about 30 microns is definitely cohesive in all stone-dusting material and should be kept as low as possible from the point of view of balling. If it be assumed however that any aggregations formed will be easily broken down in an explosion wave, their presence is not too harmful(provided the dust is normally dry) and need not be further stressed at this point.

(b) On Caking It is in the case of wetting the dust and allowing it to dry out that the danger of the very fine dust lies. When thoroughly wet the fines are disseminated throughout the dust and when dry they cake the whole mass together very firmly. A thin layer of dust containing sufficient fine material, when spread on a wet surface and allowedto dry out, sets hard like paint. It is questionable if such a thin,smooth layer would be disturbed in an explosion, in which case the wetting and consequent drying render the dust completely useless. Conditions similar to those outlined occur at and near the face in many mines, a copious but temporary discharge of moisture taking place from freshly exposed coal and strata. This is referred to in practice as "bleeding" of the strata.

For the determination of the critical amount of fine material to cause complete binding on drying out after wetting the mixtures already made up were thoroughly soaked by sprinkling on a wet surface and allowed to dry out. Although it is again difficult to judge by visual examination the critical percentage of fines to cause caking, the values are very similar to those causing balling in the dry condition. The effect of the fines is in this case much more serious and for this reason alone it would appear desirable to limit the amount of very fine material as far as possible. Fig.I6 shows the final appearance of the caked dusts.

As with a concrete, gradation of particle size in a dust tends to increase cohesion both in the wet and dried condition. For spheres of equal diameter the volume of pore space is about 48 per cent. of the total volume for cubical piling and almost 26 per cent. for hexagonal piling. Maximum solidity requires a gradation of smaller particles to fill in turn the pore space of each size. As a dust dries out there is shrinkage and if there is not proper size gradation the fine cementing material filling the spaces may part and tend to break down the strong cohesion. Theoretically, therefore, for a dust containing only two sizes - coarse dust and fine dust capable of cohesion - 26 per cent. of the finer size is all that is necessary to give strong cohesion in the wet or dried out condition.

PAPER 4

DISPERSION AND BUOYANCY TESTS.

DISPERSION AND BUOYANCY TESTS

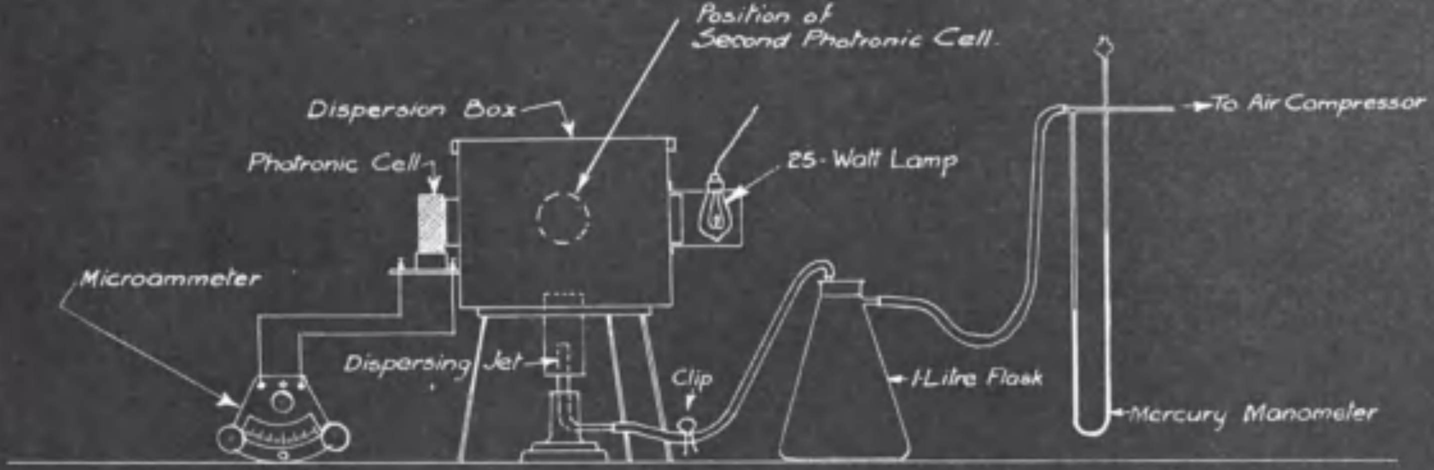
The efficiency of an incombustible dust, once it is in cloud suspension depends mainly upon its chemical composition and fineness. Its "dispersability" and "buoyancy", i.e., its ease of cloud formation and its capacity to remain suspended in a cloud over an appreciable interval of time respectively, are therefore of great importance in the question of overall efficiency.

Since the dispersability of a dust may be regarded as the ease of cloud formation of that dust, it follows that if a definite quantity of the dust is dispersed under constant conditions, the most dispersable dust will produce the densest cloud. And since the "buoyancy" of a dust is its capacity to remain suspended in a cloud, it may be regarded as a measure of the time the dust cloud, once formed, takes to settle. Consequently, after a given time interval, the most buoyant dust gives the densest cloud. These properties of dispersability and buoyancy as measured in this way depend very largely and in varying degrees upon the fineness of the dust, specific gravity, shape of particle and on the moisture content.

Apparatus used for Dispersion and Buoyancy Measurements.

To find the dispersion and buoyancy of the different dusts a method was adopted whereby the dusts were dispersed vertically under similar conditions each time into a space of constant volume. Preliminary experiments to determine dispersion

made/



Dust Dispersion Apparatus.

Fig. 17.

made use of open horizontal and vertical tubes, known weights of dust being dispersed by a constant puff of compressed air. Dispersion was estimated by the weight of dust removed in the case of the horizontal and vertical tests, but these failed with moist and balled up dusts. It was proved in these tests that moist and coarse dusts were more easily removed and blown further than dried dusts under the same conditions of blast. Estimations of dispersability by the weight of dust removed under similar conditions were therefore abandoned and a method of cloud density measurement adopted.

A view of the apparatus adopted is given in Fig.17. It consisted essentially of a box containing two recessed windows, one of which was illuminated by an electric bulb. At the other window a photronic cell was fitted and connected to a galvanometer or milliameter. One gram of dust was used in each case and dispersed centrally between the two windows by a puff of compressed air under a constant pressure of 18 inches of mercury, when the spring clip was released. The cloud density was measured by the deflection of the galvanometer from its initial reading before dispersion. This was assumed in the first instance to be proportional to the amount of light cut off by the suspended dust, as no account was taken of the effect of the colour of the dusts and their possible reflecting power. By plotting the galvanometer deflections to a time basis, the relative dispersabilities and buoyancies of the different dusts (varied in respect of fineness, moisture content, etc.) were obtained/

tained. Typical curves for a few of the dusts in their normal conditions are shown in Fig.18.

The Influence of Moisture.

It has already been shown that moisture promotes balling and cohesion among the particles. This results in an increase in force to disperse the dust or, under constant dispersing conditions, in a decrease in dispersability.

To find the decrease in dispersion with addition of moisture, the dusts were dispersed in the apparatus with varying moisture contents. The difficulty of wetting the dusts effectively and uniformly was overcome by the expedient already referred to of spreading the dust in thin layers on moist blotting paper. After mixing the dusts were sealed in glass tubes, well shaken up, and allowed to remain for a day before dispersing. At the time of dispersion duplicate samples were dried for the moisture estimation.

As might be expected the results clearly show a marked decrease both in dispersion and buoyancy with increase in moisture content. With the higher moisture contents the tendency increased for the balls of dust to adhere to the top of the dispersion box and accounts in part for the decreased dispersion. This however must be considered as reduced dispersability as there is no likelihood of the balls dispersing any more under the influence of the air blast alone.

Curves showing the effect of moisture on Pixie Powder and shale dust are given in Figs.19 and 20. The general effect of

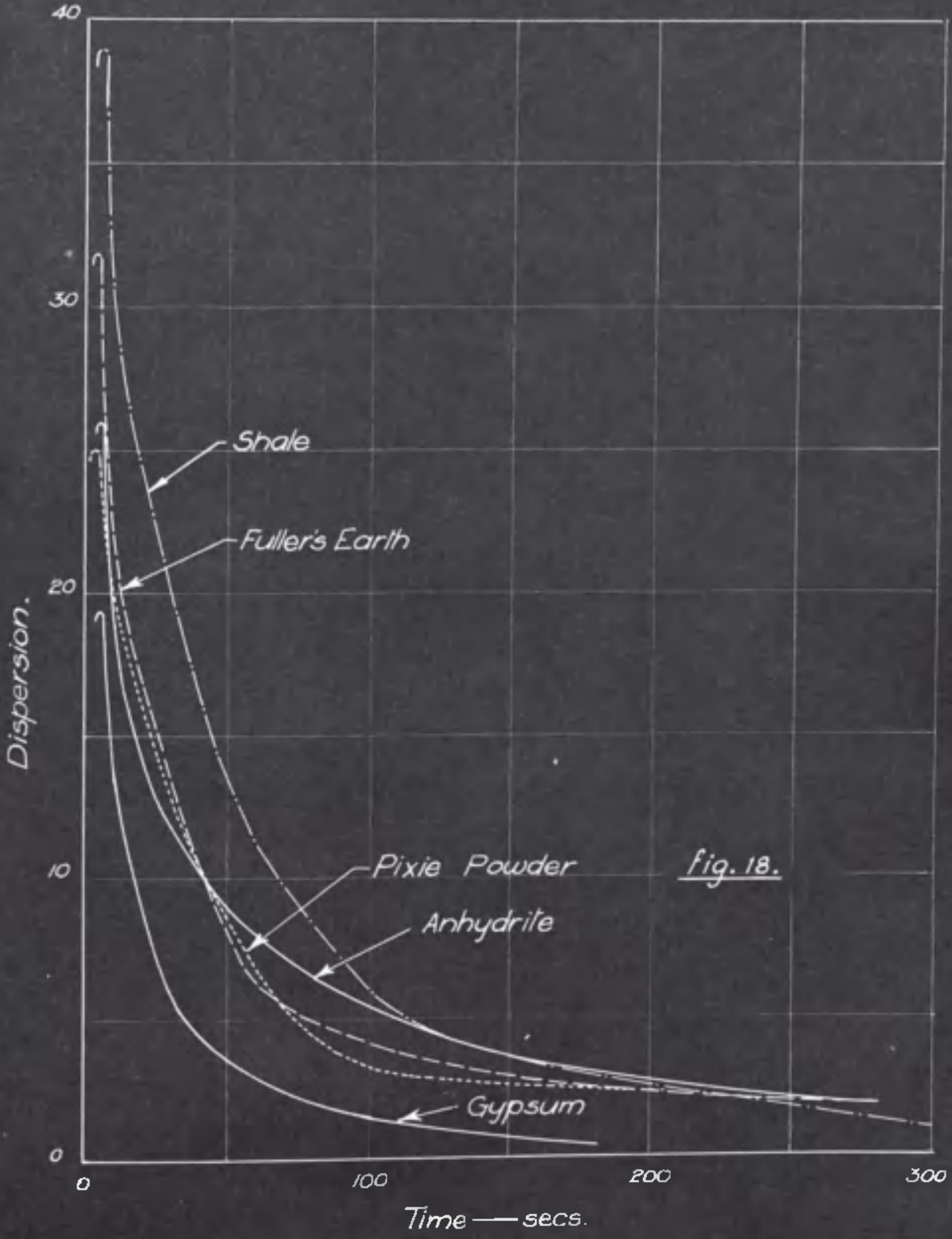

40
30
20
10
0
Dispersion.
0
100
200
300
Time —— secs.
Shale
Fuller's Earth
Pixie Powder
Anhydrite
Gypsum

fig. 18.

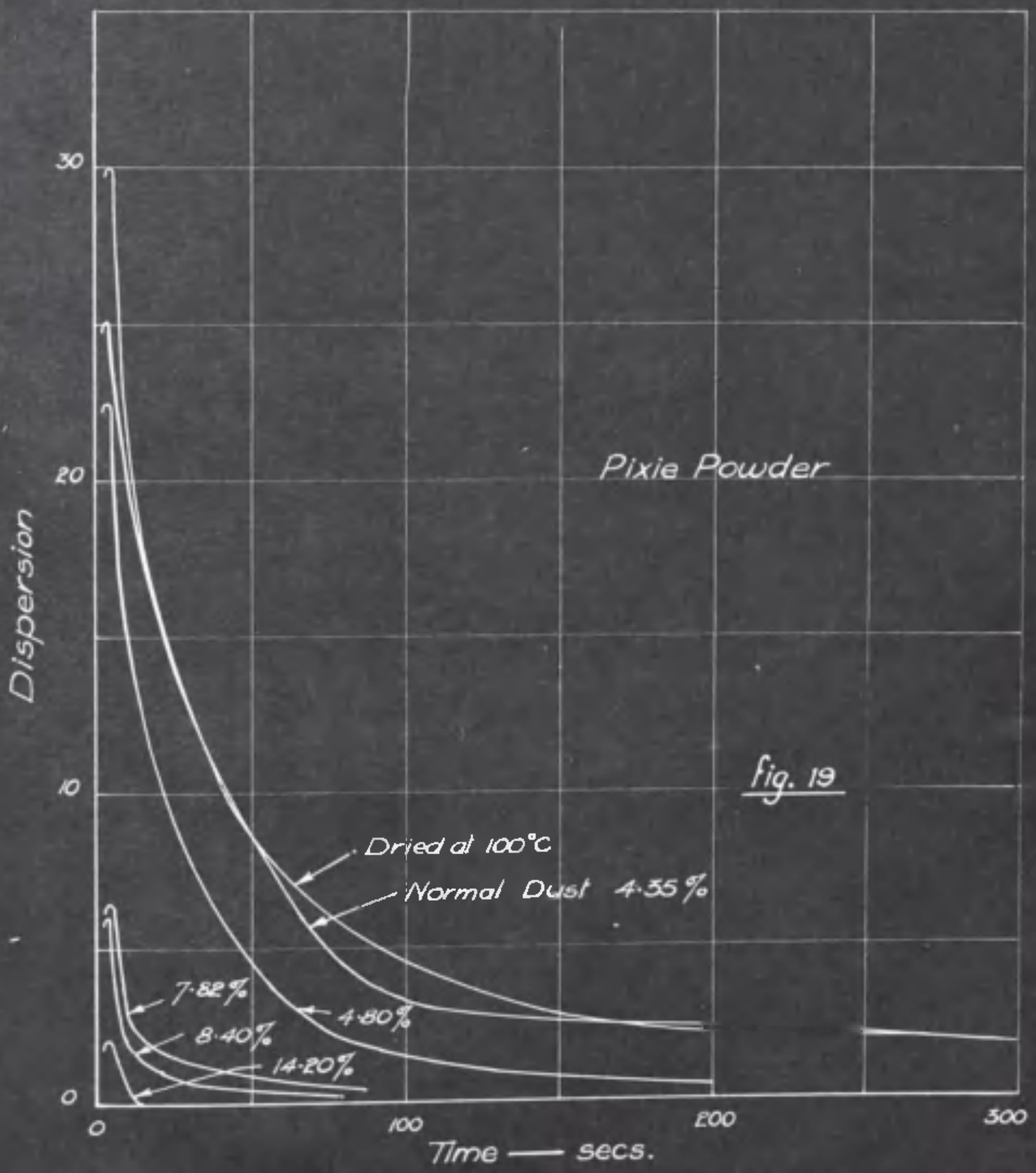

Pixie Powder
30
20
10
0
Dispersion
0
100
200
300
Time —— secs.
Dried at 100°C
Normal Dust 4·35%
7·82%
4·80%
8·40%
14·20%

fig. 19

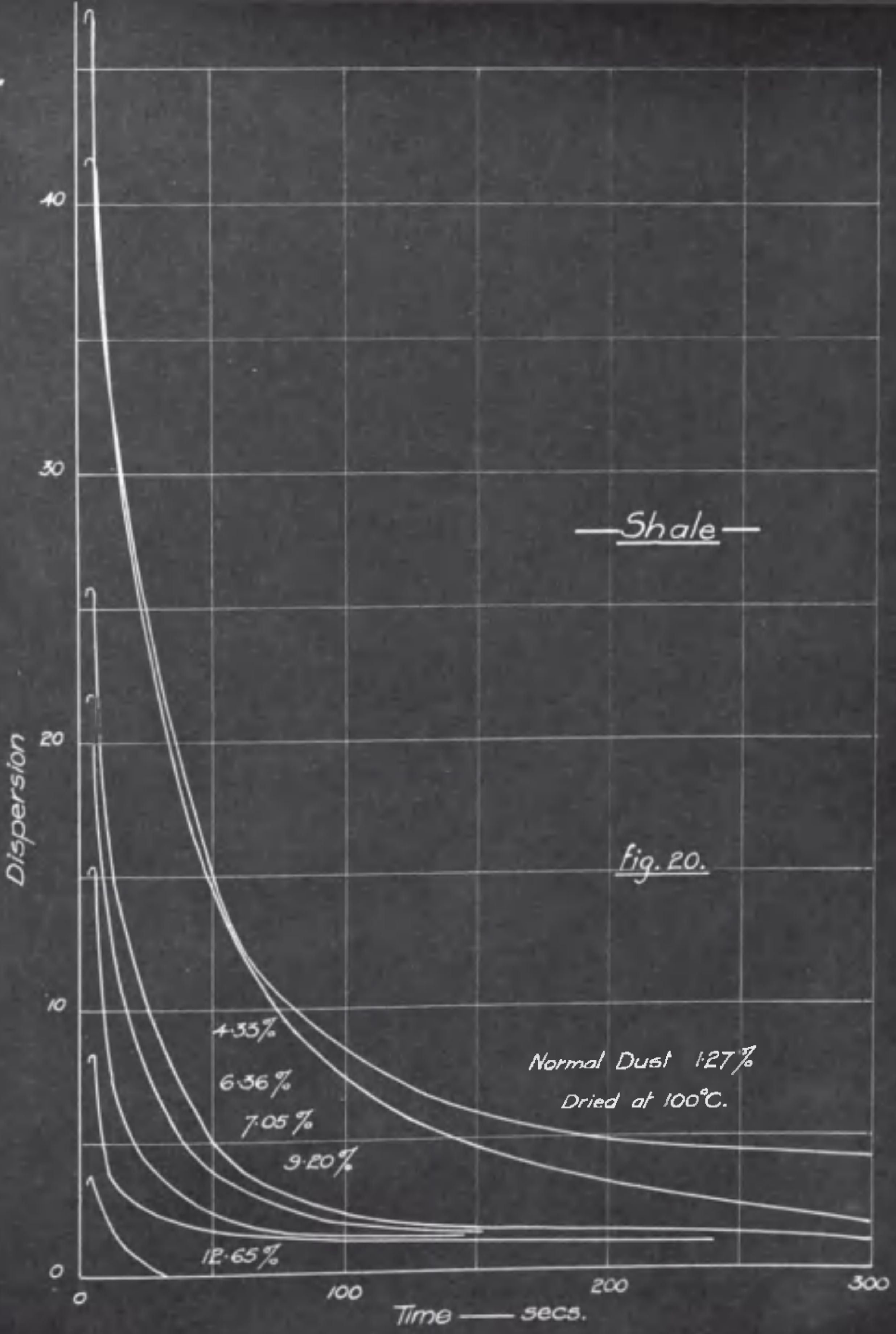


Fig. 20.

Normal Dust 1·27%
Dried at 100°C.

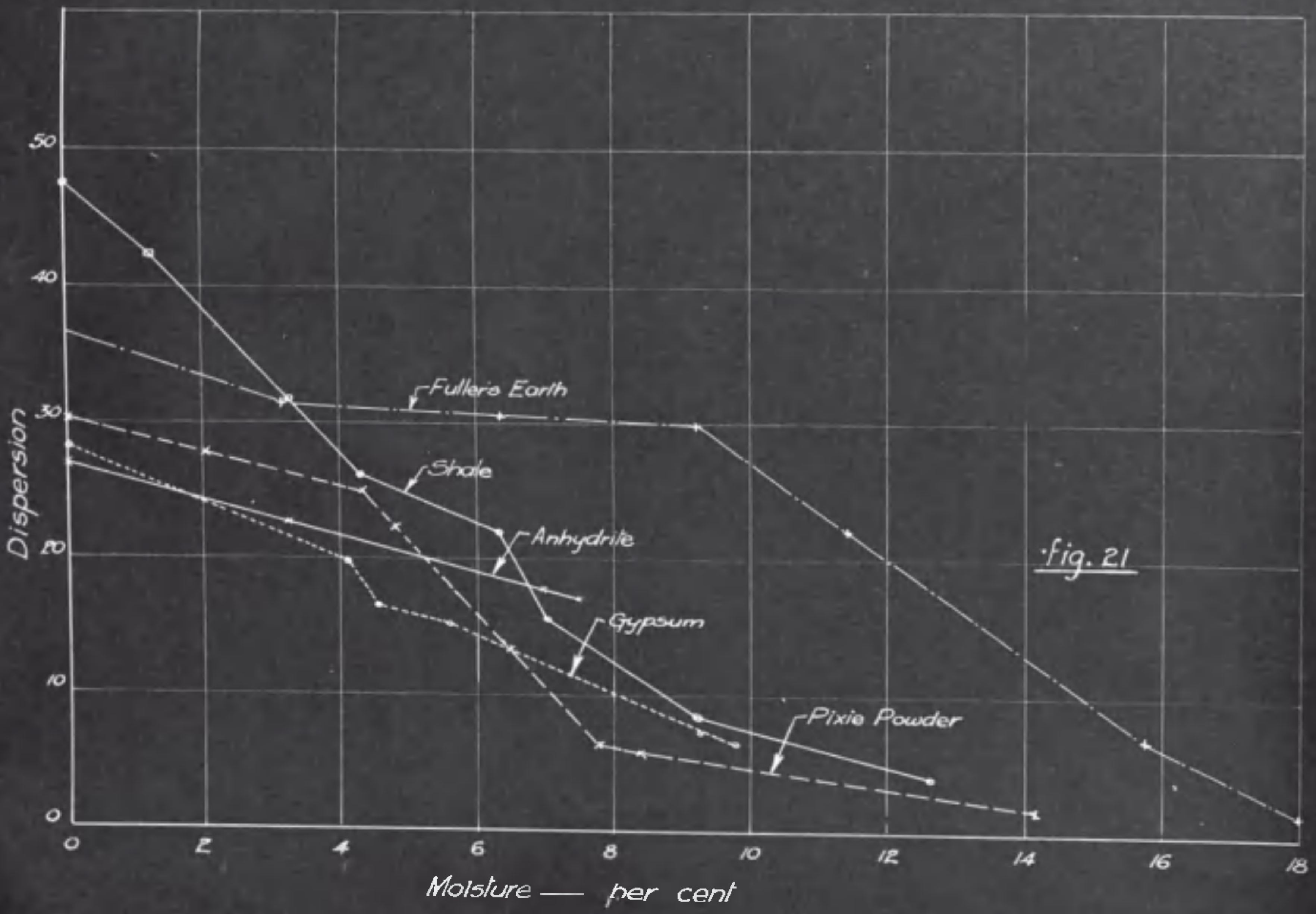


fig. 21

Dispersion
50
40
30
20
10
0
Moisture —— per cent
0
2
4
6
8
10
12
14
16
18
Fullers Earth
Shale
Anhydrite
Gypsum
Pixie Powder

moisture on all the dusts is summarised in Fig.21.

The fine shale dust is quickly affected by moisture and its maximum dispersion value falls off rapidly. Fullers Earth can absorb much more moisture than the others without being unduly affected. With 12 per cent of moisture this dust is as dispersable as the others containing only 4 - 6 per cent. Fig.21 indicates that fine dusts such as shale develop appreciable cohesion with moisture contents below their sticky point and it is evident that moisture content alone will be little guide in estimating the reduction in dispersability, without some knowledge of the fineness of the dust. For the dusts in these tests, however, there is a decrease of from 5 - 9 per cent in maximum dispersion for each 1 per cent of added moisture. The effect of the first few per cent of moisture in a dry dust is more marked than the same addition well on in the mealy condition.

This reduction in dispersion accounts for the dissimilarity existing in the effectiveness of moisture as compared with an equal percentage of combined water. The latter need not have any effect on the ability of the dust to be dispersed.

The Effect of Drying Out a Wet Dust.

Samples of the dusts which had been wetted for the previous tests were dried out and submitted to similar dispersion tests. A set of typical results is given in Fig.22 for Gypsum dust. Very little increase in dispersion was obtained on drying. Any increase can be accounted for by the attrition of the sample in charging the apparatus and the breaking of the hardened balls or

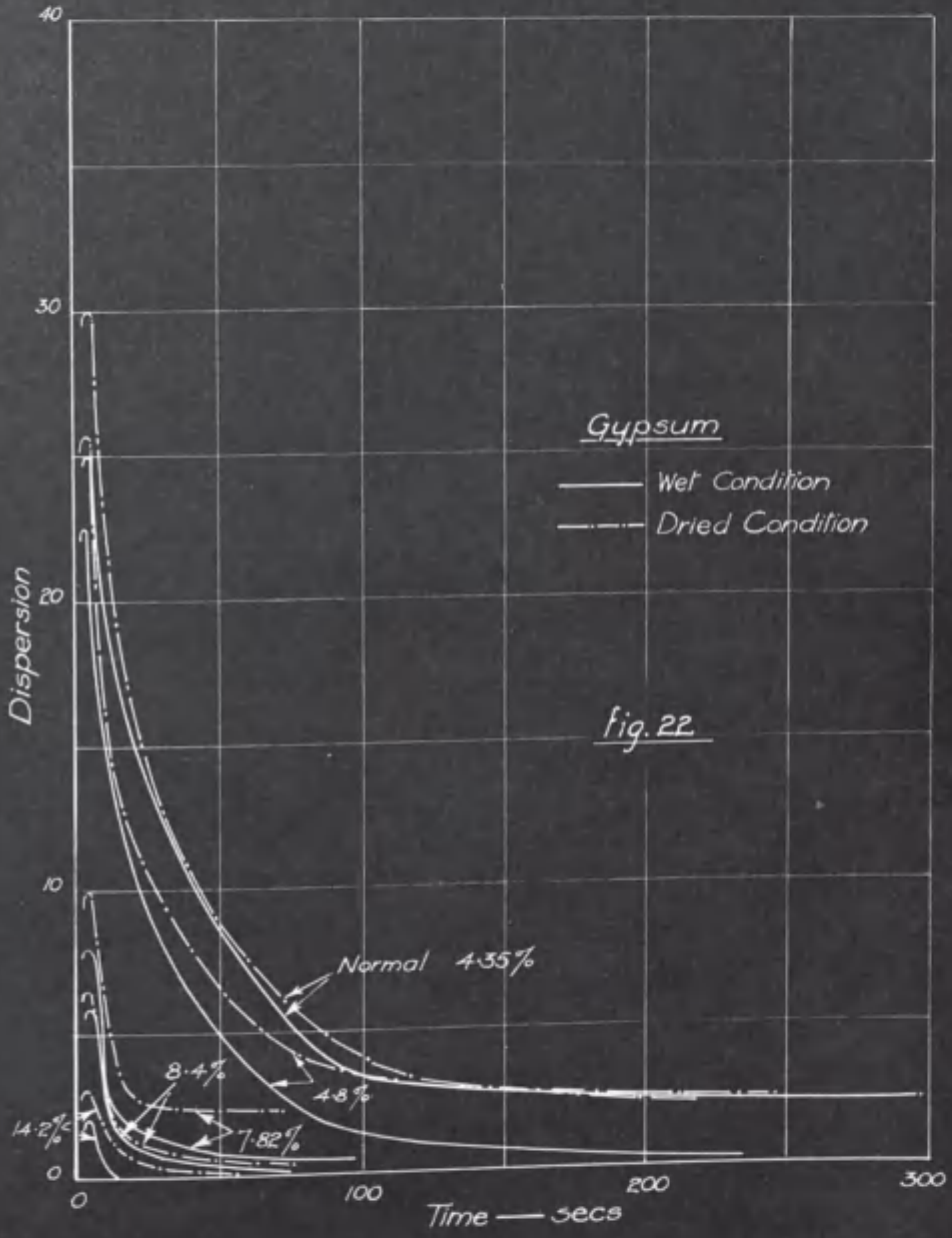


Fig. 22

Gypsum
Wet Condition
Dried Condition
Dispersion
Time — secs
40
30
20
10
0
0
100
200
300
Normal 4·35%
4·8%
8·4%
7·82%
14·2%

agglomerations against the top of the box, but even this is small.

One notable point is that the increase in dispersion is most marked generally in the case of the samples having the lowest moisture contents before drying. This, in other words, means that the less moisture the dust has initially, the less does it cake on drying.

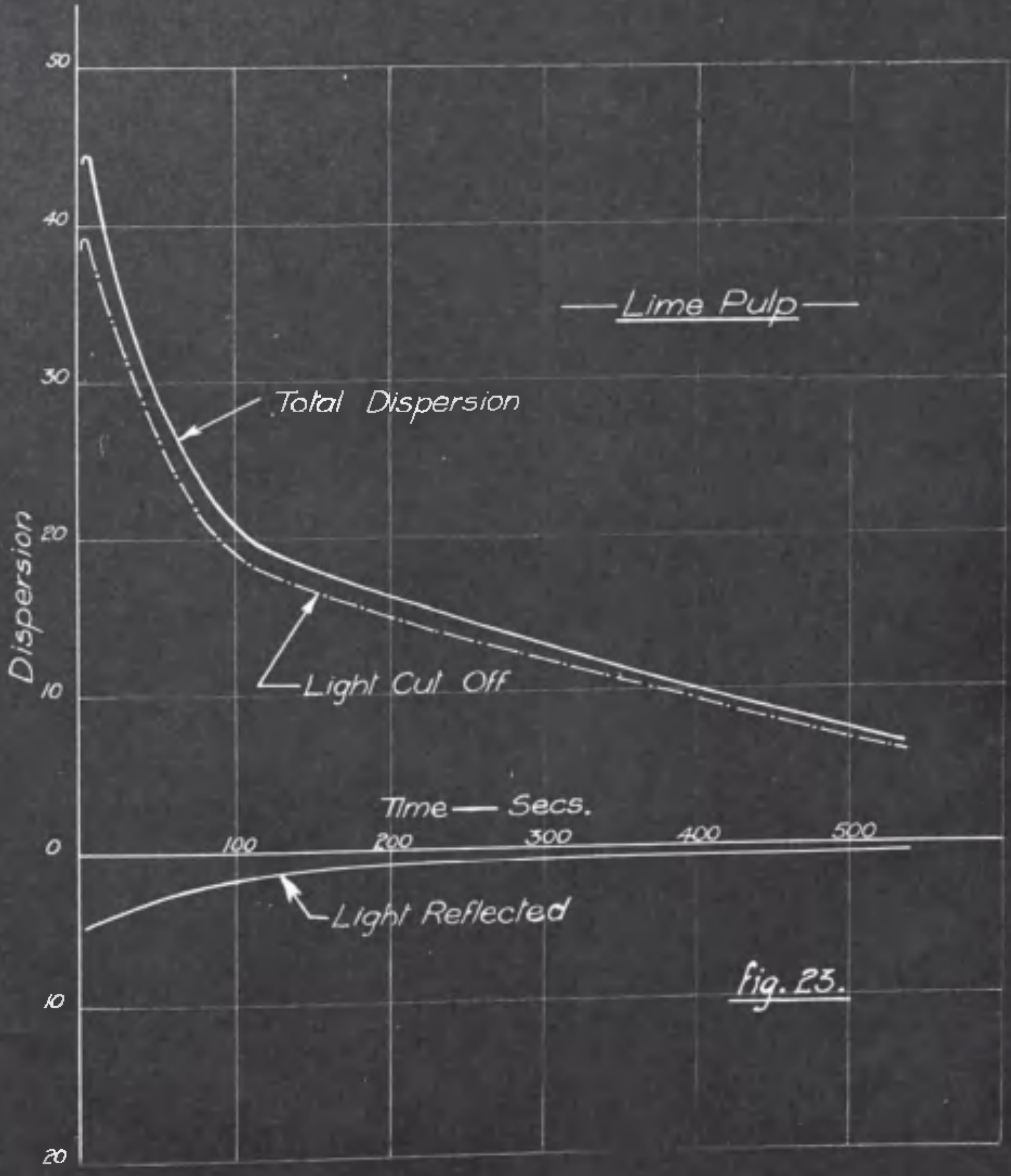
The Effect of Reflection on the test.

At this stage in the tests a second photronic cell became available and was incorporated in the apparatus to measure the amount of light reflected by the suspended dust particles into the cell.

In the tests already described the loss of light to the cell was measured really by the shadow of the particles. In the case of particles which reflect light, a certain amount must be reflected into this cell and the value of the dispersion consequently lowered.

For the measurement of this reflected light the second photronic cell was fitted at right angles to the first arrangement and the light reflected into this cell was measured also by means of a galvanometer. Since the cells were similar and placed symmetrically the light reflected into the second was assumed to be equal in amount to that reflected into the other and the readings (galvo. divisions) on this cell were added to the others to obtain the total dispersion.

At this stage the cell recesses were made a little deeper and the release clip previously used was replaced by a



— Lime Pulp —
Total Dispersion
Light Cut Off
Light Reflected
Dispersion
Time — Secs.
50
40
30
20
10
0
10
20
100
200
300
400
500

Fig. 23.

quicker spring-operated clip, ensuring a uniform and much sharper release of the air blast and giving more complete dispersion. As a result of these alterations dispersion values obtained with the new apparatus are not directly comparable with those already given.

Fig.23 shows the dispersion curves for Lime Pulp, the curves of reflected light and light cut off being typical for all the light coloured dusts. As the cloud of dust settles the reflected light is decreased but it is the maximum swing of the galvanometer which is of most importance.

The dispersion of all the dusts in their normal conditions in the new apparatus gave the following dispersion values, shale being taken as 100 and allowance made for reflected light:-

	Light Reflected per cent.	Total Dispersion
Shale	8.7	100
Softener Product	7.6	170
Limestone (Lugton)	8.85	98
Pixie Powder	9.45	77.5
Ground Gypsum	8.5	85.5
Limestone (S.Wales)	9.5	92
Anhydrite	10	117
Lime Pulp	12.5	120
Coal Dust	-	226

The correction for reflection in the case of all the stone dusts lay between 8% - 12% of the light cut off, Coal dust normally gave no measurable deflection in the second cell.

The effect of the reflection is bound up with the density of the dust cloud in the box, i.e., the greater the density of the dust cloud the greater will be the correction. It is considered however that the correction is sufficiently accurate for purposes of comparison and since the dusts are more or less all of a light colour no appreciable error is introduced.

The Effect of Fineness on Dispersability

Among the first official experiments carried out at Eskmeals it was proved that the finer the ~~stone~~ incombustible dusts used the more effective it was. In fact, the conclusion reached was that the fineness of the dust was more important than its chemical composition.(4)

Due allowance is made for the fineness of the ~~stone~~ incombustible dust used by the General Regulations in which it states that "provided that if a larger proportion of incombustible dust is used than is necessary under the foregoing Regulation, the percentage of fine material aforesaid contained in the incombustible dust may be reduced proportionately but shall not fall below 25." This allows of a reduction of from 50 per cent to 331/3 per cent of fines when the incombustible dust in the mixture reaches 60 per cent.

In estimating the effect of fineness, sieved fractions were dispersed in the usual way. Tests made with sieved and mixed fractions of dusts showed in all cases an increase in dispersion with increase in surface factor. This increase became less at high values of surface factor. The tendency of the dispersion values to fall off as the surface factor reaches high values may be due to:-

(1) Balling of the dust due to its extreme fineness.
(2) Density of cloud being so great that many of the
    particles are shielded from the light and do not
    therefore cast their shadow on the cell.

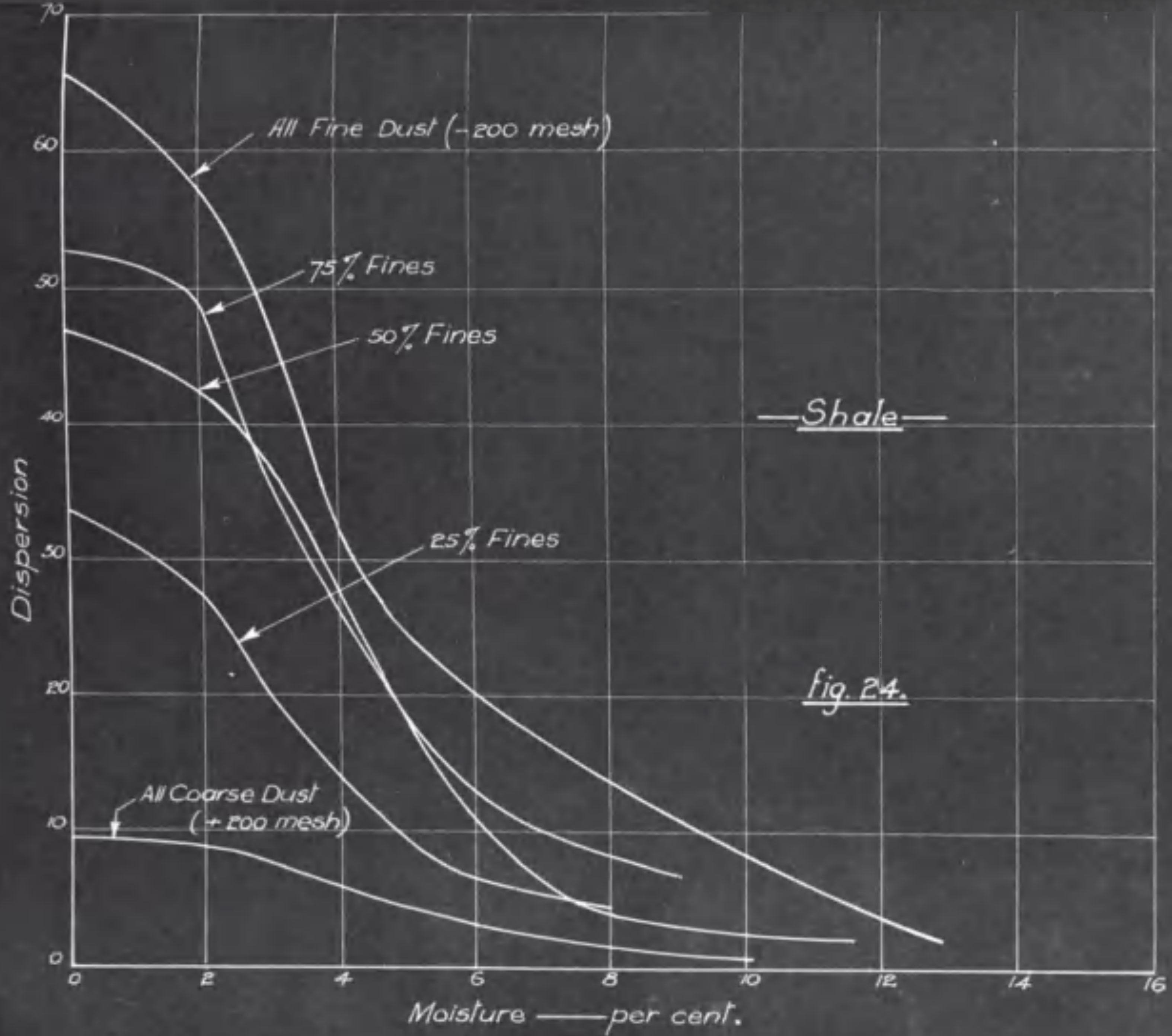
This latter feature however only enters in at high surface factors and since only a gram of dust is used in the test it is highly probable that cohesion of particles is the more important effect. The whole effect of fineness can be seen from the following values of Table 6 which show the maximum dispersabilities of various dust mixtures in compliance with General Regulations.

TABLE 6

Dust	Normal Dust	All through 200 Mesh	All above 200 Mesh	50/50 Mixture	35% Fines 65% Coarse	25% Fines 78% Coarse
Shale (Murton)	55	56	9	42	35	31
Anhydrite	38	39	7½	27½	20½	19
Gypsum	29	35	6	22	17¼	15
Limestone (Lugton)	31	32½	9½	30	22½	18
Soft. Produce	56	56½	12½	44	37	28½
Pixie Powder	31	31½	7½	22	17½	15

As moisture is added to the above mixtures the dispersion values drop, and generally the finer the mixture the more quickly is it affected. Fig.24 shows the dispersion curves for the shale mixture from which it is evident that mixtures containing 75 per cent and 50 per cent of -200 mesh size give almost the same dispersability as all-fine dust at a moisture content of 4 per cent. As already mentioned the effect of moisture is greatest at the beginning. Knowing, however, that shale dust is not likely to absorb 4 per cent of moisture from the atmosphere it would still appear desirable to have the dust as fine as possible.

The basic principle of the General Regulations has been adhered to in these tests by dispersing equal weights of all dusts. If a 50/50 coal-shale dust mixture is dispersed and the dusts are of equal fineness then there will be a correspondingly reduced quantity of shale-dust on account of its high specific gravity This is one reason for the large differences


All Fine Dust (-200 mesh)
75% Fines
50% Fines
25% Fines
All Coarse Dust
(+200 mesh)
Dispersion
0
10
20
30
40
50
60
70
Moisture —— per cent.
0
2
4
6
8
10
12
14
16

—Shale—

fig. 24.

in dispersion value between coal and stone dusts.

Considering that the proportion of dusts in the mixture when suspended are the important conditions it seems desirable that the Regulations governing the composition of dust mixtures should be based on a bulk basis rather than on weight. The disturbing forces may be considered for the moment to be sufficiently strong to raise all dusts irrespective of their specific gravity, in which case the 50/50 mixture by weight of coal and ~~stone~~ incombustible dusts gives approximately twice as much coal dust surface as ~~stone~~ incombustible dust surface.

Testing the dusts under these conditions and dispersing equal theoretical bulks in accordance with the specific gravity of the dusts the following values were obtained, corrections for reflection being applied as before.

Dust	Dispersion
Shale	56
Coal Dust	50
Softener Product	45
Anhydrite	48½
Gypsum	32
Dixie Powder	32
Lime Pulp	45
Limestone	44

These values are thus a truer measure of the cloud forming properties of the dusts, being affected only by their fineness, moisture content and any tendency they may possess to resist dispersion.

Gypsum and Limestone values are not greatly reduced for dusts having a tendency to ball, but the fineness effect and the effect of variation in size composition cannot be separated. Anhydrite has a high dispersion value and yet is probably the most readily balling of the group. Taking into account the surface factors of the dusts it would appear that the small dispersing puff employed is sufficient to disperse more or less completely any balled up aggregates. A factor representative of the quenching or heat absorbing efficiency of the dusts, when combined with the figures given should closely approach the true efficiency of any particular dust.

CONCLUSIONS. The following are the conclusions drawn from the foregoing experimental work.

(1) The dispersion characteristics of incombustible dusts can be satisfactorily measured by the apparatus described. This test reacts to alteration in moisture content and fineness and to a lesser degree to the reflecting properties of the dusts being tested. By adopting a dust of known fineness and condition as standard the changes brought about by addition of moisture or drying out can be assessed.

(2) Moisture added to a dust reduces its dispersability. The effect is most marked at low percentages and is not so marked when the dust is already in a mealy condition.

(3) Fineness of a dust increases its dispersability but moisture affects a fine dust more severely than a coarser one.

(4) Drying out a dust after wetting causes no appreciable increase in dispersion. The less moisture the dust contained before drying, the greater is the increase in dispersion when dried out.

PAPER 5

THE EFFICIENCY OF INCOMBUSTIBLE DUSTS IN THE SUPPRESSION OF FLAME

THE EFFICIENCY OF INCOMBUSTIBLE DUSTS IN THE SUPPRESSION OF FLAME

The efficiency of incombustible dusts in quenching an explosion has been proved in countless instances and doubted only in a few.

Although Mason and Wheeler, in S.M.R.B. Paper No.96,conclude that the relative efficacies of incombustible dusts depend on the proportions of CO_2 and combined water contained, it is doubtful if it has been definitely proved. From the preceding papers it is evident that,apart from heat absorption, other factors also play an important part in the efficiency of a dust.

In the Sixth Report(I9I4) of the Explosions in Mines Committee of the Home Office (4), when dealing with tests carried out in the 7½ ft. by 800ft. gallery at Eskmeals, it was stated that the fineness of the incombustible dust rather than its chemical composition afforded a measure of its probable effectiveness in preventing the ignition of coal dust with which it might be mixed. In these tests six dusts were used,viz: fullers earth, fullers earth substitute, shale dust, dolomite dust and Chance's Mud lime. With each dust it was found that equal proportions by weight with coal dust rendered the mixture incapable of propagating flame -- 40 per cent of ~~stone~~ incombustible dust allowed propagation in every case.

Later(S.M.R.B.Paper No.79), a distinct difference was observed in the suppression effected by the different dusts and from these large scale experiments the relative amounts of stone dusts required for the prevention of propagation were deduced as follows:-

Fullers Earth	IO
Shale(South Wales)	II
Shale(Yorkshire)	I2½
Anhydrite	9
Limestone	8
Calcium Carbonate	7½
Gypsum	4

The numbers denote the relative weights of each dust required.

The effectiveness of gypsum was suggested to be due to the large quantity of combined water in it and the effectiveness of limestone to its carbon dioxide content. More recent experiments (S.M.R.B.Paper No.96) tend to show that the quenching effect of a dust is dependent on the hydrated water content and the amount of carbon dioxide contained. The basic anhydrous residues are said to be very much alike.

Other experiments on the fineness of the incombustible dust have shown also that the fineness is an important factor in the effectiveness of any dust, but whether the action of a dust is dependent on the surface exposed for the explosion instant or on the decomposition products is not at all clear. The catalytic action of sodium carbonates and the marked suppressive action of sodium and magnesium chlorides cannot be explained merely on the assumption that they absorb heat(I3). Then there is the question of the dispersabilities of the dusts: it has been shown that these vary to a great extent. The method and the scale of the experiment are also important. All these factors enter into the question of dust efficiency and make the problem of real efficiency i.e. flame suppression, somewhat involved.

In order to simulate actual mining conditions, large scale gallery tests are desirable; but they do not reproduce actual mining conditions in every detail. This inability to conduct large scale tests has led many research workers to attempt the reproduction of mining conditions on a small scale in the laboratory. The explosibility of coal dusts and the effectiveness of ~~stone~~ incombustible dusts in the suppression of flame can be shown in such small scale apparatus. In so far as a routine test for the inflammability of a mine dust is concerned, the necessity for a large scale test has been eliminated by the evolution of the "S.M.R.B. Routine Inflammability Apparatus"(17,3) with which, within narrow limits, coal and ~~stone~~ incombustible dust mixtures are stated to behave as in the large experimental gallery at Buxton.

The S.M.R.B. Routine Inflammability Apparatus

This apparatus is used as a routine test under standard conditions for mine dust mixtures and shows whether or not they are inflammable, without any estimation of the percentage of combustible matter.

The construction, calibration and method of operation of the apparatus are fully described in S.M.R.B. Papers Nos.68 and 87. The criterion of inflammability, when once the apparatus has been standardised as regards pressure of oxygen and furnace voltage, is judged by the appearance or otherwise of sparks and flame from the mouth of the inflammation tube. The intensity of the report and the volume of flame serve as guides in comparing different coaldusts. When determining the inert dust limit of any coal dust the percentage of ~~stone~~ incombustible dust is varied by 5 per cent. each time until there is no flame, but only a few sparks, when the mixture issues from the inflammation tube.

The Inflammability of Coal Dusts

Experimental The S.M.R.B. apparatus was used in the tests to be described. After standardisation tests were carried out to determine the effect of the fineness of the coal dust on its inflammability as measured by the amount of incombustible dust required to suppress inflammation.

The incombustible dust used was shale in its normal condition (moisture 0.79 per cent.) and fineness(85 per cent. thro'200 mesh). Results obtained for two well known inflammable coals are given as follows:-

Arley Coal Dust

Coal Dust mesh size	Ash in Coal per cent	Shale dust in mixture to suppress inflammation per cent.
50 - 80	3.82	--
80 - I00	3.83	5
I00 - I50	3.82	30
I50 - 200	3.5I	50
200 - 300	4.23	65
thro'300	4.36	70
0 - I5 micron.	4.47	75

Silkstone Coal Dust

Coal Dust mesh size.	Ash in coal per cent	Vol. matter in coal per cent.	Shale dust in mixture to suppress inflammation per cent.	
40 - 50	I.85			
50 - 60	I.60			
60 - 70	I.95	36.99		
70 - 80	I.86	35.83		
80 - 90	I.73	36.57		
90 - I00	2.5I	35.70		
I00 - I20	I.77	35.55	5	Just Inflammable
I20 - I50	I.97	34.85	I0	
I50 - 200	2.07	33.37	35	
200 - 250	2,29	35.I2	50	
250 - 300	2.3I	34.5I	65	
thro'300	2.35	33.56	65	

Arley coal dust becomes inflammable in the size between 80 and

IOO mesh and the Silkstone dust in the IOO-I20 mesh size. The variation in ash and volatile matter in the second series is negligible and cannot be regarded as having any effect on the increase in inflammability. Decrease in size of particle and increase in surface per unit weight is the cause of the increasing inflammability.

The Relative Quenching Effects of the Incombustible Dusts.

Experiments with the various incombustible dusts were next carried out to determine the relative efficacies of these materials in their normal condition. Sized fractions of Silkstone coal dust were used in the tests and the values of Table 7 give the percentages of the incombustible dusts necessary to render the mixtures non-inflammable.

TABLE 7

	Coal Dust - mesh size				
Incombustible Dust	thro' 300	thro' 250	I50 - 200	I20 - I50	Moisture per cent. in Stone Dust
Pixie Powder	80	75	45	I5	4.55
Shale(Murton)	70	70	35	IO	I.27
Fullers Earth	75	70	40	IO	3.55
Ground Gypsum	75	75	45	20	4.78
Limestone(Lugton)	80	75	45	IO	0.99
Softener Product	85	80	45	I5	2.35

The results show that there is not the large variation in effectiveness as between one dust and another that has been found in large scale experiments. Over different sizes of coal dust there is not a great difference in effectiveness.

With this apparatus and form of test shale is the most effective dust. This can probably be accounted for by its fineness and high dispersability. As far as this method of testing is concerned, chemical composition does not appear to influence the percentage of dust required to any appreciable extent. The two main factors governing the efficiency of the dusts in this test appear to be:-

(I) Fineness or Surface Factor.

and (2) Capability of intimate dispersion with the coal dust within the apparatus.

In these experiments the coal and stone dusts were intimately mixed before dispersion as they are in the S.M.R.B. experiments. This is not generally the condition in actual practice. Also, the method of ignition is different and, depending on the manner in which the dusts leave the dust tube, the results may or may not compare with those obtained under more natural conditions and on a larger scale. It is claimed, however, that for routine work the test is stringent and the results err on the side of safety.

The Effect of the Fineness of the Incombustible Dust

The effect of varying the fineness of the ~~stone~~ incombustible dust was found, using the same apparatus, and again using sized fractions of coal dust. It was found that for every dust the effectiveness increased with fineness. Typical results for PixiePowder and Limestone dust are given in Tables 8 and 9.

TABLE 8.

Pixie Powder mesh size	Silkstone Coal Dust - mesh size			
	thro'300	200/250	I50/200	I20/I50
I00/200	90	75	70	50
200/300	80	70	60	45
thro'300 mesh	70	60	55	30

TABLE 9

Limestone(Lugton) mesh size	Silkstone Coal Dust - mesh size						
	2.7µ	4.2µ	thro'300	300/250	250/200	200/I50	I50/I20
70 - 90	95	95-97½	95	80	65	60	40
90 - I00	95	95	95	70	60	60	35
I00 - I50	95	95	90	85	80	60	20
I50 - 200	85	80	90	75	65	60	25
200 - 250	80	80	85	75	65	40	25
thro'300 mesh	70	65	75	65	50	40	30

With the very fine elutriated fractions of coal dust a decrease in the amount of incombustible dust was occasionally found and this is taken to be due to balling and increased cohesion of the very fine coal dust.

The Effect of Moisture on the Incombustible Dust Limit.

To determine the effect of moisture on the amount of incombustible dust to make a coal dust non-inflammable, tests were carried out with the gauze diaphragm at the entrance to the inflammation tube in position.

Incombustible ~~Stone~~ dusts were wetted to various moisture contents and mixed with dry Silkstone coal dust.

As the moisture content of the incombustible ~~stone~~ dusts was increased, the proportions of such dusts required to prevent inflammation of the coal dusts increased. The wetting caused the incombustible ~~stone~~ dusts to ball up and a screening action took place in the 30-mesh gauze. Aggregations of damp dust were held on the gauze while the drier coal dust passed through to be ignited. The screening effect explains the abnormal increase of wet incombustible ~~stone~~ dust required to prevent inflammation.

At the same time the results might be taken as a measure of the effect of balling on the quenching efficiency of an incombustible ~~stone~~ dust. The effect is likely to be even greater in practice.

The following results were obtained using shale, limestone and gypsum.

TABLE IO

SHALE(Murton)

Moisture in Incombustible Dust.per cent.	Ratio of Mixture Shale/Coal.	Remarks
Dry	50/50	No explosion
8.70	50/50	Violent explosion
	55/45	-do-
	60/40	Explosion
	65/35	Short flame
	70/30	-do-
	75/25	No explosion
I0.60	70/30	Short flame
	75/25	No explosion
I3.40	75/25	Explosion
	80/20	Short flame
	85/I5	No explosion

LIMESTONE

Moisture in Incombustible Dust.per cent.	Ratio of Mixture Limestone/Coal	Remarks
Dry	50/50	No explosion
6.50	70/30	Violent explosion
	75/25	Explosion
	80/20	No explosion
9.30	80/20	Short flame
	85/I5	No explosion
I2.30	80/20	Short flame
	85/I5	No explosion

GYPSUM

Moisture in Incombustible Dust.per cent.	Ratio of Mixture Gypsum/Coal	Remarks
Dry	70/30	No explosion
2.00	70/30	No explosion
3.00	70/30	No explosion
6.30	70/30	Explosion
	75/25	Short flame
	80/20	No explosion
I0.30	75/25	Explosion
	80/20	No explosion
25.00	80/20	Explosion
	85/I5	No explosion

A series of tests were made with the gauze removed so that the whole mixture of ~~stone~~ incombustible and coal dusts could be projected through the inflammation tube. As before, the incombustible dust was mixed with the dry coal dust.

The results obtained were the reverse of those obtained with the gauze in position -- as the moisture content of the ~~stone~~ incombustible dust increased, a smaller quantity was required to prevent ignition of the mixture. This may be explained in part by the action of the water itself as a quenching material and also by the adhesion and imprisonment of dry coal dust in the damp ~~stone~~ incombustible dust: no screening action takes place with the gauze removed. Apart altogether from the moisture in the ~~stone~~ incombustible dust there is not such good dispersion of the coal dust. With the gauze removed the dust mixtures are shot through the tube as more or less compact masses.

From the point of view of the correct manipulation of the apparatus, the following typical results for anhydrite/coal mixtures are therefore possibly not of great value.

ANHYDRITE

Moisture in Incombustible Dust. per cent.	Ratio of Mixture Anhydrite/Coal	Remarks	Mixtures dried at 100 deg. Cent.	
Dry	50/50	No expl.		
	45/55	-do-		
	40/60	-do-		
	35/65	Explosion		
4.40	35/65	No expl.	35/65	Explosion
	30/70	Explosion	40/60	No expl.
7.00	30/70	No expl.	40/60	No expl.
	25/75	Explosion	35/65	Explosion
10.70	30/70	No expl.	40/60	No expl.
	25/75	Explosion.	35/65	Explosion.
13.30	30/70	No expl.	40/60	No expl.
	25/75	Explosion	35/65	Explosion.

Drying the mixtures causes an increase in the percentage of anhydrite required. The moisture being removed, the coal as well as the incombustible dust is able to disperse more freely.

Conclusions

A summary of the important conclusions drawn from the foregoing experiments is as follows:

(I) The apparatus used, although stated to give results comparable with those obtained under large scale conditions, is not sufficiently accurate in its present form for routine work because,(a) it does not distinguish between the effects of incombustible dusts of different chemical composition in the same manner as recent large scale tests; and(b) its reaction to moist dust mixtures is of little value. Results are entirely different depending on whether or not the gauze is used.

(2) The effect of moisture in incombustible dust is to reduce its dispersion considerably and hence its efficiency. In the light of the results obtained, the heat absorbing capacity of the water is negligible in comparison with its dileterious effect on the ~~stone~~ incombustible dust.

(3) A combination of the practices of watering and stone-dusting as allowed by General Regulations is to be deprecated as the principles are entirely in opposition. In general, the effect of moisture on an incombustible dust is to require an increased initial quantity of that dust, if inflammation is to be suppressed. Weight for weight of coal dust rendered non-inflammable, the amount of dry dust required is increased approximately from 5 - I0 per cent. above that required for no inflammation in the dry condition, with the addition of each I per cent. of free moisture

PAPER 6

TESTS ON THE MOVABILITY OF DUST LAYERS

TESTS ON THE MOVABILITY OF DUST LAYERS

The question of the ease of moving the dusts is altogether apart from that of their power of dispersion. Damp dusts and coarse dusts, for example, can be moved in certain circumstances when fine dry dust cannot be disturbed. Their dispersabilities, however, are generally very poor.

The ease with which a layer of dust can be moved is more or less a measure of the force of adhesion between the dust and the surface on which it is placed. This force is dependent, therefore, on the nature of the surface, on the composition and fineness of the dust and on the method in which the dust was applied. Once the dust is moved, its dispersability properties play a part in the formation of dust clouds. It is not to be implied, however, that a dust which is easily moved is necessarily one which easily produces a dust cloud.

In determining the most effective size of dust to apply to the surfaces of mine roadways it must be borne in mind that a very fine dust adheres in much the same way as paint and, if applied with some force, a very strong air-blast may be required to remove it. This is another manifestation of the cohesive forces already mentioned. On the other hand, if the dust applied is too coarse, it rebounds from vertical surfaces and falls to the floor. A certain amount of fine material is thus necessary for adhesion to vertical and overhead surfaces, and it can be taken that the major portion of the dusts used are sufficiently fine to be capable of doing this.

In U.S.A., where the dust is mostly applied by machines, a finer product is recommended for use than for hand application.

The grading of size recommended is that all the dust should pass a 50-mesh sieve and 70 per cent. should pass a 180-mesh sieve. Colorado Regulations demand an even coarser dust. Here the dust is applied by blower and the largest size of particle is ⅛ inch with only 20-30 per cent. passing a 200-mesh screen. These mines, however, differ from our own in that they have horizontal shelves which catch and hold the coarser dust. The finer sizes, capable of floating in the air for a short period, eventually settle on top of the coarser dust surfaces.

The position of the dust in the roadway section and the size of the particles will thus have an important bearing in the question of efficiency in an explosion wave.

Experimental Work

To investigate the adhesion of dusts to surfaces and to find the effect of several factors on the air velocity required to dislodge, a series of tests were made in a small wind tunnel connected to a fan drift. Any desired velocity, up to 100 ft. per sec., could be obtained by varying the fan speed.

Series I Equal weights of the various incombustible dusts in their normal condition were sprinkled lightly and evenly with pepper dusters on smooth glass plates of 19 sq. ins. area. These surfaces, sunk flush with the tunnel bottom, were then subjected to gradually increasing velocities and the weights of dust removed in 5 minutes at each velocity determined. It was found that after 5 minutes there was little likelihood of any further dust being removed unless a change was made in the velocity.

As the velocity was increased from zero to the test velocity, puffs of dust were blown from the surface at first, but these ultimately ceased and little or no further dust was removed. At high velocities the dust surfaces became windswept in appearance and when this stage was reached, with increase in velocity, the dust tended to lift off in patches which were at once dispersed. The typical windswept appearance of samples of shale and gypsum are shown in figs.25 and 26.

The weights of dust removed in 5 mins. at the various velocities are given in figs. 27-29 for coal dust, shale and gypsum. Gypsum is the most difficult of all to remove. The shale result is typical of the limestone dusts as well, both being more easily removed than gypsum but not so easily as coal dust.

<u>Series 2</u> The same procedure was repeated with the dust layers doubled and trebled in weight. It was found that for the removal of similar percentage weights from dust layers of different thickness, the thicker layers required a much higher velocity. The actual weight of dust removed at similar velocities was only very slightly altered as the layers increased in thickness. This is assumed to be due to the flattening of the surfaces already referred to. These results are also shown in figs. 27-29.

<u>Series 3</u> In the previous experiments it was observed that the roughnessof the surface of the dust had a pronounced effect on the amount removed, and care was taken to have the test layers of as nearly the same original roughness as possible.To investigate the effect of the shape and surface condition of the dust sample,gypsum dust was used,distributed in various ways and subjected to a constant, steady velocity. Fig.30 shows a set of typical curves, the dust being most fully and easily moved when the surface was rough. The rough surface to which the test results refer was

fig. 25(a)
<u>Shale Dust before Test</u>.

fig. 25(b).
<u>After Test</u>
5 mins. in Air Velocity 45ft./sec.

fig. 26

<u>Gypsum Dust after Test</u>.

5 mins. in Velocity of 55ft./sec.

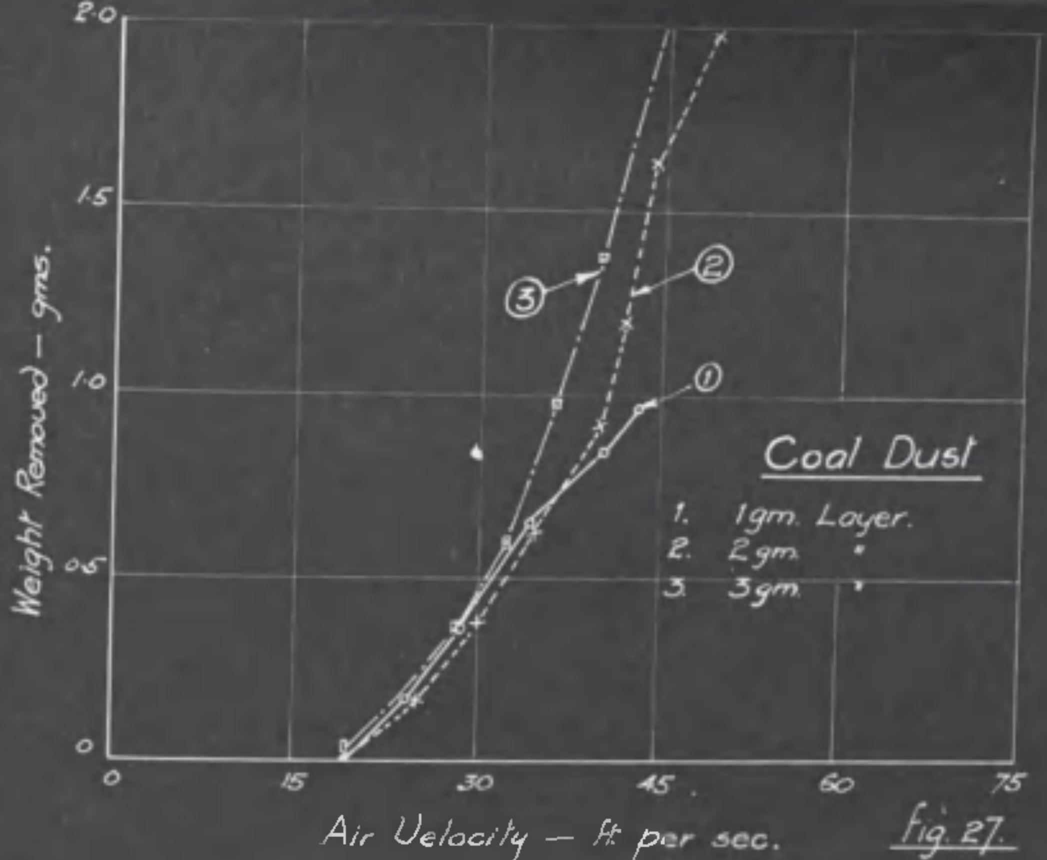

2.0
1.5
1.0
0.5
0
0
15
30
45
60
75
Weight Removed – gms.
Air Velocity – ft per sec.
③
②
①
Coal Dust
1. 1gm. Layer.
2. 2gm. "
3. 3gm. "

Fig. 27.

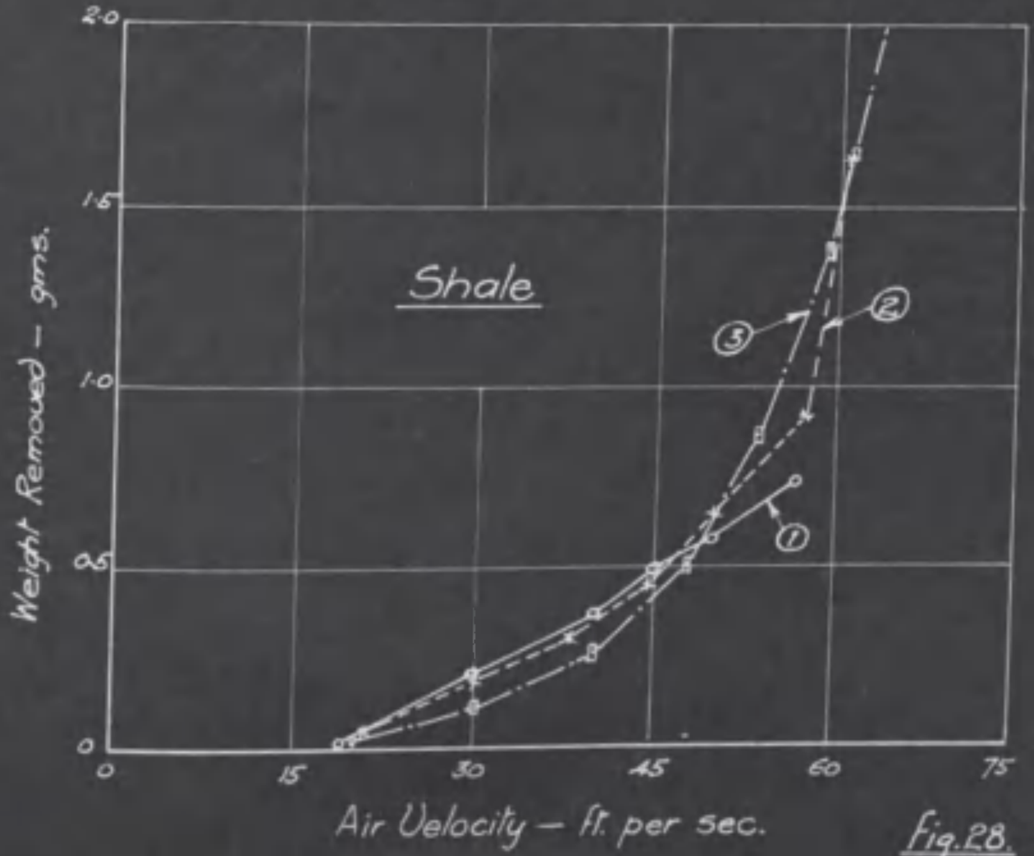

2.0
1.5
1.0
0.5
0
0
15
30
45
60
75
Weight Removed – gms.
Air Velocity – ft. per sec.
Shale
③
②
①

Fig. 28.

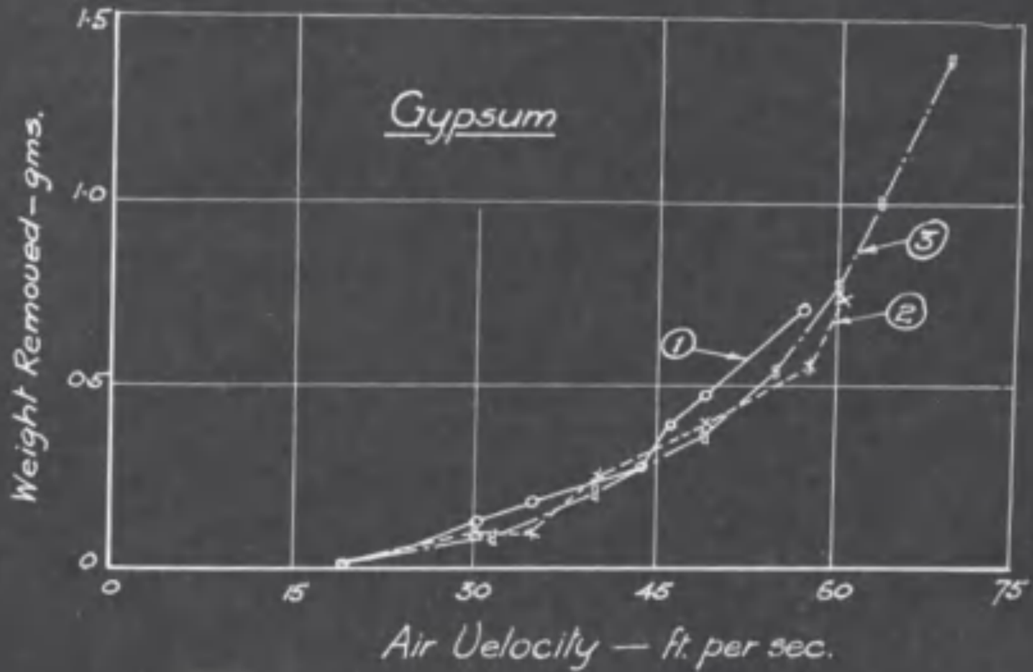

Gypsum
Weight Removed - gms.
1.5
1.0
0.5
0
0
15
30
45
60
75
Air Velocity — ft. per sec.
①
②
③

Fig. 29.

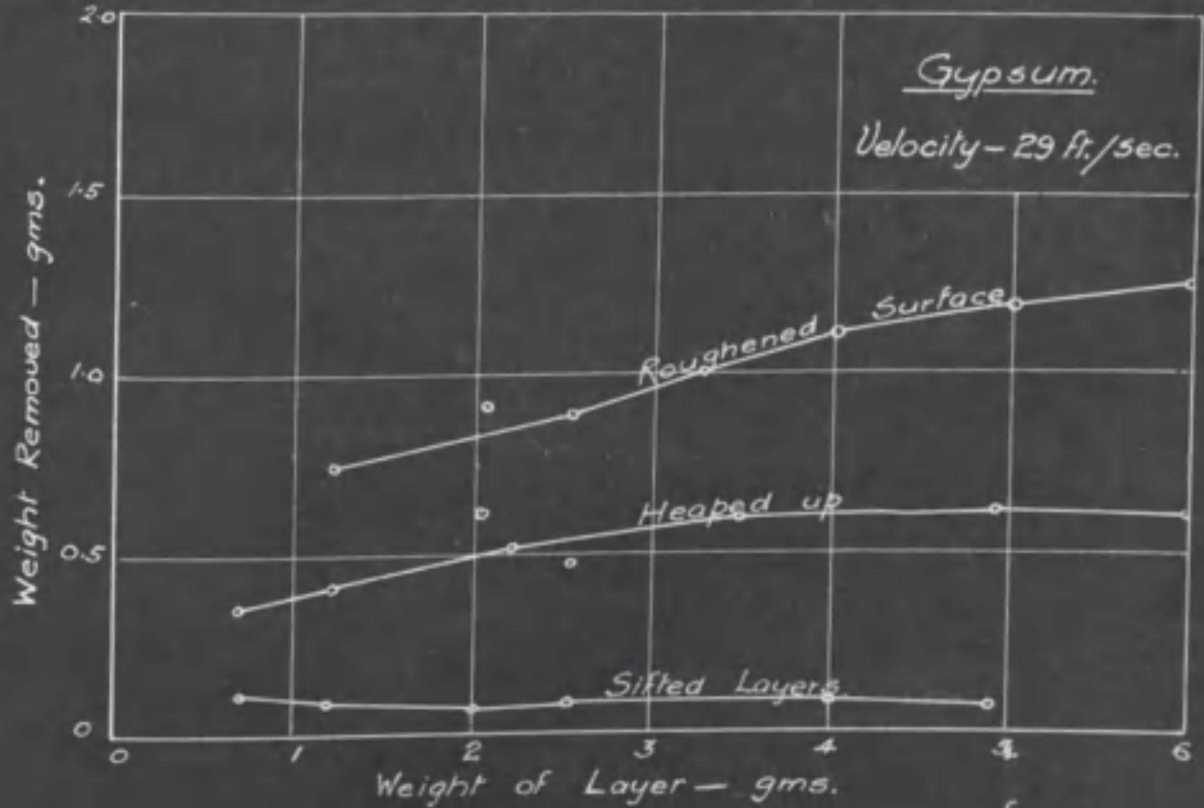
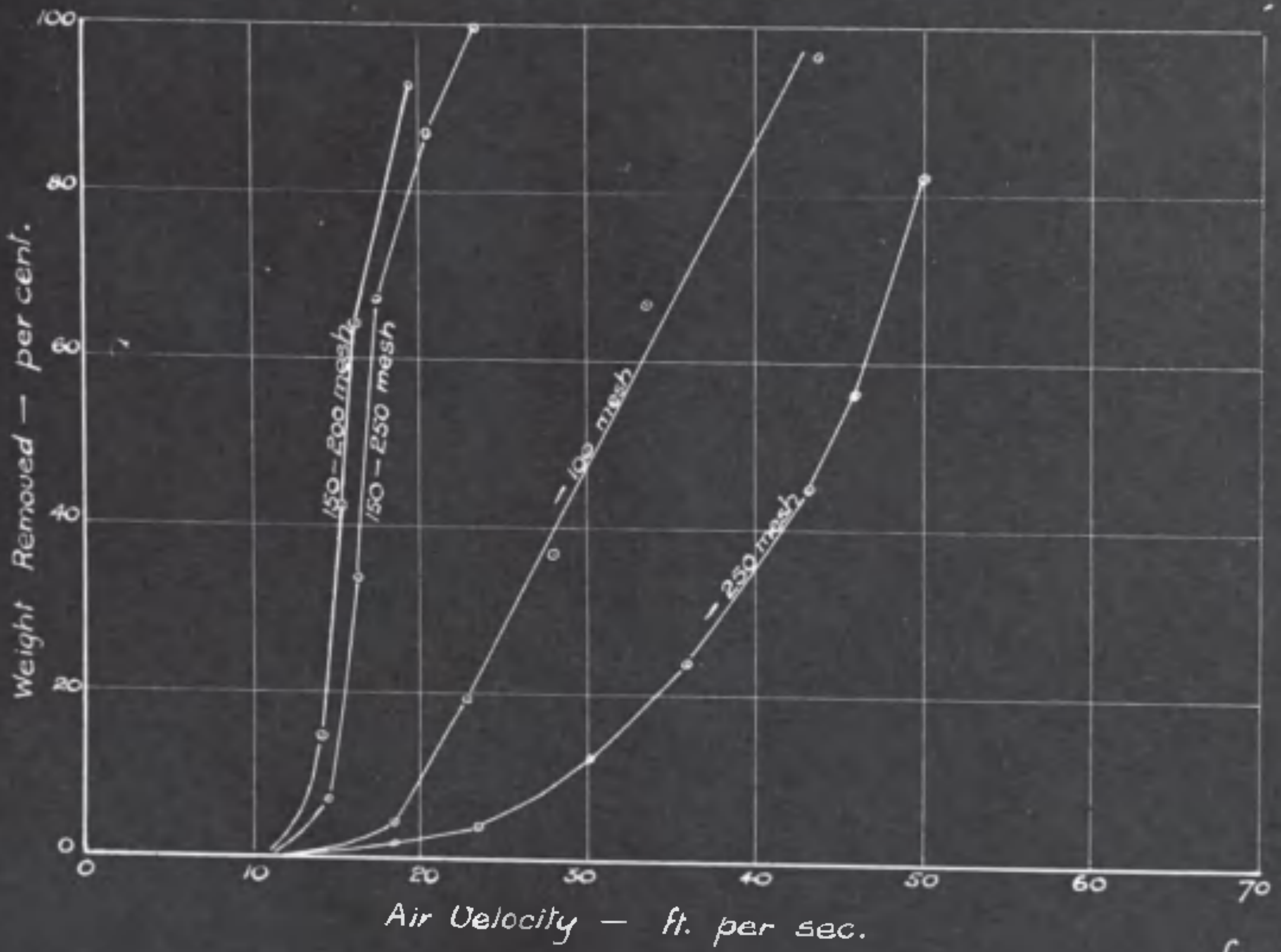

Gypsum.
Velocity - 29 ft./sec.
Weight Removed — gms.
2.0
1.5
1.0
0.5
0
0
1
2
3
4
5
6
Weight of Layer — gms.
Roughened Surface
Heaped up
Sifted Layers

Fig. 30.



100
80
60
40
20
0
Weight Removed — per cent.
0
10
20
30
40
50
60
70
Air Velocity — ft. per sec.
150 – 200 mesh
150 – 250 mesh
– 100 mesh
– 250 mesh

Fig. 31.

obtained when the sifted layer was riffled with a knife across the two diagonals at 1/4 inch intervals. When the dust was deposited in a roughly conical heap of about 1½ inches diameter at the base in the centre of the plate the amount removed decreased, but still exceeded that removed from the same quantity of dust spread in an even layer.

As the weights of the samples increase it will be observed that the weight removed tends to fall off and become a constant and this is again attributed to the rounding off and windsweeping of the profiles.

Combining the results of tests 2 and 3, it would appear that, in order to give the dust the best possible opportunity to rise or move under a comparatively weak disturbing force, the material should expose a maximum roughness to the blast combined with a minimum thickness of layer. The provision of a very thin film of dust over all surfaces causes a smoother layer, more cohesion and consequently a greater amount of material in contact with the surfaces. This contact layer is most unlikely to be moved at all.

<u>Series 4</u> Using coal dust as a representative dust, various sized fractions were tested under the previous testing conditions. Fig. 31 shows the effect of the fineness of the dust on the air velocity required to remove. A stronger adhesion to the test plate and between particles and a smoother external surface generally account for the lower rate of removal of the finer sizes. Coal dust of 150-200 mesh size is most easily removed and, although possibly not of great account in forming a dust cloud, particles of this size

are definitely inflammable and capable of taking part in an explosion.

Series 5 It was anticipated in these tests that the effect of local eddies, due to roughness of duct, obstructions and timbering, would increase the amount of dust removed at any velocity. To investigate this effect, sets of timber were placed in the experimental tunnel and a series of tests carried out with the timbers in position. Fig.32 shows the increase in the weight of dust removed by the eddies thus formed.

The effect of velocity on layers of coal and ~~stone~~ incombustible dust was investigated and these results are also shown in fig.32. Layers of coal dust(I gm.) and limestone dust(2 gm.) were used and their positions varied.

With the limestone dust on top, coal dust formed the contact layer on the plate surface. This allowed of both dusts being removed over a greater area of plate and of a good removal of dust compared with the other condition.

With the layers reversed, the ~~stone~~ limestone dust provided the contact layer on the plate. At the same velocities, although the lighter dust was on top, much less dust was removed.

By analysis of the dust remaining in each case, the weights of limestone and coal dust removed were calculated. The results(fig.32) show that, for all practical purposes, it is immaterial which dust is on top as far as the amount of coal dust removed is concerned; but for the removal of the maximum amount of ~~stone~~ incombustible dust, it must form the top layer.

Series 6 As moisture was added to limestone dust it balled up. When this moist dust was spread on a dry surface it was removed to a greater extent than the same dust in the dry condition. This is because the balling of the dust is equivalent to an increase in particle size. The dispersion of the dust, however, was very much reduced.

The procedure in mines is generally the reverse of that just mentioned, the dry dust being applied to a moist or damp surface. This results in a condition totally different from the previous one. To simulate this practical condition, the glass test plate was moistened to various degrees and the dry limestone and coal dusts applied.

It is evident from fig.33 that a minute film of moisture, such as produced by simply breathing on the glass, makes a great difference to the adhesion of the dust layer -- especially the ~~stone~~ incombustible dust which is easily wetted. In these experiments it was not found possible to apply sufficient water to affect the dust at the surface of the layer and this was removed in all cases.

Coal dust sprinkled on wet ~~stone~~ incombustible dust was always almost totally removed. The nature of its contact appeared to make little difference. The amount of ~~stone~~ incombustible dust removed onthe other hand depended greatly on the contact with the water films. When the coal dust was next to the water film, it prevented the firm adhesion of the ~~stone~~ incombustible dust. The decrease in the amount removed(fig.33) when the limestone was on top of the coal dust is due to its penetrating the thin coal dust layer and making contact with the moisture film.

It was found also that no material difference resulted in allowing a wetted ~~stone~~ incombustible dust layer to dry or cake before 'blowing' it. A dry,caked layer is thus just as ineffective as one just spread on a wet surface.

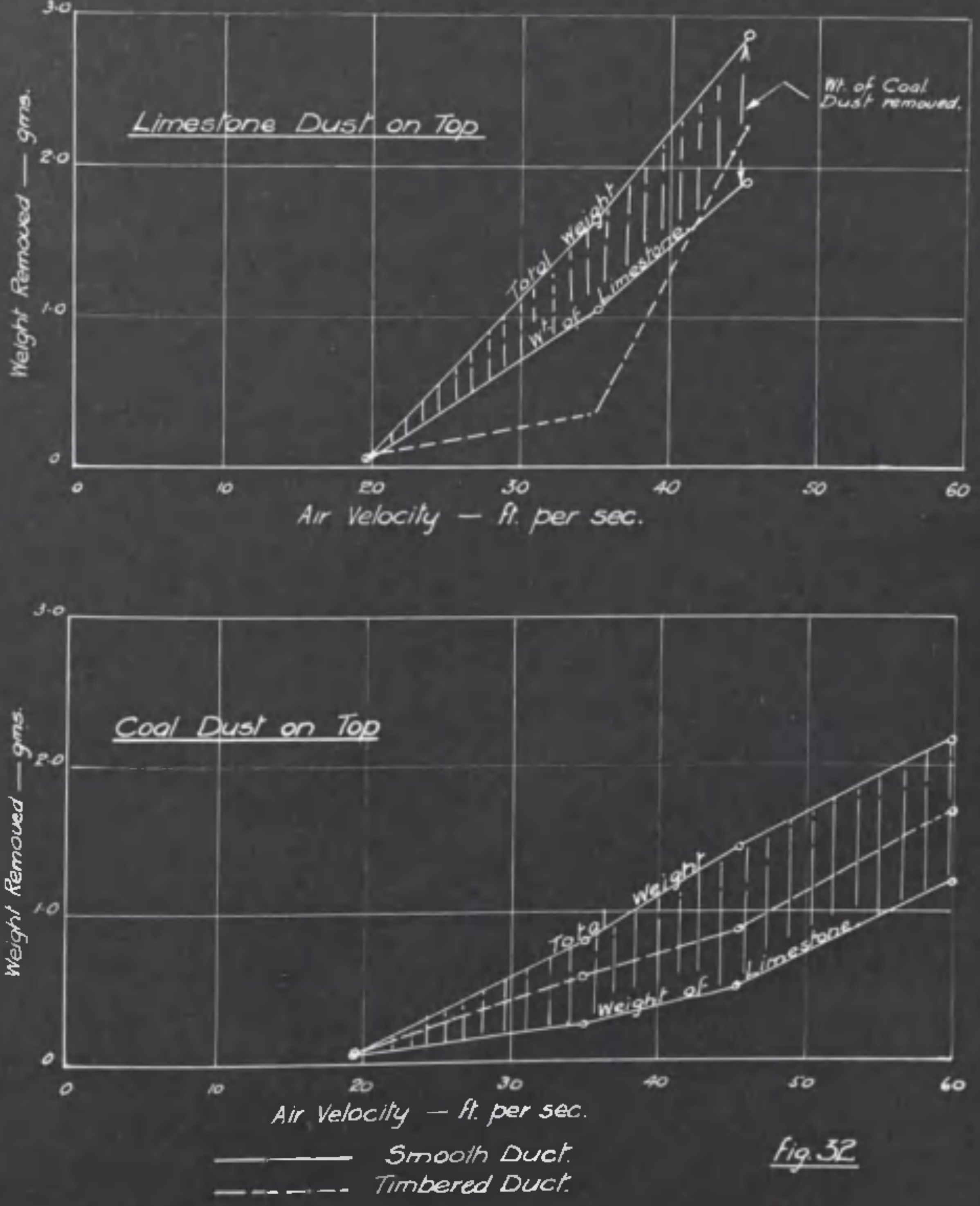
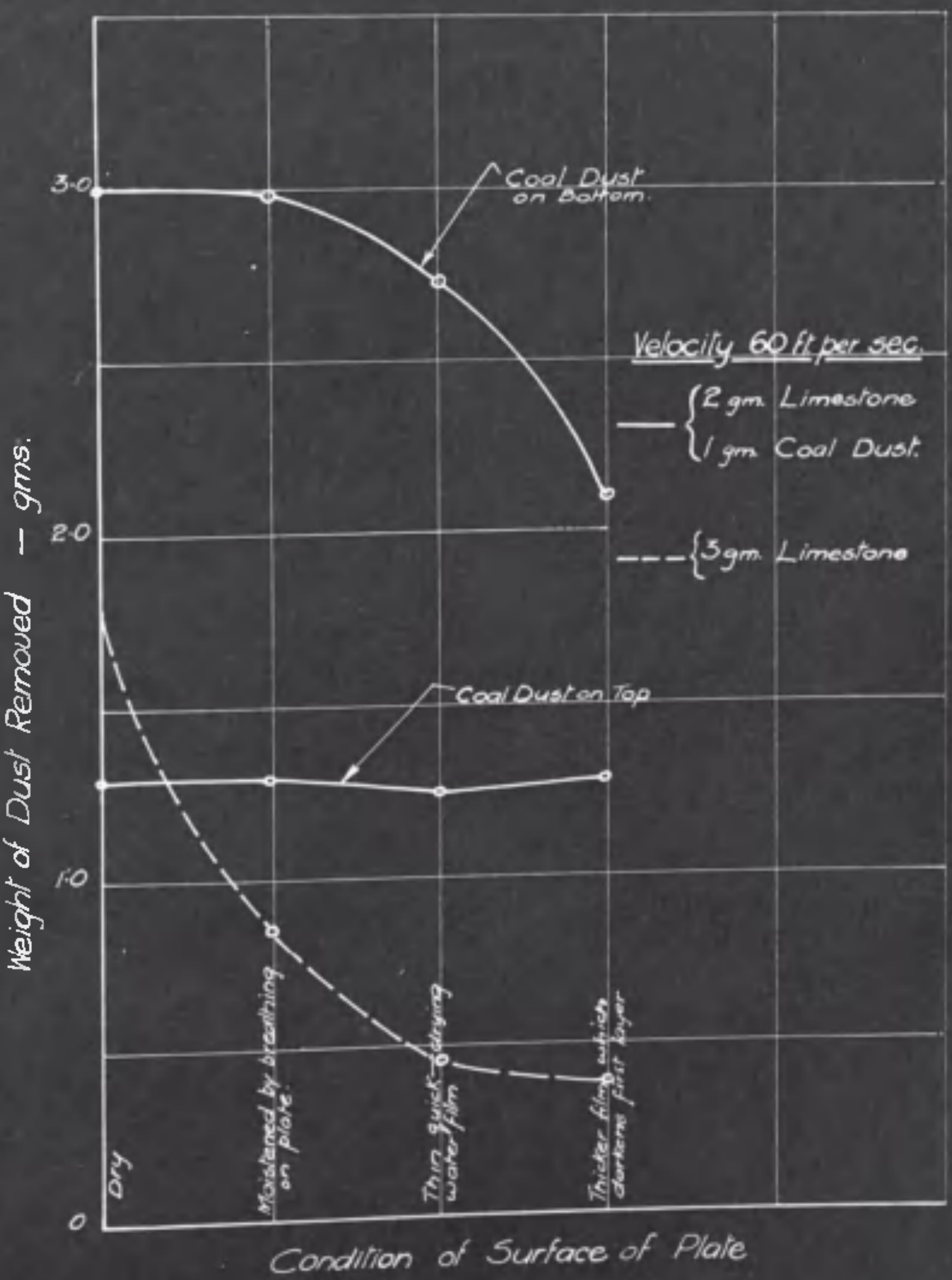

Limestone Dust on Top
Weight Removed — gms.
3·0
2·0
1·0
0
0
10
20
30
40
50
60
Air Velocity — ft. per sec.
Total weight
Wt. of Limestone
Wt. of Coal Dust removed.
Coal Dust on Top
Weight Removed — gms.
3·0
2·0
1·0
0
0
10
20
30
40
50
60
Air Velocity — ft. per sec.
Total Weight
Weight of Limestone
Smooth Duct.
Timbered Duct.

Fig. 32



Weight of Dust Removed — gms.
3·0
2·0
1·0
0
Coal Dust on Bottom.
Velocity 60 ft per sec.
2 gm. Limestone
1 gm. Coal Dust.
3 gm. Limestone
Coal Dust on Top
Dry
Moistened by breathing on plate.
Thin quick-drying water film
Thicker film which darkens first layer
Condition of Surface of Plate

fig. 33.

Discussion of Results. These tests show that the resistance which the dust offers to the air blast is most important. Coarse dusts offer more resistance with least surface adhesion and hence are most easily removed. Fine dusts tend to flatten out their irregularities and form a smooth surface offering little or no resistance to the moving force. Thickness of layer does not therefor greatly assist in increasing the amount removed. A definite quantity of dust will be removed at each velocity irrespective of the depth of the layer. It is meaningless,therefore, to state the velocity at which a dust can be removed without knowledge of its nature, fineness, depth of deposit and its position with regard to local air eddies.

The test velocities were always reached by a comparatively slow increase(compared with an explosion) and with absence of shock. At all times eddying of the air current and shocks assisted in a greater removal of dust.

Experimental workers on coal dust explosions record the slowest explosionas travelling at about I20m.p.h.,the more violent ones at300m.p.h. and the most violent one, according to the records of the timimg instruments, at about I300 m.p.h. There is little doubt,therefore, that dry,loose dusts would be easily raised by a very weak explosion and dispersed in the air by the pioneering wave. It may be that the top layers only are involved and that the flattening already alluded to may take place even in an explosion to some extent. If this is the case then the composition of the surface layers is of great importance.

In the case of a coal dust explosion initiated by means of a small firedamp explosion, the results show that coal dust could, if on top of the deposit, be raised in the initial low velocity stages without the stone dusts below being much disturbed. An explosion could therefore travel a greater distance before attaining sufficient violence to raise enough incombustible dust for its suppression. To ensure therefore that the incombustible dust will be as effective as possible in these circumstances, the amount deposited should be in thin layers offering a rough external surface and should, where possible,be underlain by coal dust.

As far as the condition of the surface of adhesion is concerned this should be dry. In a mine the strata may be damp and when the stone dust is applied(and possibly with some force) it will adhere most tenaciously. If sufficient moisture is on the surface or eventually comes to the surface, the stone dust at the contact will become caked and extremely difficult to remove. This prevents the dust from lifting off in patches at high velocities. Only the loose surface dust will be removed and,if affected also by moisture, its power of cloud formation will be reduced.

A layer of coal dust will prevent this deleterious effect of contact with wet strata to a certain extent and, since it also improves the contact in the dry condition, will assist in the greater removal of the stone dust.

PAPER 7.

EXPERIMENTS ON THE WETTING OF DUSTS

EXPERIMENTS ON THE WETTING OF MINE DUSTS.

Much importance has recently been given to the application of "wetting" solutions for the wetting and caking of the dust deposits in mine roadways to prevent the dispersion of dust into the air. As a means of eliminating discomfort in travelling dusty roads the method, in the few cases where it has been tried, has so far met with fair success. This treatment has been applied only to the floor dust on travelling roads, but has not yet been used in place of incombustible dust to render coal dust harmless. It may be that "wetting" will be more extensively adopted in the future, in the suppression of dust clouds by sprays or in the wetting of broken coal on the face, and may eventually replace the practice of stone dusting in places where wetting solutions can be applied for making coal dust non-dispersable.

In the laying and damping of dusts the phenomenon of wetting is of great importance. ~~Stone~~ Incombustible dusts are normally easily wetted by an ordinary water spray but coal dusts as a rule show an inherent aversion to wetting by water. General Regulations allow of the treatment of coal dusts by water alone in place of ~~stone~~ incombustible dust provided that "it is always combined throughout with 30 per cent. by weight of water in intimate mixture" -- a condition impossible to attain by spraying unless it is accompanied by a great deal of mechanical mixing. Consequently, where damping with water is practised on roadways, mixtures of ~~stone~~ incombustible and coal dusts are not uniformly wetted, the water being effective only with the ~~stone~~ incombustible dust. The use of water, therefore, for the average mine dust is not sufficient and other "wetting" solutions must be used.

The difficulty in wetting coal dusts has been overcome by the use of wetting agents, and particularly by the use of Perminal W, a wetting agent used in the textile industry.

In view of the possibility of a more extensive use of wetting agents in the future, the tests of this section were carried out to find the wetting characteristics of the dusts likely to be encountered in practice, using water and dilute solutions of Perminal W as wetting agents.

Experimental Work.

In experimental work on wetting agents carried out by the Safety in Mines Research Board at Buxton, the wettability of dusts and the wetting power of solutions have, up to the present, been judged by visual results or by the amount of solution required to bring dusts approximately to the same wetted condition. This method approaches very closely the practical treatment of dusts in the mine, but uniform and comparable results on the question of the wettability of dusts have been obtained in this research by other methods.

Tests with Water. As a preliminary experiment the relative ease of wetting of the various ~~stone~~ incombustible dusts was found. The results were obtained by measuring the rates of rise of water in similarly packed tubes of the dusts. This experiment and its results have already been described in Paper 2 (Fig.11). These curves do not give a true measure of the ease of wetting, as wetting in practice takes place from the top downwards. Furthermore, the dusts are not generally so much compressed as in the tubes. The curves of fig.II, however, show the relative rates at which water soaks up through the similarly packed dust columns.

To obtain some idea of the amount of liquid necessary to wet a dust and also to eliminate compression of the dusts, the apparatus shown inset in fig. 34 was adopted. A long capillary tube was supported in a level position and a Gooch crucible, with a filter paper on the grid, was arranged with the grid at water level in the larger vessel. A quantity of IO gms. of the dust under test deposited on the wet porous surface of the bottom of the crucible and the rate and amount of absorption noted by the movement of the liquid in the horizontal graduated tube. The curves (fig.34) for the most part show the same inter-relationship as in fig. II, with the exception of fullers earth, which, in this method is the most absorbent of all. Clogging of the columns and swelling and disintegration by water are assumed to account for the slow rate of wetting in the vertical tube method. In both experiments coal dust did not wet at all.

Mixtures of coal dust and the easily wetted Pixie powder were next tested and the results are shown in fig.35. Small percentages of coal dust did not notably increase the time of soaking,due to the relatively small coal surface. The time and difficulty in wetting increased considerably after 30 per cent. of coal dust was incorporated in the mixture. A slight increase in the quantity of liquid absorbed was also obtained and this is considered to be due to alteration in the bulk density of the mixture with the addition of the coal dust. With low coal proportions it was noted that the coal dust was in the form of

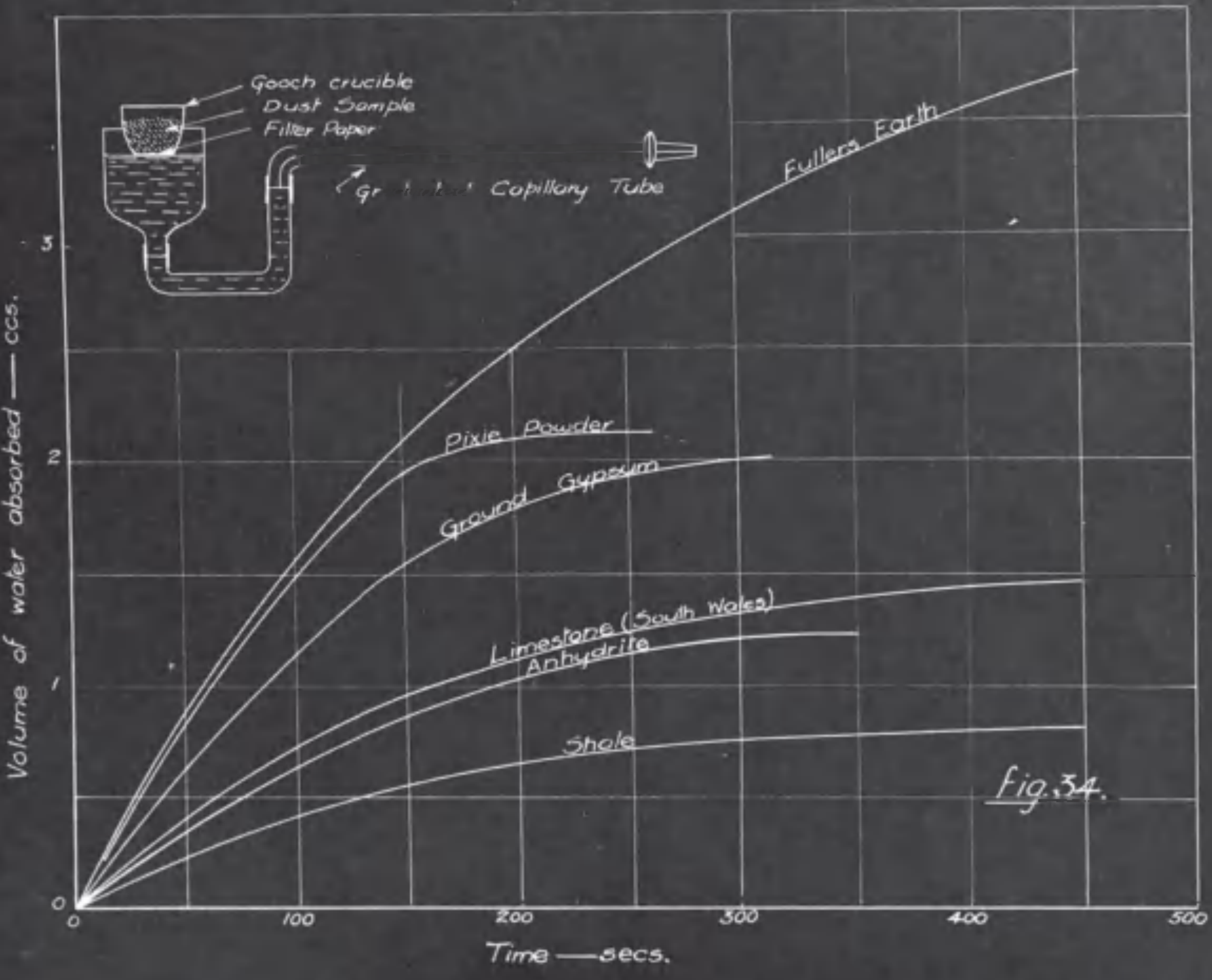

Gooch crucible
Dust Sample
Filter Paper
Graduated Capillary Tube
Fullers Earth
Pixie Powder
Ground Gypsum
Limestone (South Wales)
Anhydrite
Shale
Volume of water absorbed — ccs.
0
1
2
3
Time — secs.
0
100
200
300
400
500

Fig. 34.

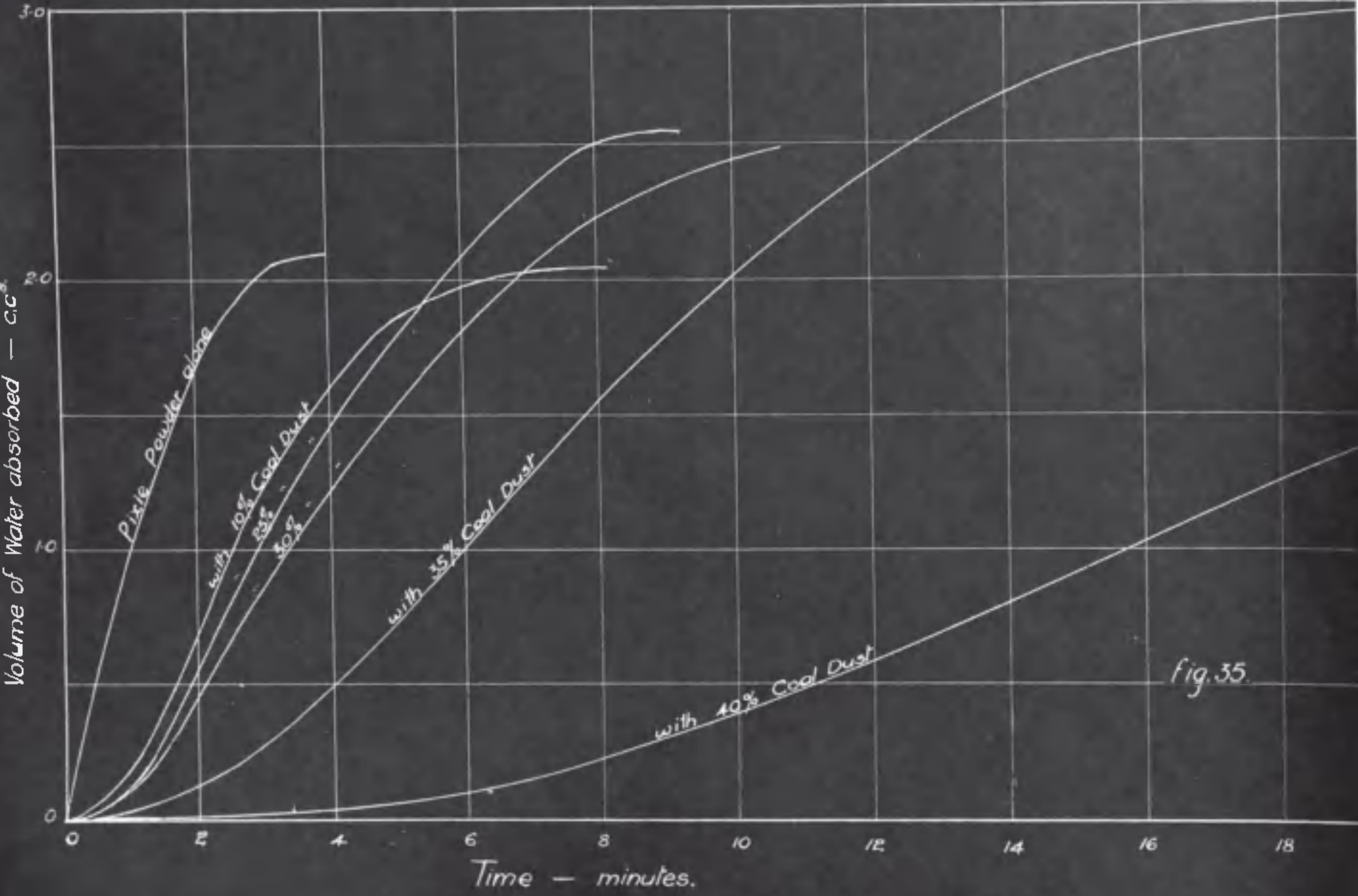

Volume of Water absorbed — c.c^s
3·0
2·0
1·0
0
0
2
4
6
8
10
12
14
16
18
Time — minutes.
Pixie Powder alone
with 10% Coal Dust
25%
30%
with 35% Coal Dust
with 40% Coal Dust

fig. 35.

bands after wetting, showing that it was carried upwards in stages on the surface of the ascending liquid. With high percentages of coal dust the same effect was not observed.

Tests with Perminal W

To assess the relative increase in rates of wetting with the use of a wetting agent, it was decided that a testing method employing downward percolation should be employed, since upward soaking is the reverse of wetting practice in the mine. At first, layers of the dust, uniformly compressed, were covered with a known weight of liquid in a suitable vessel and attempts were made to drain and siphon off the excess liquid after a known time, to obtain the amount absorbed by the dust in that time. With some of the dusts, however, due to the speed of soaking and the time error in pouring on and siphoning off the liquid, the general inaccuracy was too great. The following method of measuring the speed of wetting was therefore adopted. A quantity (5 gms.) of the dust to be tested was gently compressed under a load of 50 gms. in a Gooch crucible and a IO c.c. volume of the wetting agent introduced, with little or no disturbance, by means of a pipette. The time of soaking to the bottom was measured by using a 2-volt electric circuit and galvanometer. A "kick" was obtained when the liquid was continuous from the top of the dust to the connection in the base of the crucible(fig. 36). Repeated results were in very good agreement considering the slight differences in fineness and grading which is always present in the dusts. Tests proved that, with the compression load kept uniform, no liquid soaked down the sides of the crucible and that the whole of the mass was uniformly soaked when the circuit was established. No

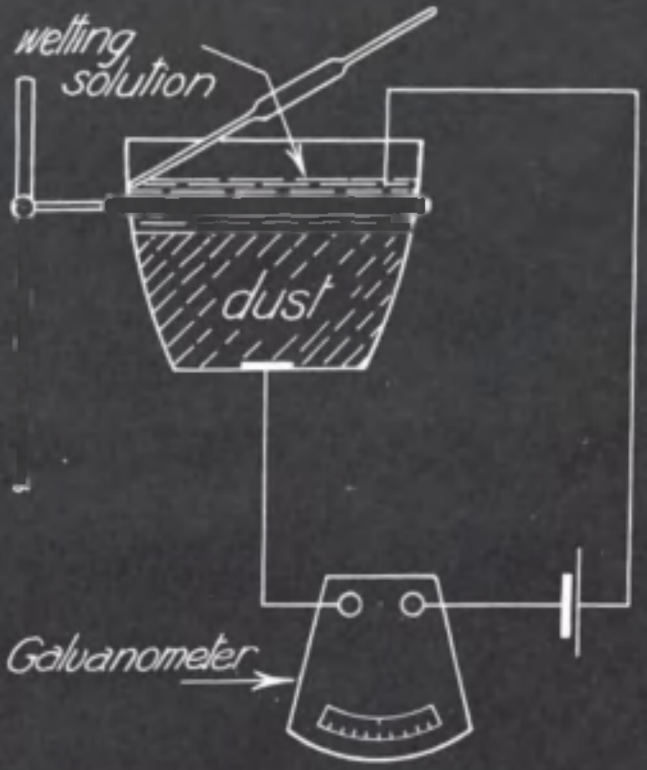


Fig. 36.

consistency was obtained when tests were made on the uncompressed dusts.

A comparison of the rates of soaking of water and Perminal W solutions are given in Table II.

TABLE II

Dust	Soaking time in seconds using					
		Perminal W solution				
	Water	I%	2%	3%	4%	5%
Shale	I02	93	82.5	72	78	84
Lime Pulp	62	64	64	58	64	65
Softener Product	85	83	88	83	87	86
Limestone	23.4	22.3	I5.7	26	24	26
Pixie Powder	I3.5	I4	I3	I3.6	I4	I4.2
Ground Gypsum	4	4.2	4	4.4	5..	4

These results again show that shale is the most difficult incombustible ~~stone~~ dust to wet and that, of the incombustible ~~stone~~ dusts used, it alone benefits by the addition of Perminal W. The other dusts are not assisted in their wetting by the use of Perminal W, but, on the contrary, their time of wetting is slightly increased. By reverting to the vertical tube method and substituting Perminal solutions for water this result was verified. Clogging of the mass by the colloidal matter of the wetting agent may be partly responsible for this effect.

The Wetting of Coal Dusts

This investigation did not include the trial of other wetting agents and the tests to be described were carried out with Perminal W only, as this has so far been accepted as the most effective solution for use in mines. Its wetting power depends, among other things, upon its complex organic constitution and its low surface tension. The effect of this reduced surface tension can be seen in figs. 37 and 38 which show a mass of coal dust wetted with 3 per cent. Perminal W solution, and a similar mass of the same dust when sprayed with an equal volume of water. The surface tension of the water causes large globules only to be formed and no wetting takes place. Figs. 39 and 40 are photomicrographs showing the effect of wetting a very thin film of coal dust on a slide with Perminal W and water respectively. The uniform spacing of the particles due to the low surface tension of the former and the coagulation due to the high surface tension of the latter are clearly seen.

Experiments of a preliminary nature were carried out with various concentrations of Perminal W in solution. The graded solutions were placed in vertical tubes and I/2 gm. samples of coal dust were placed on top of the liquids. The times for complete wetting and sinking into the solutions were noted and plotted against solution strength in fig.4I. A similarly shaped curve could also be obtained using the downward soaking apparatus of fig. 36. With this apparatus, using very weak Perminal W solutions, no matter how evenly the dusts were compressed, wetting became irregular and always took place either down the side or through a narrow channel. This limited action is attributed to the reduced strength of the solutions, on the hypothesis the active material is absorbed in the upper layers of dust. This absorption of active material has been shown recently by other investigators (I8) since this work was commenced. The absorption of the active wetting agent is shown by the curves of fig. 42, and was obtained by the continual addition of coal dust to the solution. For the two samples of

fig. 37.

fig. 38.

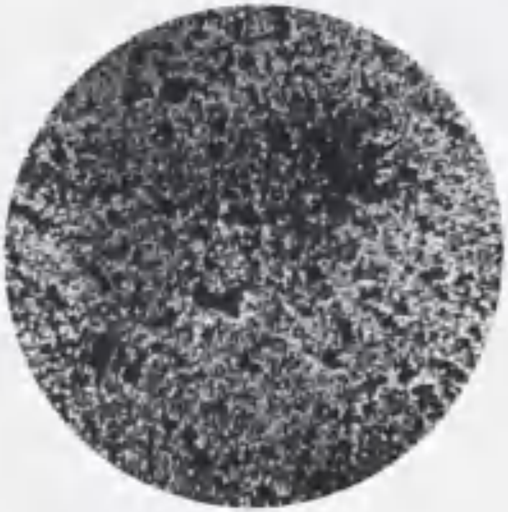


fig.39 x 40.

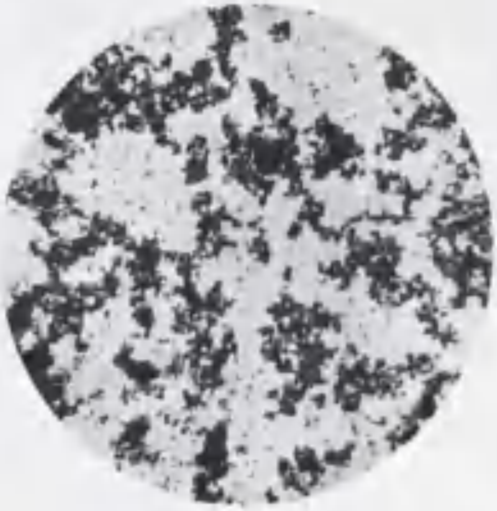


fig . 40 x 40.

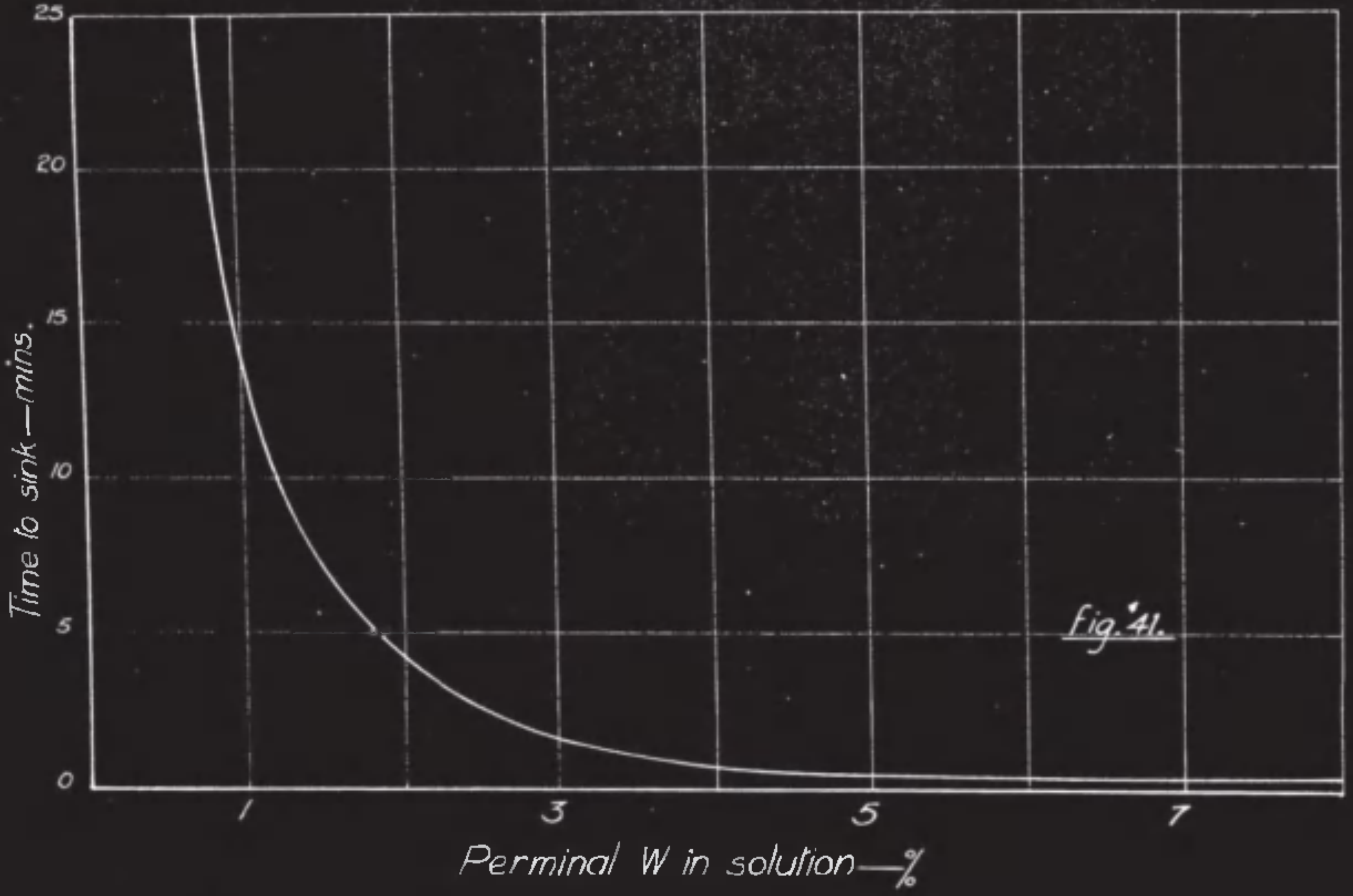


Fig. 41.

solution (30 c.c. and 50 c.c.), an amount of coal dust roughly equal in weight to that of the solution can be wetted in each case before the solution is appreciably weakened. This holds, of course, only for the strength of solution used(3 per cent.) with the particular coal dust in use.

As might be expected, fine coal dust is not so easily wetted as coarse dust. Using the apparatus already described, the curves of wetting for a series of sieved fractions of different coals were obtained. These are shown in fig.43. Two bituminous coals and a semi-anthracite were tested in this way and a decrease in wetting time was found with decrease in volatile content or increase in carbon content. This result is not in agreement with the work of Wheeler and Tideswell (I9) who state that for coals of equal fineness, the ease of wetting increases with decrease in carbon content. Microscopic examination of the sieved fractions, however, showed that, although the coals were crushed and sieved in the same manner, the amounts of adherent fine material differed greatly. Also, the characteristic shape of particle and the size distribution varied. It is considered that these factors may possibly have a larger bearing on the rate and ease of wetting than the nature of the coal substance as governed by carbon and volatile content.

The Binding of Coal Dust Deposits with Perminal W and Calcium Chloride

From time to time it has been suggested that the coal or other dusts could be layed or bound by some agent which would so bind or cake the dust that it would be incapable of dispersing in an explosion.

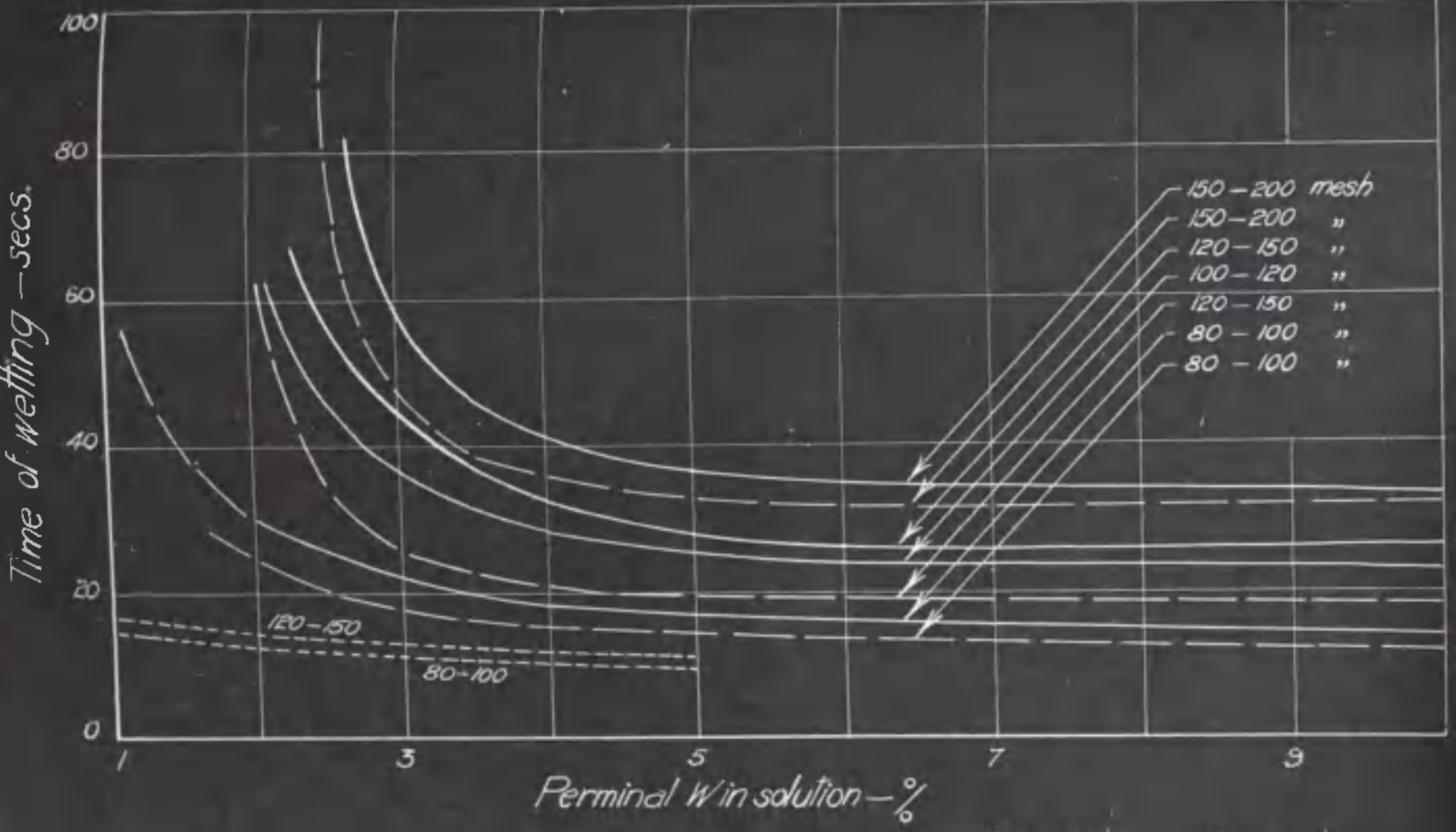


Fig. 43.

		Per cent Volatile Matter.	Per cent Fixed Carbon.
———	Bituminous Coal	43·74	54·70
— — —	Bituminous Coal	38·10	59·30
- - - -	Scotch Anthracite	13·50	83·52

The earliest attempts in this country were made with solutions of calcium chloride but these were eventually abandoned when the stone dust remedy was introduced and proved to be superior in the matter of making coal dust harmless. Laboratory and large scale tests with other wetting and binding agents were later conducted by Thornton (20), Briggs (2I) and others, but these tests seldom passed the experimental stage.

In connection with the laying of floor dust on travelling roads, recent practical tests on the treatment of such deposits have shown (22) that, by suitably wetting the dust with a wetting agent and by subsequent spraying with a solution of calcium chloride, the dust can be bound into a compact mass which cannot readily be degraded and dispersed.

Perminal W solution alone exerts a marked binding action compared with water, but the final condition of the mass, although fairly hard, is dry and the dust is dispersable when the cake surface is broken. The use of calcium chloride is necessary in certain proportions to keep the mass moist, and although the hardness of the deposit may suffer, the dust is rendered practically non-dispersable even when broken up. Calcium chloride in this way binds the dust.

In order to determine the influence of the calcium chloride on the caking of the dusts, a number of samples were sprayed with equal amounts of Perminal W (3 per cent.) solution and allowed to dry for one week. Thereafter the dusts were sprayed with equal volumes of different solutions of calcium chloride, giving each sample a different calcium chloride content. The relative rates of drying and the final moisture content were determined and the final "hardness" of the mass found by a simple drop penetration test. With increase in the calcium chloride content the ultimate moisture content was increased but the firmness of the deposit reduced. The samples were soft, definitely wet, and undoubtedly non-dispersable at moisture contents over IO percent. The excessive application of calcium chloride is thus to be avoided as the firmness of the mass is of some importance in practice, especially in the case of travelling roads.

Double Decomposition

In the discussion of a recent contribution(22) to the practice of wetting and laying dusts, the suggestion was made by Prof. E.K. Rideal that other solutions might be used after the calcium chloride treatment to cause precipitation of a salt or salts in the interstices of the dust mass, thus possibly decreasing its rate of drying out and binding it more firmly.

Although this will necessarily complicate any underground treatment and possibly the analysis of roadway dust samples also, its possibilities were examined on a small scale in the laboratory.

Dust samples, similar to those treated in the previous tests, were wetted by spraying with Perminal W solution in the same way and, after a week, were sprayed with calcium chloride solutions of various strengths. Solutions of Magnesium sulphate were then added when the calcium chloride had just soaked into the dust, and calcium sulphate was precipitated according to the equation -

$$CaCl_2 + MgSO_4 = CaSO_4 + MgCl_2$$

Magnesium sulphate was used in preference to sodium sulphate as

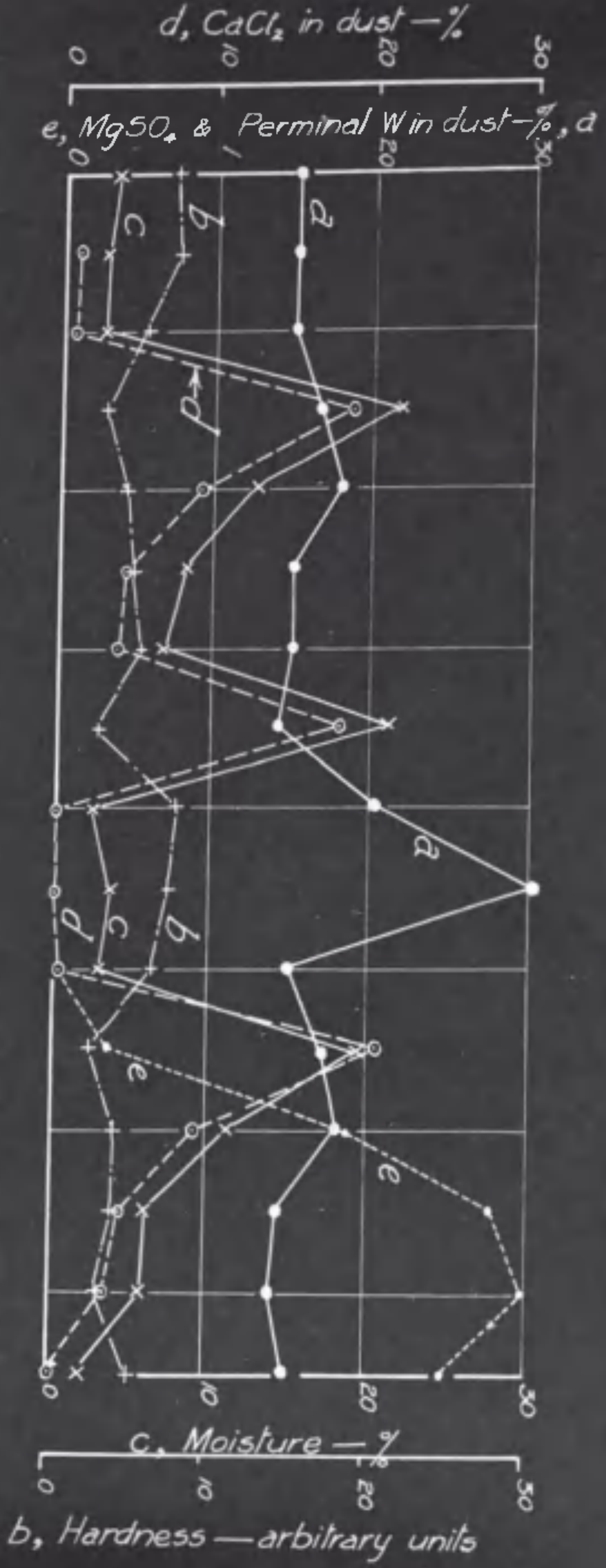

d, CaCl₂ in dust—%
0
10
20
30
e, MgSO₄ & Perminal W in dust—%, a
0
20
30
a
b
c
d
e
a
b
c
d
e
0
10
20
30
c, Moisture—%
0
10
20
30
b, Hardness—arbitrary units

fig. 44.

the magnesium chloride formed has the lowest vapour pressure of these hygroscopic salts and would tend to keep the dusts in a more moist condition.

Although calcium sulphate was precipitated in varying amounts, no decrease in the rate of drying of any dust sample was obtained. The precipitate appeared to be confined mainly to the surface of the dust and had no appreciable effect on either the ultimate moisture content or the hardness of the deposit.

The hardness, moisture content and the amount of the various substances present in the samples of the last tests are summarised in fig.44. Moisture contents are seen to be dependent on the percentage of calcium chloride present but are also influenced by the atmospheric temperature and humidity. The results given are those ultimately obtained at an average temperature of 63 degs. Fah. and relative humidity 67 per cent. It is apparent that the hardness or firmness of the bound mass is dependent mainly on the Perminal W content.

In the light of these results also it would appear that the precipitation of calcium sulphate in the dusts in the quantities tested offers no advantages comparable with the additional work and expense incurred by the extra spraying.

PAPER 8.

MINE DUSTS: THEIR EFFECT UPON ILLUMINATION

MINE DUSTS - THEIR EFFECT UPON ILLUMINATION.

The primary consideration affecting the choice of a suitable incombustible dust for use in mines are that (I) it should be efficient as a safeguard against the initiation or propagation of a coal dust explosion, and (2) it should not be injurious to health. These are determined mainly by such properties as the specific heat, specific gravity, moisture content, size and shape of particles, caking or balling properties, and the chemical composition of the dust. *An important secondary consideration is the probable effect of* the dust upon underground illumination. Attention has been drawn by those concerned with the problem of mine lighting and miners' nystagmus, to the beneficial effects to be derived from bright or white surfaces. Although the poor underground illumination in general is primarily due to the low candle powers of the lamps carried by the workmen, the effectiveness of these sources of light is greatly reduced by the absorption of light by rock, coal and coal dusty surfaces, by dust in suspension in the atmosphere, and the general lack of contrast.

The increased illumination to be derived from whitewashed or light-coloured surfaces by reason of increased reflection of incident light has long been recognised, and the Statute now requires the use of such aids, where practicable, in specified parts of the mine. A similar effect to that obtained by whitewash is acheived by treating the surfaces of the mine roadways with a white or light-coloured dust. It is surprising to find at many mines that, where the use of incombustible dust is required by law for the protection against the dangers of coal dust, dark-coloured dusts are still being used for that purpose, although light-coloured dusts, which compare very favourably with the darker dusts in price and effectiveness, are readily available.

Experimental A measure of the amount of incident light reflected from a surface is given by the 'reflection factor' for that surface. In order to show the variation in the amount of light reflected by incombustible dusts in common use, and by common mine strata, as well as the effects of treating these strata with different incombustible dusts and with coal dust, the following series of experiments were carried out.

To assess the amount of light reflected by different dusts, trays containing uniformly sprinkled layers of the dusts to be tested were used; and for the values of mine strata, slabs of each stratum were used. Each surface was matched against a standard white matt surface by means of a 'Luxometer' portable photometer, a convenient constant source of illumination being used. During the experiments the position of the photometer, light source and slabs or dust trays were kept constant throughout. The actual values of reflection factor obtained are thus only true for the condition of the test, and vary with alteration of position of either the test surface, light source or photometer. But under any given set of conditions the relative values of the different surfaces tested remain the same.

Relative Reflection Factors of Incombustible Dusts.

Table I2 gives the relative reflection factors,found by the method described, and serves as a guide to the relative efficiency of the various dusts in respect of their effect upon illumination when used underground.

The reflection factor for the standard white matt surface is taken as IOO.

TABLE I2

Dust	Reflection Factor.
Limestone Dust (South Wales)	63.5
" " (Lugton)	34.8
" " (Cults)	37.6
Ground Shale (Murton)	35.4
Softener Product	63.0
Lime Pulp (Darlington)	76.5
Pixie Powder	5I.5
Anhydrite	59.5
Ground Gypsum	70.0

Values for pure coal dust varied from 5 to 7.

These results show a wide variation in the reflection factors for dusts prepared from limestones quarried in different parts of the country, and demonstrates very clearly that a dust is not necessarily of a light colour because it is prepared from limestone -- a view that is not uncommon. The variation is due to differences in the composition and impurities in the limestone. Since this is a common feature in most deposits of limestone, even in the same quarry, it means that an appreciable variation in the reflection factor is to be expected in the dust obtained from one source: this detracts somewhat from the value of such dusts for use in mines from the viewpoint of underground illumination. For control purposes in dusting operations underground, there is a slight advantage in the use of a dust that is uniform in colour.

Relative Reflection Factors of Mine Strata

The strata associated with coal seams varies considerably in texture, composition and colour, but in general has a low reflection factor. This preponderance of dark, poorly reflecting strata is usually referred to as lack of contrast.

The reflecting power of various materials met with underground have been given by Atkinson and Allsop(23) and by Llewellyn(24) as follows:

	Material	Reflecting Power - per cent.
(23)	Coal	5
	Rough Timber	7 to 20
	Shale	20 to 25
	Whitewash	70
(24)	Clift	25
	Ironstone	22
	Fireclay	83
	Timber(covered with coal dust)	IO
	Whitewashed Post	50
	Bright Coal	4 to 7
	Dull Coal	2 to 3

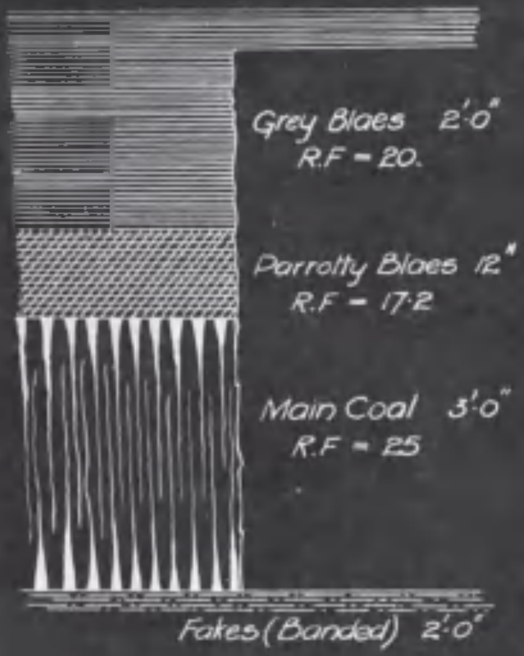
The values given were obtained from photometric tests underground.

Typical reflection values for the strata associated with two coal seams at a local colliery, as determined by the slab method already described, are shown in figs. 45 and 46. The theoretical average values of 22 per cent.and I9.I per cent. are very poor even for freshly exposed strata free from dust deposits. It is also evident that for one seam the reflection factor is even higher than that of its enclosing strata. As will be shown later, the amount of light reflected from these surfaces is still further reduced in practice by the addition of even a very thin layer of coal dust.

Effect upon Reflection Factor of Strata by the addition of DUSTS

To obtain a measure of the effect upon reflection of the addition of different dusts to the strata shown in figs.45 and 46, each rock slab was treated with successive layers of dust, a measured quantity being evenly sprinkled in each test.

(a) Effect of adding Coal Dust Table I3 gives the values of reflection factors obtained on adding successive layers of lightly



Average R.F. - 22

Fig. 45

Average R.F - 19·10.

Fig. 46.

TABLE 15

Strata under Test.	Relative Reflection Factors of the Diffent Surfaces.						
	With Clean Surface	Test (a) With Deposits of Coal Dust weighing		Test (b) With Layers of Lugton Limestone Dust (superimposed upon (a)) weighing			
		1·75 gms. per sq. ft.	3·435 gms. per sq. ft.	0.866 gm per sq. ft.	1.57 gm. per sq. ft.	3.40 gm. per sq. ft.	4.875 gms. per sq. ft.
Grey Blaes	20	9·85	7·4	15	21	27·5	35·5
Soft Black Blaes	15·75	13·10	6·96	12·5	25·5	33·5	35
Parrotty Blaes	17·20	11·9	7·4	15	25	32	35
Fakes.	18·75	8·62	7·4	15	22·5	29	32
Coking Coal	20	13·13	7	15·5	23·5	28·5	33·5
Main Coal	25	9·05	7·5	21·5	23	26·5	28·5
Bo[illegible] Fakes	14·8	11·71	7·4	13·5	26·5	28	36
Sandstone Band	33·6	12·3	9·05	15·5	24	35	35

and evenly sprinkled coal dust. The decrease in reflection factor after the addition of the first thin layer is very marked and varied from I7 per cent. for the soft black blaes to 63 per cent. for the sandstone band. From actual tests carried out at collieries the weight of dust used per square foot of surface in the test is often reached by deposition during the nosmal course of working in the region of conveyor loading stations in the course of a day or two. In dusty mines, therefore, reflection factors are rapidly reduced during the normal course of working. The results also show clearly that the lighter coloured strata are more adversely affected, due, of course, to the greater contrast afforded. The deposition of 3.435 gms. per sq. ft. is sufficient to reduce reflection to a minimum, that is, to the reflection factor for a pure coal dust surface. The irregularities in the surface of the rock slabs under test, and the difficulty of ensuring absolute uniformity in the dust layer, account for the small discrepancies in the values obtained. The sandstone slab had the most irregular surface.

(b) Effect of super-imposing successive layers of Limestone dust upon the layers of coal dust

The effect upon the reflection factor of super-imposing layers of limestone(Lugton) dust upon the existing layers of coal dust is also given in Table I3. It will be seen that the values obtained after the addition of the second layer are, for all practical purposes, the same as that for the limestone dust alone. In other words, the addition of 4.875 gms. per sq.ft. is sufficient to raise the reflection factor to the maximum possible value using limestone dust. In a roadway IO ft. by 8 ft., this quantity of dust is equivalent to the addition of 6 oz. per foot run. This amount would be insufficient in practice, however, due to the impossibility of spreading the dust evenly on the rough, exposed surfaces.

Photometric measurements made underground have shown that the illumination of underground roadways can be improved to the extent of I00 - 400 per cent. by an application of light-coloured dust. Figs. I6 - I9 of the First Report of the Miners' Nystagmus Committee(25) show this improvement most effectively.

Conclusions

This investigation shows that:-

(I) The reflection factors of incombustible dusts in common use in mines vary considerably, even for dusts with very small differences in composition.

(2) The reflection factors for ordinary mine strata are very low.

(3) The reflecting power of rock surfaces can be appreciably raised by the application of a dust with a high reflection factor, thus effecting a considerable increase in the underground illumination.

(4) Reflection factors are quickly reduced by the deposition of coal dust during the normal course of working.

(5) The whiter the dust the more quickly is its reflection factor reduced by the deposition of coal dust.

The reflection factor should, therefore, receive very careful consideration by all who are called upon to choose an incombustible dust for use in mines. Other things being equal, the dust with the highest reflection factor should be chosen. Even if the cost of such a dust is a little higher, the extra cost involved is likely to be justified by the many additional advantages to be derived from increased illumination. After all, the incombustible dust used in coal mines, although primarily provided in compliance with the Statute as a safeguard against coal dust explosions is, fortunately, seldom called upon to act in this capacity. But all the time these dusts are lying in a mine roadway, they continually function as reflectors (or absorbers) of incident light. Steps should be taken to see that they give the maximum reflection possible by using only materials with high reflection factors.

In order to maintain a high value of reflection, the incombustible dusts should be applied in small quantities at frequent intervals and not, as is often the case at present, in large quantities at long intervals.

PAPER 9

THE DETERMINATION OF DUST CONCENTRATION IN THE ATMOSPHERES OF COAL MINES

THE MEASUREMENT OF DUST CONCENTRATION IN MINE AIR

Deposited coal dust is at all times a potential danger from the explosion point of view, but when in suspension in the atmospheres of mines it gives rise to other dangerous conditions. Its physiological effect on underground workmen is of great importance. Although it is stated that coal dust is relatively harmless, its inhalation in large quantities over long periods cannot be without harmful results.

Modern methods of mining are prolific coal dust producers. With the increasing adoption of coal-cutting machinery, loaders and conveyors,the amount of dust produced and disseminated is, in many cases, worthy of serious attention. Both from the point of view of safety from explosion and physiological hazard,it is desirable to keep the concentration of coal dust in the air as low as possible.

To assess accurately the relative dustiness of mine atmospheres and to check methods of dust control generally, a reliable and accurate measuring technique is essential. This investigation has,consequently, been carried out with the following objects in view:-

(I) To review the dust sampling equipment now available and compare the methods of sampling most suitable for general control work in coal mines.

(2) The determination of the concentration of dust in the air in different parts of the mine and with different mining operations in progress.

Dusts and their Properties

Research studies on colloids and fine particles of matter generally have shown that striking physical and chemical changes often take place when a substance is finely divided. It is due to these changes that the problems of collection and estimation of dusts and of their settlement and wetting are rendered so difficult.

Dust in its simplest sense may be said to be that fine, solid matter found floating or in suspension in the air at any time. The size of dust therefore varies with the nature of the material and the velocity of the air current, a high air velocity being capable of raising and holding in suspension comparatively large and heavy particles.

According to Blacktin (26), " dust may be emperically defined as a powdered, finely divided form of homogeneous or heterogeneous solid substances, mixed with or without any due regard to, or any immediate knowledge of particle size, difference of limits, proportionality, or condition amongst its parts". This rather wide classification does not imply air-borne dust and gives no limit or idea as to the maximum size of solid particle still to be classed as dust. Gibbs (27) classifies the sizes of suspended solid material as follows:-

(I) Dusts Particles greater than IO microns which settle out with increasing velocity.

(2) Clouds Particles 0.I to I micron which settle with uniform velocity according to Stoke's Law.

(3) Smokes Particles 0.00I to 0.I micron which do not settle in air.

Here again no upper size limit for the general term dust is implied.

This classification is based on the rate of fall of the different sizes and this in turn is governed by the air-resistance of the particles. Gibbs (27) gives the rates at which spherical particles of unit density will settle in still air as follows:-

Diameter of Particle in cms.	Rate of Settling cms./sec.
10^{-2}	30
10^{-3}	0.3
10^{-4}	0.003
10^{-5}	0.00003

From tests carried out with various sampling instruments, the largest particles found floating in mine air had greatest dimensions of 150 microns or thereby. Such particles were only found, however, in the vicinity of their point of origin as they settle very quickly.

The air-resistance of very small particles consists of the bombardments of air molecules. When the particle is fairly heavy and large these external forces can be considered as uniform, but when the particle is very small, these external bombardments greatly affect it and drive it about in Brownian movement. This explains the slow rate of settlement of clouds and smokes. As the size of the particle diminishes, the force impelling it downwards diminishes at a greater rate than the exposed surface. This accounts for the extreme "buoyancy" of substances which are normally two or three thousand times as heavy as the air they float in.

Disperse systems of solids and gases are termed 'aerosols' and these systems show well-defined and peculiar properties. Scientists have shown for example that aerosols, like hydrosols, depend for their stability on the relation or otherwise between the charges of the individual particles. Particles bearing the same electrical charge are mutually repellant and have no tendency to 'flock' or coalesce through attraction to each other. The properties of stability and large exposed surface per unit mass are two very important properties of very fine dusts when dispersed as aerosols, and account for much of the difficulty and danger associated with such systems.

Another property of a finely divided solid is that of its capacity for adsorbed gas. Each fine dust particle adsorbs on its surface a layer of gas, of thickness depending on the size of particle and its chemical activity. These adsorbed gas layers are difficult to displace and account for the difficulty in wetting very fine dust particles.

Increased chemical activity and increased solubility are also notable features of fine dusts and are entirely dependent on the increased surface exposed.

It is thus apparent that the finer the dust, whatever the kind, the more difficult will it be to deal with. The finest dust also is the most dangerous from the physiological point of view, dust less than IO microns and particularly that below 5 microns being the size which finds its way to the inner recesses of the lungs.

The problem of the estimation of dustiness and proper dust control is rendered difficult by the fact that particles of the size mentioned are almost invisible to the naked eye. Our ordinary conceptions of dustiness are based on the larger, visible particles.

The Measurement of Dust Concentration

From the earliest dust studies, the problem of an efficient and reliable dust sampling method has always been difficult and it is only comparatively recently that satisfactory methods can be said to have been found. Generally speaking, the estimation of suspended dust constitutes two distinct requirements, viz:-

(I) Extraction of a representative sample of the dust from the air.

(2) Weighing, counting or otherwise assessing the amount, nature, and size of the particles present in the sample taken.

Historical

The earlier sampling methods were naturally on the gravimetric principle, a known weight or volume of air being drawn through a convenient filtering medium. Probably the earliest dust collectors were the cotton wool filters. A certain amount of the suspended dust was caught, but not all of it, due tothe nature of the filtering medium. The sample and its weight having been obtained, examination of the whole deposit could only be made after destruction of the filter. This was the great objection to the use of this medium, since by destroying the filter by incineration, all combustible substances were destroyed. If a liquid medium was used to separate the dust, particles soluble in the liquid were lost.

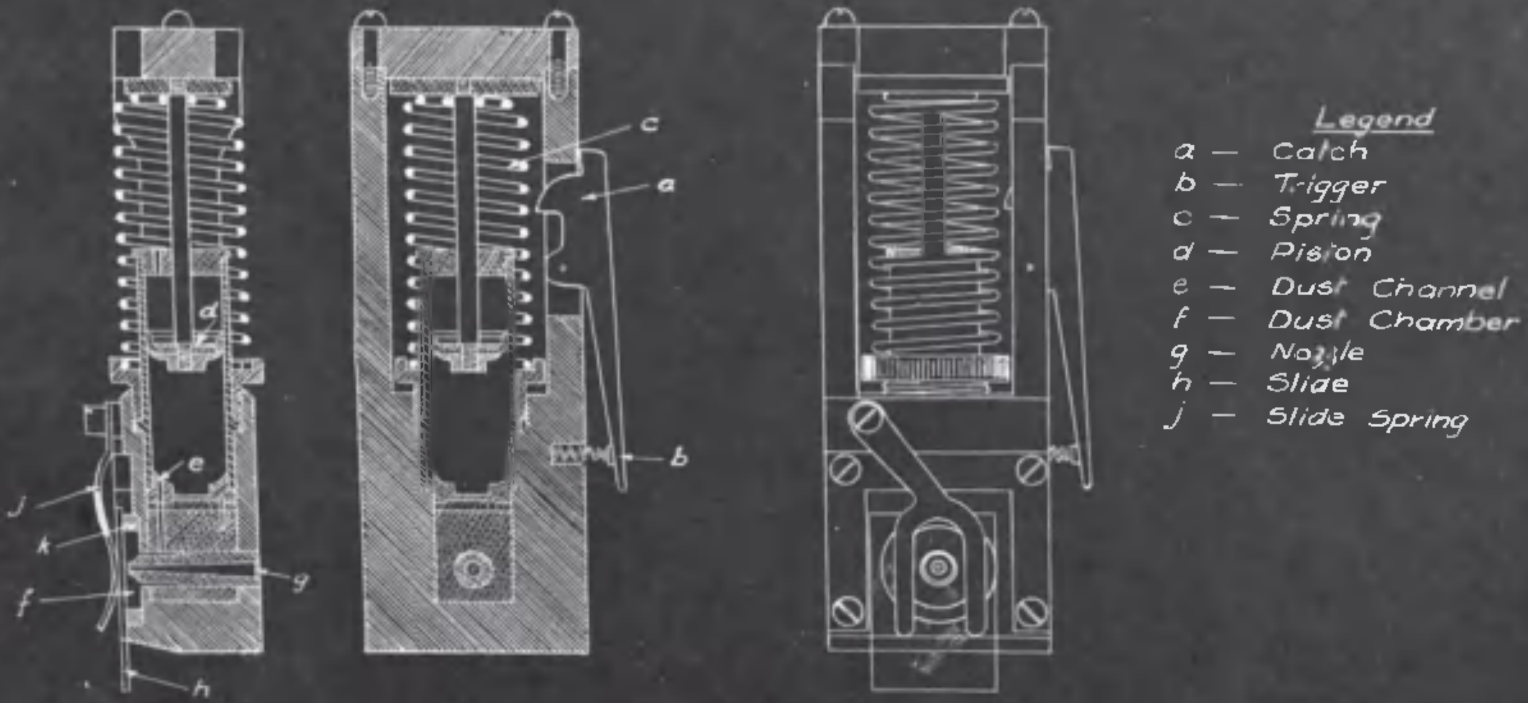
As an improvement on the cotton wool filters, the sugar-tube filter was developed and became quite popular. In I9II-I2, experimental work was carried out by the Consolidated Goldfields Ltd., of South Africa when the sugar-tube filter was used for the first time. The same principle was observed in this method of sampling, a known volume of air being pumped through a tube of closely packed sugar granules. On dissolving the sugar in water, the insoluble dust was obtained. All water soluble particles, however, were lost. Any particles of colloidal size were lost in filtering as no special filters were employed.

For a really efficient method of sampling,these gravimetric methods did not suffice and both possessed the disadvantage that the finest dust was either missed in sampling or lost in the subsequent treatment.

This unsatisfactory state of the technique of dust sampling led to the development of other methods. In this connection the research work done in South Africa, where the need was greatest, did much to advance the standards in methods of dust sampling. It was there that the konimeter was developed and, although many improvements and changes have been made since then, the konimeter still holds a place among the more modern dust sampling instruments.

The konimeter principle was first suggested in I9I6-I7 by Sir. Robert Kotzé, the South African Government mining engineer. The method consisted essentially of projecting a small volume of air at high velocity on to a glass plate, generally coated with adhesive.The dust in the air was caught on this sticky medium and formed a ' spot '. This spot could be examined microscopically and the number and size of the particles counted. The action of the Kotzé konimeter (fig. 47) is, briefly, as follows:-

When released from its position at the foot of the chamber, the piston *d* sucks in air through channel *e*, the chamber *f* and the nozzle *g*. The nozzle is 0.8 mm. at the narrow end and has a smooth bore. Air, leaving the nozzle end at high velocity, impinges on the



Kotzé Konimeter

Fig. 47.

greased slide h placed 0.5 mm. away from the nozzle end. The slide is held in position and forms an airtight joint by means of the spring j. It can be moved about at will to accomodate several rows of 'spots'.

In I923 Kotzé designed a new konimeter (fig. 48). The principle he adopted was that of the hydro-konimeter and departed altogether from greased plate impingement. This instrument consisted of an exhaust hand pump a,of about 500c.c. capacity, connected by tubing to a corked glass container into which was put 2 c.c. of water. On pumping, a stream of air was drawn down the impinger tube and struck the baffle plate under water. The action of the air jet on this baffle plate caused the dust to be washed off into the tube. To determine the dust content of the air a small cell was used, I or 2 mm. deep and I/4 inch diameter,made from brass tubing. A drop of the solution was poured into the cell, the latter covered with a cover slip, and the dust particles allowed to settle out on the micro-slide below and later counted with the aid of a microscope and graticule.

Dr. Owens also designed a konimeter in which he dispensed with the adhesive substance on the slide plate. In his instrument (fig. 49) the dust adhered to an ungreased slide. The moisture formed with the expansion of the air leaving the jet was sufficient to cause the dust particles to adhere. Moist air, however, was necessary. The air to be sampled was first of all passed through the humidifying chamber where it was saturated with moisture by contact with the wet blotting paper fixed round the inside of the chamber. As the air passed through the jet A , the fall of pressure caused

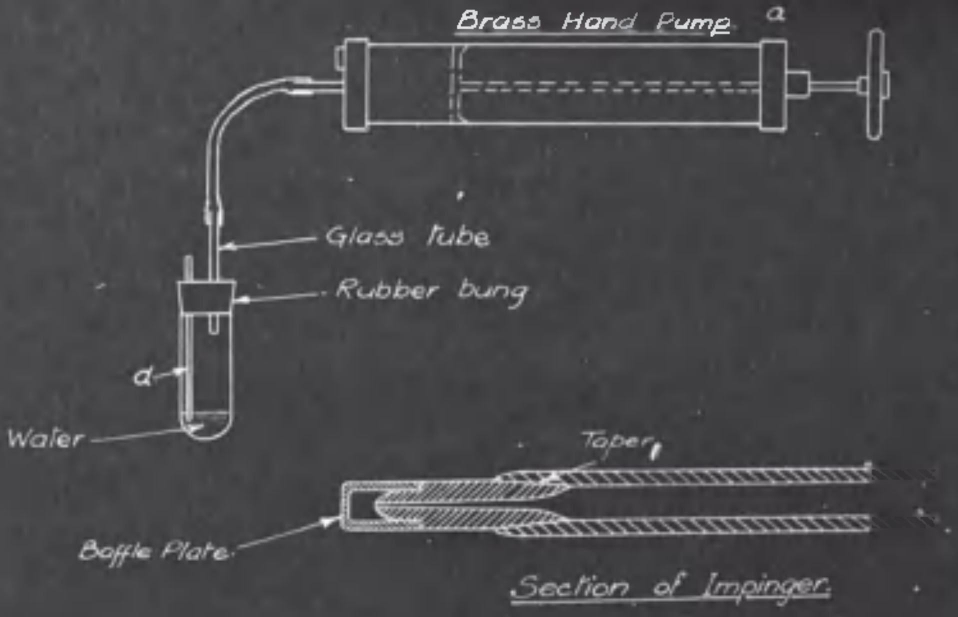

Brass Hand Pump
a
Glass tube
Rubber bung
d
Water
Taper
Baffle Plate
Section of Impinger.

Fig. 48.

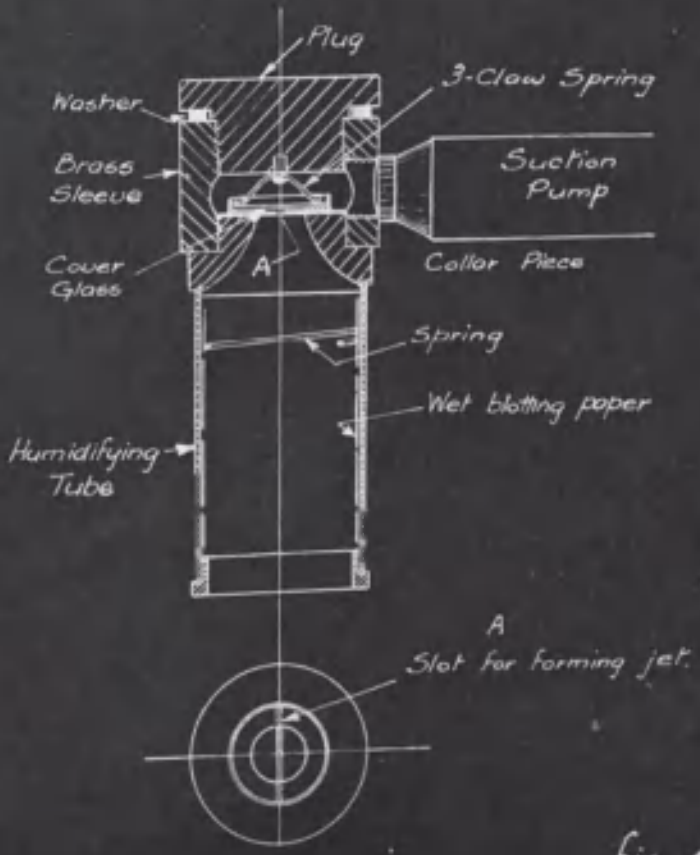

Plug
3-Claw Spring
Washer
Brass Sleeve
Suction Pump
Cover Glass
A
Collar Piece
Spring
Wet blotting paper
Humidifying Tube
A
Slot for forming jet.

Fig. 49.

condensation of moisture and the dust and moisture were deposited in a ribbon-shaped line on the slide placed I mm. above the jet nozzle. When the moisture disappeared the dust particles were counted microscopically. Owens found that , on samples taken simultaneously in the same air, the Kotzé konimeter only gave a count of 5 per cent. of the particles obtained by his dust recorder.

Modern Dust Sampling Methods and Instruments

The general problem of the estimation and sampling of air-borne dust has received great impetus recently and has resulted in a very marked improvement in existing types and in the development of some entirely new dust sampling principles. The necessity for complete trapping of the very finest particles has been realised and has resulted in many refinements in practically all methods.

At present, the methods available and in use for the estimation of dust in air fall into three distinct groups, viz:

Group I In which a known volume of air either deposits or impinges its dust on a slide, thus enabling the number and size frequency of the particles present to be estimated under the microscope and the concentration to be expressed as a number of particles per c.c. of air.

Group 2 Where the dust is extracted from a known volume of air in weighable quantity by some type of filter, enabling the concentration to be expressed as a weight of dust per unit volume of air

Group 3 Comprising methods which give only simple density comparisons but which do not, as a rule, yield any definite values of dust concentration, either by weight or particle counts.

The instruments of the first group comprise konimeters of practically all types, sedimentation cells and thermal precipitators.

The underlying principle of konimetry has already been outlined.

With sedimentation cells a volume of air is entrapped by simultaneously closing the ends of the cell, and the dust in this volume allowed to settle out on cover slips in the bottom of the cell. The great disadvantage of the method is the length of time (4 - 6 hrs.) the cell must be set aside to allow the finest dust to settle out completely. Being both cheap and portable as well as efficient, the instrument is limited by its capacity and by the time necessary to obtain complete settlement of all the dust. There can be no doubt as to its efficiency, as no air stream is used and no nozzle effects or any question of breakage of particles on impingement on a slide are introduced. As a means of checking other instruments or providing an absolute standard of measurement,it is as efficient as other more expensive apparatus.

The principle of thermal precipitation was recently incorporated in an instrument designed by Green and Watson and is described in great detail elsewhere.(28) The dust, in this instrument, is precipitated by means of a hot platinum wire and the record takes the form of a narrow strip on a cover slip. This strip can be examined microscopically and the particles sized and counted. For work in coal mines where, as a general rule, the air currents are moderately brisk, the precipitator is very slow: sampling only at the rate of 6.5 c.c. per minute it is of little use for snap-sampling in quickly varying concentrations. For the measurement of low or dense concentrations which persist over long periods, however, its results cannot be surpassed by other methods. Lack of portability, the time taken to obtain a reasonable sample and the succeeding microscope technique make the instrument none too attractive for ordinary control purposes in coal mines.

Filtering methods constitute a separate group, as the dust is expressed as a weight per unit volume of air instead of a particle count. The great advantage of the method is that, if desired, a sample can be obtained which can be micro-chemically analysed and the proportions of the constituents found. Size-frequency determinations can also be made on slides prepared from the filter samples.

The earlier cotton wool and sugar-tube filters have already been referred to and their main drawbacks outlined. Potassium nitrate, as a soluble filtering medium, has nevertheless been used recently(29) with some success.

Research workers on the subject of dust collection have realised the necessity of obtaining the dust free from extraneous material from the filtering medium and unaffected chemically or physically, either by solution or excessive heat. The natural alternative to the use of solid filters requiring incineration and soluble filters is the use of volatile solid filters. Much work has been done recently in the development of such filters. The development of these filters is due to Matthews and Briscoe(30) who produced satisfactory filters of anthracene, naphthalene and benzoic acid. Briefly, their filters consisted of a pad of the substance, formed either by pressure or by recrystallisation from a sludge. Efficiencies as high as 99.6 per cent. for benzoic acid and 99.3 per cent. for naphthalene were obtained. Work on this subject is still proceeding and recently a still more suitable substance - salycilic acid - has been given prominence.

Work on volatile solid filters generally has shown that their efficiency is remarkably high and that, on subliming the filter pad to obtain the sample, no dust is removed.

Methods of the third group, involving density measurements are very few and can still be said to be in the experimental stage. For certain control purposes, however, they may ultimately find a useful field.

The "Arkon Kapnograph" is a typical instrument of this type, the dusty air being continually projected on a moving, greased film. The depth or density of the trace on the film is the only criterion of dustiness.

A more recent innovation is the Tyndallometer, an instrument based on the Tyndall effect in optics. The refraction caused by the particles in suspension in a beam of light gives the measure of the dust concentration. It is thus only comparative and up to the present has not been the subject of any practical trials.

Comparison of the KONIMETER and VOLATILE FILTER PAD Methods of Measuring Air Dustiness in Coal Mines.

Little or no work has been done in connection with the measurement of dense dust concentrations caused by the normal working operations of a coal mine, or in regard to the relative usefulness and limitations of different methods of dust sampling in this work.

Since sedimentation cells do not satisfy the practical requirements of a routine testing method and the thermal precipitator was not fully developed at this stage, it was decided to investigate and compare the application of the konimeter and the volatile solid filter to the problem of dust sampling in coal mines.

Tests with the Konimeter At the outset a number of preliminary tests were made and a number of 'spots' obtained in mine atmospheres of varying dust concentration.

Instrument The instrument used was a Zeiss No.I Pattern konimeter (fig.50), reckoned to be the most reliable of instruments of the konimeter class. In principle it is similar to the Kotze and consists of a small spring-controlled plunger pump, a fine nozzle and a greased slide plate: it has, in addition, a microscope for the examination of the spots.

By releasing the plunger, a sample of 5 c.c. or 2.5 c.c. can be drawn in and impinged on the circular glass slide plate, coated with adhesive. The dust adhering to the slide plate constitutes a spot of which the plate is capable of holding 30. These can be examined under the microscope by rotation of the slide plate.

fig. 50.

The microscope has a magnification of 200 and can be fitted with a condensing lens for working with dark-field illumination.

Method of Counting Spots Counting of particles is effected by means of the squared graticule or the symmetrical sectors provided on the microscope diaphragm: these lines also aid in the estimation of particle size.

Sector counting is the method usually adopted. By counting the particles in the two sectors, each subtending an angle of I8 degrees, the concentration is calculated thus:

$$\text{No. of Particles per c.c.} = \frac{\text{Count of two sectors} \times \text{IO}}{\text{Volume of sample in c.c.}}$$

The lines of the graticule form squares of I mm. side and the smaller parallel strip along the sector (0.05 mm.) is also provided to help in size measurement. Since the eyepiece has a magnification of IO, all particles as measured by comparison with the graticule lines are IO times their actual size.

To make the counting and measurement of the particles less laborious and more accurate, a greater magnification than that afforded by the microscope alone was adopted. A point-o-lite beam was projected through the konimeter microscope and the spot thrown upon a ground glass or translucent paper screen about 2 feet distant. The visible particles were then counted from the reverse side of the screen.

It became early evident that, in the counting of the particles, there was a liability to serious error, both in respect of the actual counting process itself and in the estimation of the total number of particles present. The general distribution of the dust in the spot is important in this respect, as may be seen from the few typical results given in Table I4. These were obtained from three methods of estimation, viz:-

(I) By a complete count of all visible particles in the dust spot.

(2) By a count of the particles in two sectors only.

(3) By the 'average square' method.

The last method consisted of counting the number of particles in one of the central squares and multiplying the result by the number of squares covered by the more or less uniformly dense area of the spot. This was generally found to be about 20 for the spots examined, taken with this particular instrument.

TABLE I4

Showing variation in Concentration Values with different methods of counting (5 c.c. samples)

No. of Spot	Absolute Total Count	Double Sector Count	Estimated Total Count (by sectors)	Count of Particles in Average Square	Estimated Total Count by Ave. Square Method.
I	I04	6	60	8	I60
2	I857	258	2580	III	2220
3	569	47	470	33	660
4	392	86	860	27	540
5	I3I8	II6	II60	58	II00
6	965	207	2070	46	920

Reference to the table shows that great discrepancies exist in the figures obtained by the three methods. The 'average square' method gives a result more closely to related to the complete count than does the sector method, probably because the average square method is not so much affected by the eccentricity of deposition of the dust spot. The inconsistency revealed, however, rather shakes the faith in results obtained by any method of counting other than a complete sount of the whole spot.

Other difficulties in counting were also experienced. Many of the smaller particles, of largest dimension about 2 - 3 microns, become embedded in parts of the adhesive film and cannot be seen, while others are obscured by the larger particles. How many fine particles are missed in this way is a matter for conjecture. For the smaller visible particles also, continual focussing is necessary since all sizes are not in focus at one time, and a count with the larger particles in proper focus misses a large proportion of the smaller ones.

Moreover, the number of particles that can be estimated per c.c. is variable, depending upon the average size of the particles, the evenness of their distribution , and the volume of the sample. With a uniformly dense spot from 2.5 c.c. of air it has been possible to obtain counts up to I200 particles per c.c. and this can be taken as about the maximum count possible with a uniformly distributed spot. With this concentration in any volume in excess of 2.5 c.c. the spot becomes uncountable: but a badly distributed spot, giving complete blackness towards the centre, also becomes uncountable and yet may contain less than I000 particles per c.c.

It has been stated (3I) that calcium carbonate is slightly soluble in glycerine and glycerine jelly. Since these materials more used for coating the slide plate it was anticipated that very fine carbonate dust might be altered or dissolved if left too long before counting. On investigation of this feature using spots from limestone dust clouds, no visible change in counts, shape or size of particle could be detected after one week. And it is unlikely that spots would require to wait longer than a week before examination.

Another feature of the konimeter is that it can only take a snap sample. While this is certainly an advantage under certain circumstances it is often a disadvantage and especially when comparative tests are being made with another instrument which can only sample over a much longer period. Due to the transient nature of dust clouds, two spots taken in quick succession at the same point in a mine generally gave very different results. To obtain an average figure for the dust concentration at any point underground a great number of spots would require to be taken at short intervals of time. Nevertheless, the maximum concentration of dust in suspension is of value, especially in view of the danger of coal dust as an explosive agent. Unfortunately, a concentration of coal dust that would be explosive would be uncountable by the konimeter, although an uncountable spot would not necessarily indicate danger.

From these preliminary observations on the application of the konimeter, made in relatively dusty coal mines, it was found that the majority of the spots taken in the region of the coal face and in other dusty areas were mostly uncountable, even on the 2.5 c.c. samples. Figs. 5I to 54 are typical spots taken from atmospheres near a coalcutter and a conveyor discharge respectively, and show the entire futility of assessing the dustiness by any method of spot counting.

Tests with Volatile Solid Filters.

Since the konimeter had proved to be of little value in the more dusty regions of the mine, comparative tests were made on the application of filters, whereby a weighable quantity of dust could be collected.

The naphthalene filtering medium was adopted and the filters were prepared from naphthalene crystals , previously

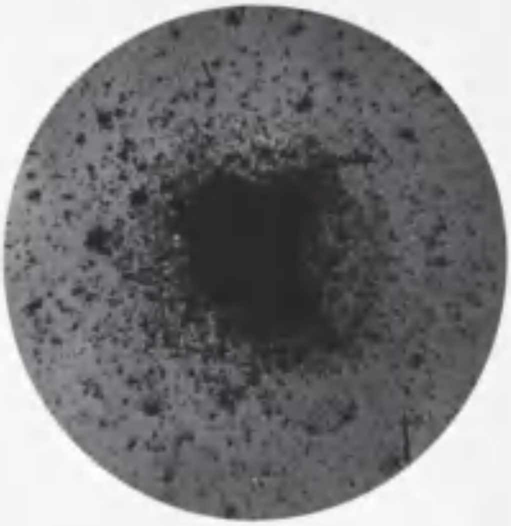


fig. 5I x 63
Spot taken behind Coalcutter

Fig. 52 x I50
Same Spot.

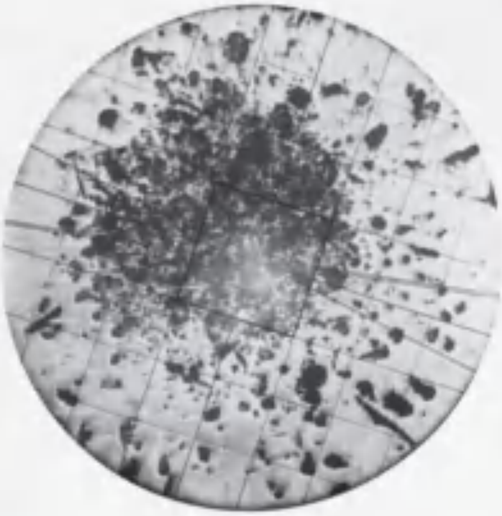


fig. 53 x 85
Spot at Conveyor Discharge

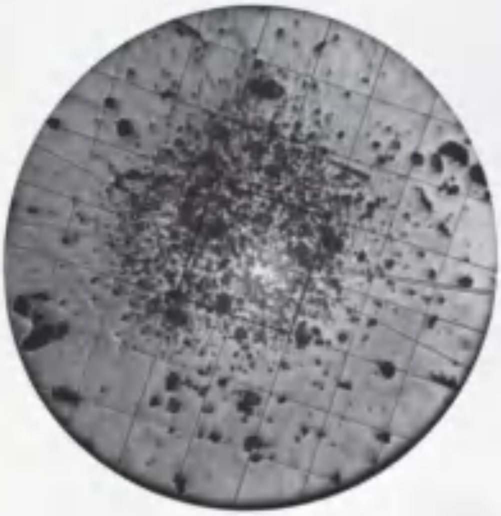


fig. 54 x 85
Spot from Gate-end Loader.

purified by distillation, and mixed to a sludge with alcohol. A portion of the sludge was then pressed into a brass tube 3 inches long by 3/8 in. internal diameter to form a pad about 1/4 in. thick which rested upon a perforated zinc grid: this grid rested on a projection in and near one end of the tube. While drying and until ready for use the filter ends of the tubes were sealed by means of small rubber caps.

In sampling, the filter tube was inserted in the end of a rubber tube attached to a single-acting hand-operated air pump and a known volume of the air to be sampled drawn through the filter.

To obtain the entrapped dust the filter pad was transferred to a watchglass and the naphthalene very slowly volatilised, leaving the dust deposit unaffected chemically and physically. Figs. 55 and 56 show typical dust deposits obtained by this method. For microscopic examination and size-frequency determinations, slides were prepared by spreading out a portion of the deposit with pure alcohol.

With the samples obtained, only a very rough estimate of the amount of combustible and incombustible matter could be made, but this difficulty could be surmounted by taking larger samples and carrying out a suitable analysis. Larger samples, however, mean either a filtering apparatus of larger capacity or an extended sampling period. The latter alternative would thus mean that the average result is obtained over (and probably affected by) a longer period of time. The time over which the samples extended in most cases was from 5 - 10 minutes.

Comparison of Methods

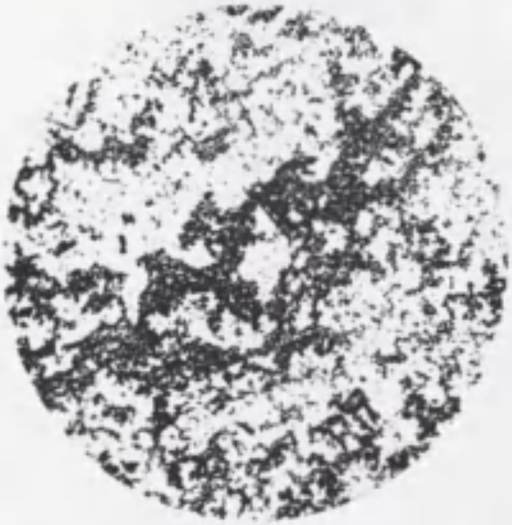


fig. 55 x 35

Typical Filter Pad Sample
after volatilising naphthalene.

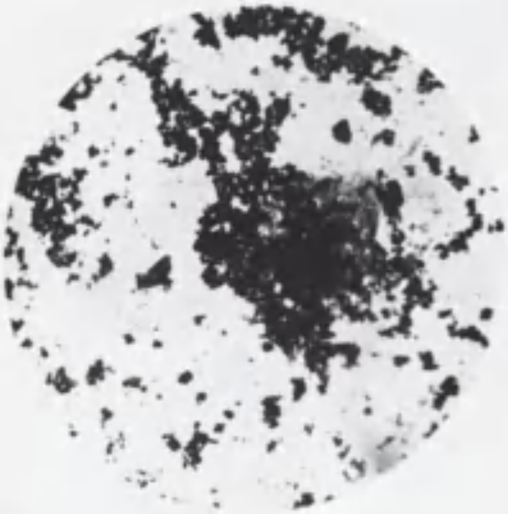


fig. 56 x 135.

Typical Pad Sample.

Comparison of Methods.

In order to compare, under practical conditions, the relative usefulness and accuracy of both sampling methods, several dust surveys were carried out. At first these were completed in a dry and dusty mine with the result that most of the konimeter spots were uncountable and of little help in the comparison. Another series was therefore made in a much less dusty mine and the results obtained are shown graphically in fig. 57.

The procedure adopted was to take a filter sample, a konimeter sample, and a measurement of air velocity at a number of stations in one ventilating district, together with a note of any dust-forming agencies in the immediate vicinity of each station.

From fig.57 it is evident that no agreement exists between the results obtained by the two methods. This is because konimeter results take no account of the particle size or the nature of the dust substance. The konimeter counts also show clearly the wide range of values obtained by spots taken in quick succession at one station - an indication of the transient nature of the concentrations - and show the necessity for taking a large number of spots at one station in order to obtain a fair average value of dustiness.

Because of the transient nature of the concentrations, the constant changing of the working operations, and the numerous changes in the velocity and direction of the air current throughout the circuit, it was impossible,in this instance, to obtain useful information concerning the influence of air velocity upon dust concentration and particle size.

Size Analysis Since size of particle is of such importance

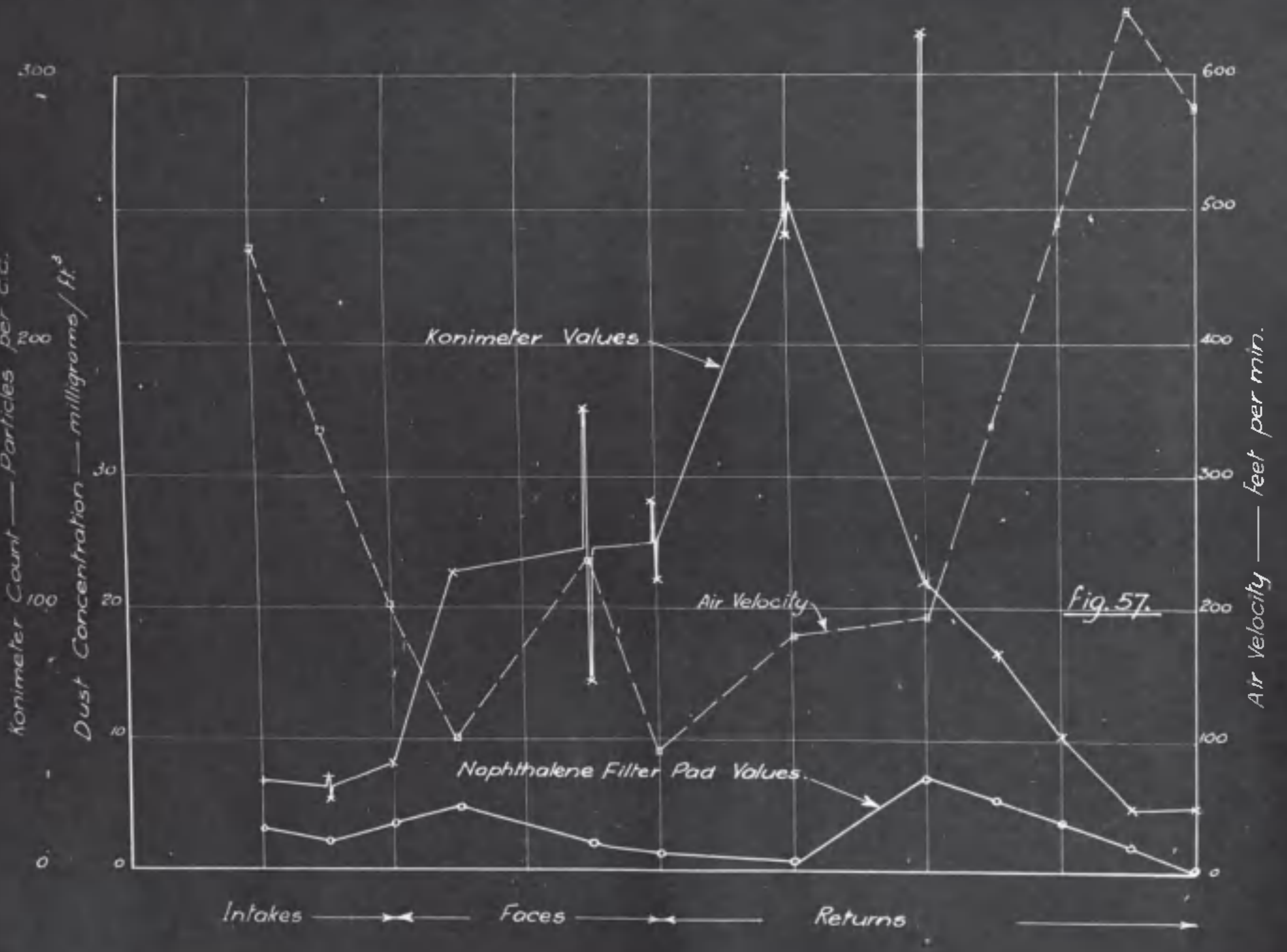

Konimeter Count —— Particles per c.c.
0
100
200
300
Dust Concentration —— milligrams / ft.³
0
10
20
30
Air Velocity —— feet per min.
0
100
200
300
400
500
600
Konimeter Values
Air Velocity
Naphthalene Filter Pad Values
Intakes
Faces
Returns

Fig. 57.

physiologically, any efficient method of dust sampling must enable a size analysis of the particles to be made. Both the konimeter and the volatile filter pad are capable of yielding this information. In the absence of other means, a size analysis affords a means of comparing the efficiencies of different methods of sampling.

A size analysis was carried out on samples obtained under similar conditions by each method. In the case of the konimeter spots, particle size was measured by a gauge when the enlarging screen was used. Estimation by comparison with the size of the graticule squares was resorted to when the screen was not in use. With the filter samples slides were prepared for microscopic examination. Size-frequency estimations were made for a few representative fields in the several samples, size being determined by means of an ocular micrometer.

The percentage of dust with largest dimension less than 5 microns were found to be as follows:-

For Konimeter Samples......... 85.50 per cent.
For Filter Pad Samples........ 90.30 " "

The results are remarkably close and show that the dust normally in suspension is very fine. Difference in results may be attributed to the number of fine particles in the spots which are obscured by larger particles or embedded in the adhesive film, and in any error due to the examination of only representative fields in the case of the filter pad samples.

Conclusions From the foregoing investigation into methods of sampling, the following are the conclusions arrived at regarding the amount and nature of the dust to be sampled in the average coal mine:-

(I) Many of the concentrations met with are very dense, and particularly during coal cutting and when coal conveying and loading are in progress.

(2) On the average, about 90 per cent. of the particles normally in suspension are under 5 microns in size.

(3) Where there is adequate ventilation the dust concentration varies rapidly and between wide limits. For the determination of maximum dustiness a snap sample is necessary, but for average dustiness a sample over a fairly long period is required.

With regard to the two sampling methods tested, the following are their salient advantages and disadvantages:-

Konimeter.

(I) It can provide a snap sample and is thus capable of determining maximum dustiness when the spots are countable.

(2) Even when the spots are uncountable, their density does give some idea of relative dustiness.

(3) It is generally unsuitable for taking an average sample.

(4) For accurate work in dusty atmospheres the instrument is of little use since the spots are uncountable.

(5) It does not yield any information regarding the proportions of the several types of dust present.

(6) Where the spots are countable there is a liability to serious error in counting: the average square method is more reliable than the sector method.

Volatile Solid Filter

(I) There is no limit to the density of dust concentration it can sample.

(2)The result obtained is a measure of the average dustiness over the time of sampling(5 - IO mins.).

(3) It is of no value for snap sampling.

(4) It does not enable immediate results to be obtained: also, it entails more laboratory work than the konimeter.

(5) Judging from the number of fine particles trapped,it is probably more efficient than the konimeter.

(6) It affords a means of obtaining a sample large enough to permit of analysis to determine the proportions of combustible or other matter present.

Dust Concentrations during Coal Mining Operations.

Dust is produced in almost every operation incidental to the actual working and transporting of coal, the amount being largely dependent on the type of operation and the condition and nature of the coal. A dusty atmosphere, consequent on the handling of large quantities of coal in certain parts of the mine, does not necessarily indicate a point of dust production. In this sense production and dissemination of dust are distinctly different aspects of the problem but often difficult to keep apart. As this section deals mainly with the concentrations of dust associated with certain mining operations, no attempt is made to discriminate between them.

Dustiness in coal mines can be directly attributed in the first place to the breakage of coal, but here an anomaly exists. Tests carried out on the degradation of coal by crushing showed that there was no relation between the hardness or strength and the tendency to produce much fine dust. Indeed it was often found that hard, splinty coals were more dusty than friable coals. The main factors influencing the amount and fineness of the dust produced appear to be the planes of cleat in the coal, its lamellar structure and its moisture content. In the mine, other factors such as depth, method of working, seam thickness, etc., have a pronounced bearing on the amount of dust produced.

Coalcutting. This operation is responsible for the greater proportion of both coal and stone dust formed at the face, and although many devices and practices tend to reduce the dust produced and disseminated during this operation, this is undoubtedly the crucial point in dust production.

The dangerous dust-laden atmospheres prevalent behind a coal-cutter, and especially when cutting in the underclay below the seam, have often caused some alarm and called for improvements in the system or method of coal-cutting.

To assess any improvement in the air condition an instrument giving a definite value of concentration is essential. The inadequacy of the konimeter in this work is shown by the photographs of figs. 5I and 52. The spot shown, at two different magnifications, is typical of those taken in the vicinity of the 'gummer' behind a longwall coal-cutter.

Tests carried out with naphthalene filters in similar concentrations gave values varying from I8 - 50 milligrams per cubic foot, depending on the type of coal being cut and the state of the ventilation. Much denser concentrations could have been obtained, however, by sampling closer to the cutting chain where the dust was not evenly dispersed in the air current. The concentrations given, nevertheless, are those breathed by the workmen at the rear end of the machine.

Blasting

That blasting produces or,at least, raises into suspension a considerable amount of fine dust,is a fact that cannot readily be denied. Skilful placing of shots and properly balanced charges, together with the use of the most suitable explosive well tamped home, do much to reduce the amount of dust found in the atmosphere just after shotfiring. Whether the dust produced in the operations of blasting are due entirely to the rapid dispersion of the dust formed by the fracture of the material or whether most of it is due to the shock wave is difficult to prove. This dust together with the fumes produced by the decomposition of the explosive constitute a formidable atmosphere, but, where good ventilation exists, the problem is not in any way a menace. Much fine dust, however, is put into the air current, carried outbye and deposited elsewhere. In some cases where heavy rounds of shots are fired in poorly ventilated situations, the atmosphere may be highly dangerous both from the standpoint of dust concentration and noxious gas content.

As with the dense concentrations during coalcutting, the konimeter is again practically useless for obtaining definite values where the dust clouds are dense. It is able, however, to show the growth and decline of the concentration before and shortly after firing in quite an effective manner. Figs. 58 - 64 show successive spots taken on a longwall conveyor face within a minute of the firing of a shot in coal towards the end of the coal-getting shift. The seam in question was hard and relatively dusty and the particulars of the shot were as follows:-

Seam thickness..............	4'0"
Depth of undercut...........	4'0"
Depth of shothole...........	2'9"
Explosive charge............	2 oz. Polar Saxonite

Sampling station.... 25 yds. on return side of shothole.
Air Velocity....... 80 ft. per minute.

The progressive increase and then the decrease as the cloud passed the sampling point are evident. How much of this dust is due to actual coal breakage and how much to the raising of the surrounding dust cannot be estimated. The normal dust concentration, however, is reached again within a minute of firing the shot.

With heavier explosive charges and more sluggish ventilation the dust hazard after shotfiring is increased. For this reason

fig. 58 x 92
Spot taken before Firing.

fig. 59 x 92
Just after Firing.

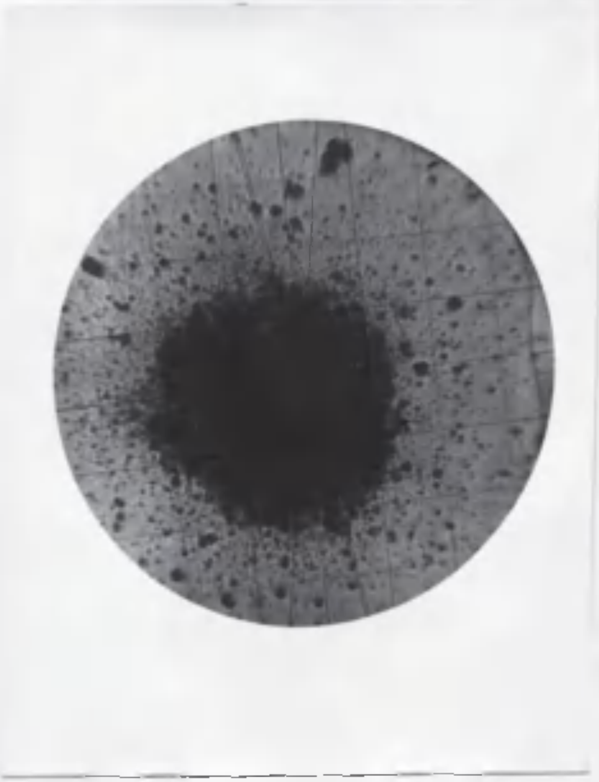


fig. 60 x 92
First of Smoke Cloud
passing Sampling Station.

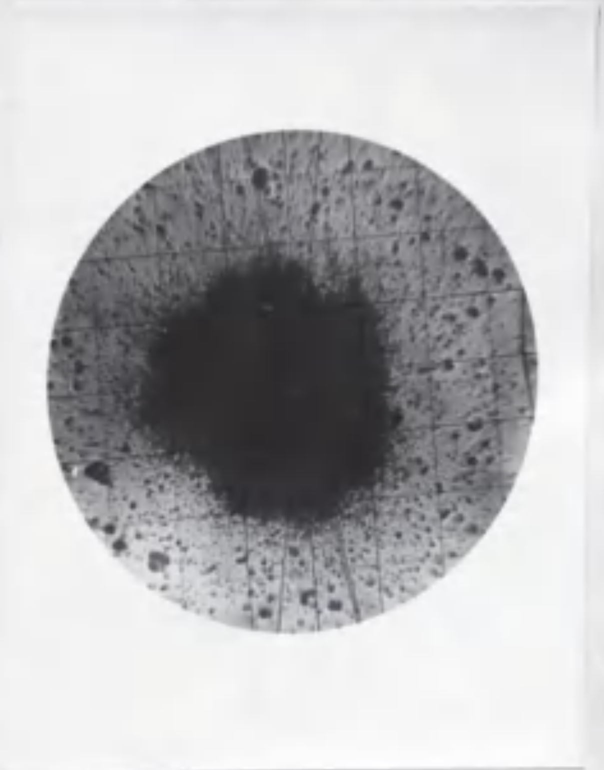


fig. 61 x 92
Densest part of Cloud.

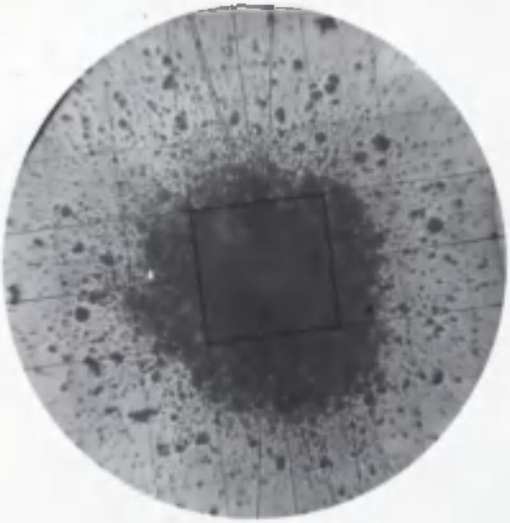


fig. 62 x 92
Cloud diminishing in density.

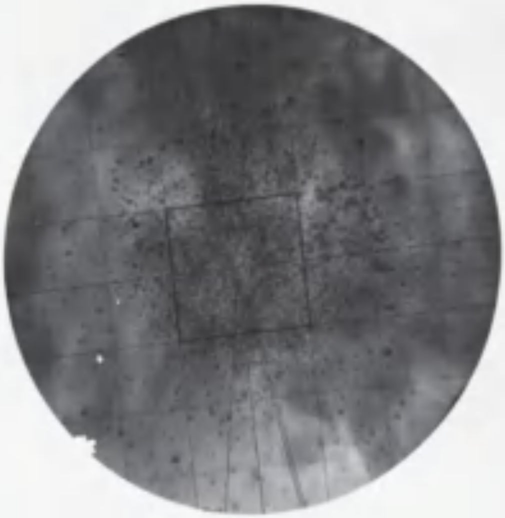


fig. 63 x 92
Almost normal again.
I minute after firing.

fig. 64 x II5

Same spot as fig. 6I.

the dust conditions after firing ripping shots are more dangerous. Further, the proportion of rock dust is greater.

Tests made with the konimeter gave spots similar to those already shown. Filter samples on the average, for the same underground conditions, gave values varying from 6 - 18 milligrams per cubic foot in the atmosphere just after the firing of a heavy ripping shot.

Since it is highly probable that much of the dust in these atmospheres is raised into suspension by the concussion, other more gentle methods of breaking coal and rock such as Cardox, Hydrox, Coalbursters and pneumatic picks , which provide no concussion , at once suggest themselves as possible means of dust reduction.

Cushioned Blasting

It has been suggested that the high velocity of escaping gases from improperly stemmed holes causes much of the consequent dustiness after shotfiring and it has been observed that shots stemmed with sand-clay stemming give altogether better shots, much less smoke and less dust. Similar claims have also been made for the practice of cushion-blasting and it was decided to carry out a test on the effect of cushioning on the amount of dust produced.

In order to obtain definite counts from konimeter spots the experiments were carried out in a damp and relatively non-dusty mine. Arcwall headings were chosen for the tests, and the conditions for the shots, apart from the confinement of the charges, were similar. One shot was fired with rigid sand-clay stemming and the other with a Voortman Plug and a 6 inch air cushion. The following are the particulars relating to these shots:-

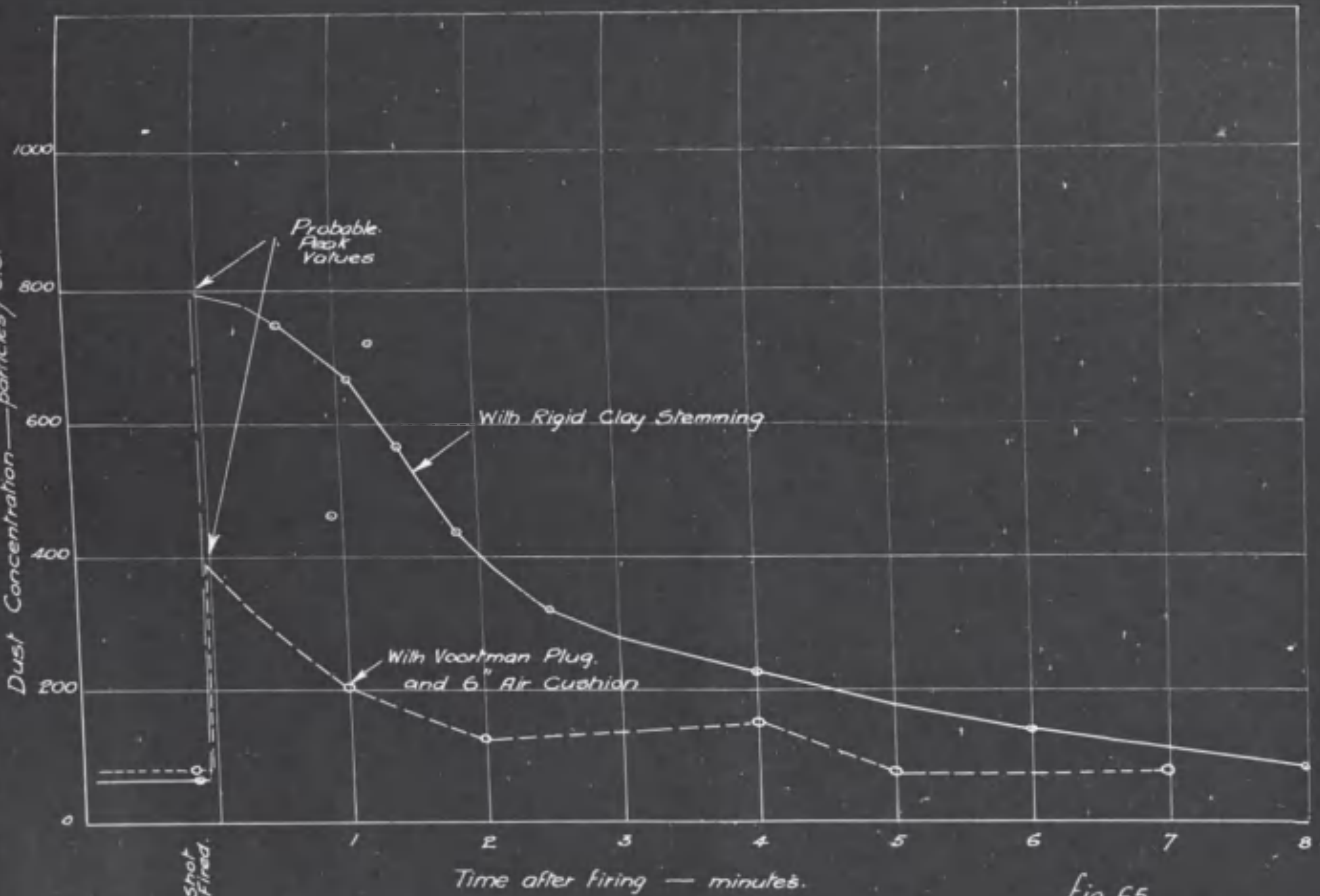

Probable Peak Values
With Rigid Clay Stemming
With Voortman Plug. and 6" Air Cushion
Dust Concentration — particles/c.c.
1000
800
600
400
200
0
Shot Fired
1
2
3
4
5
6
7
8
Time after firing — minutes.

Fig. 65

Depth of Shotholes.................. 3'5"
Seam Thickness.......................3'0"

Arcwall Heading ...... 10 ft. wide
Depth of Undercut..... 4'10"
Explosive Charge ....6 oz. Black Powder.

Sampling Station......... 10 ft, from face
Ventilation ....Fair.

The results of the konimeter counts are shown graphically in fig.65 and the superiority of the cushioned shot clearly evident. Apart from these values, the shots were different in their effects. The cushioned shot was definitely more effective.

Drilling

Drilling by either rotary or percussive drills is also responsible for the production of dust. Although the hazard of compressed air percussive drills in hard rocks is definitely great unless special precautions are taken, the same danger is not associated with drilling in coal. The amount of very fine dust produced in coal drilling is relatively small.

Tests of the borings from holes drilled by hand in coal showed that the quantity of dust below 100-mesh seldom exceeded 10 per cent. of the whole weight of the borings.

Although this adds to the general dustiness, by adding to the amount to be dispersed during filling and loading, no really dusty atmosphere was ever encountered using rotary drills either in coal or in rock.

Dust Concentrations at the Face

Apart from raising into suspension dust already formed by other means, the intensive filling by miners on machine-cut conveyor faces causes a certain amount of dust production in itself.

The actual dustiness of a conveyor face depends upon a number of factors, but mainly upon;

(a) The skill of the fillers in 'getting' the coal and shovelling it on to the conveyor.

(b) The position of the conveyor as governing the amount of casting to be done.

(c) The conveyor type as regards action, speed, material of construction and amount of spillage and grinding.

(d) The air velocity on the face.

The Dust Survey In order to obtain some idea of the variation and maximum concentrations present in a mechanised mine, a survey was made in a section of a dusty mine equipped with coal-cutters and conveyors.

The survey was carried out in the direction of the air current, a konimeter spot and a filter pad sample being taken at each sampling station, together with a note on the proximity or otherwise of any dust producing agencies. The layout of the district showing the sampling points is given in fig. 66 and the graphs of figs. 67 and 68 show the variation in dust concentration by weight. As so many of the konimeter spots were of uncountable density the konimeter results have not been included in the graphs.

The actual data taken in surveys of this kind is similar to that given herewith, referring to the survey just described.

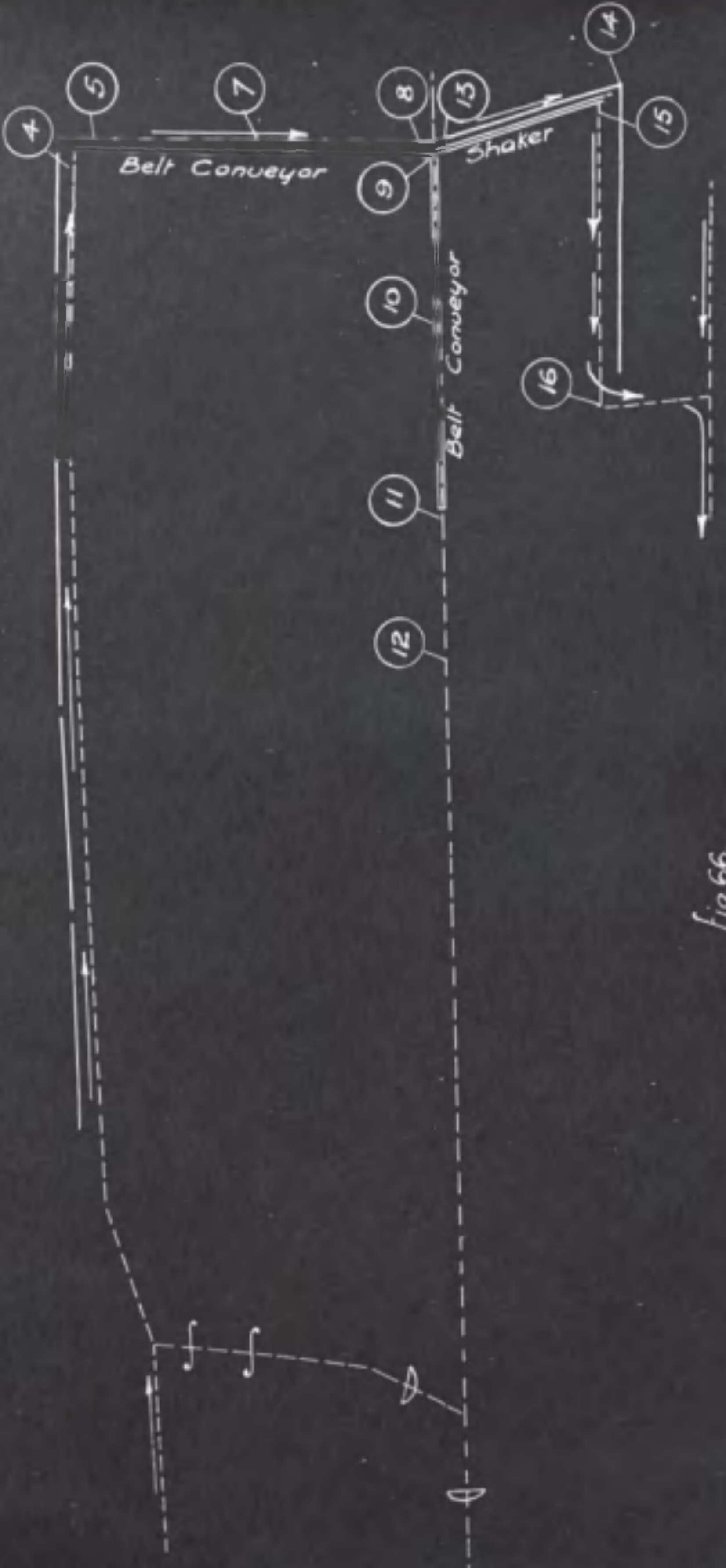


fig.66.

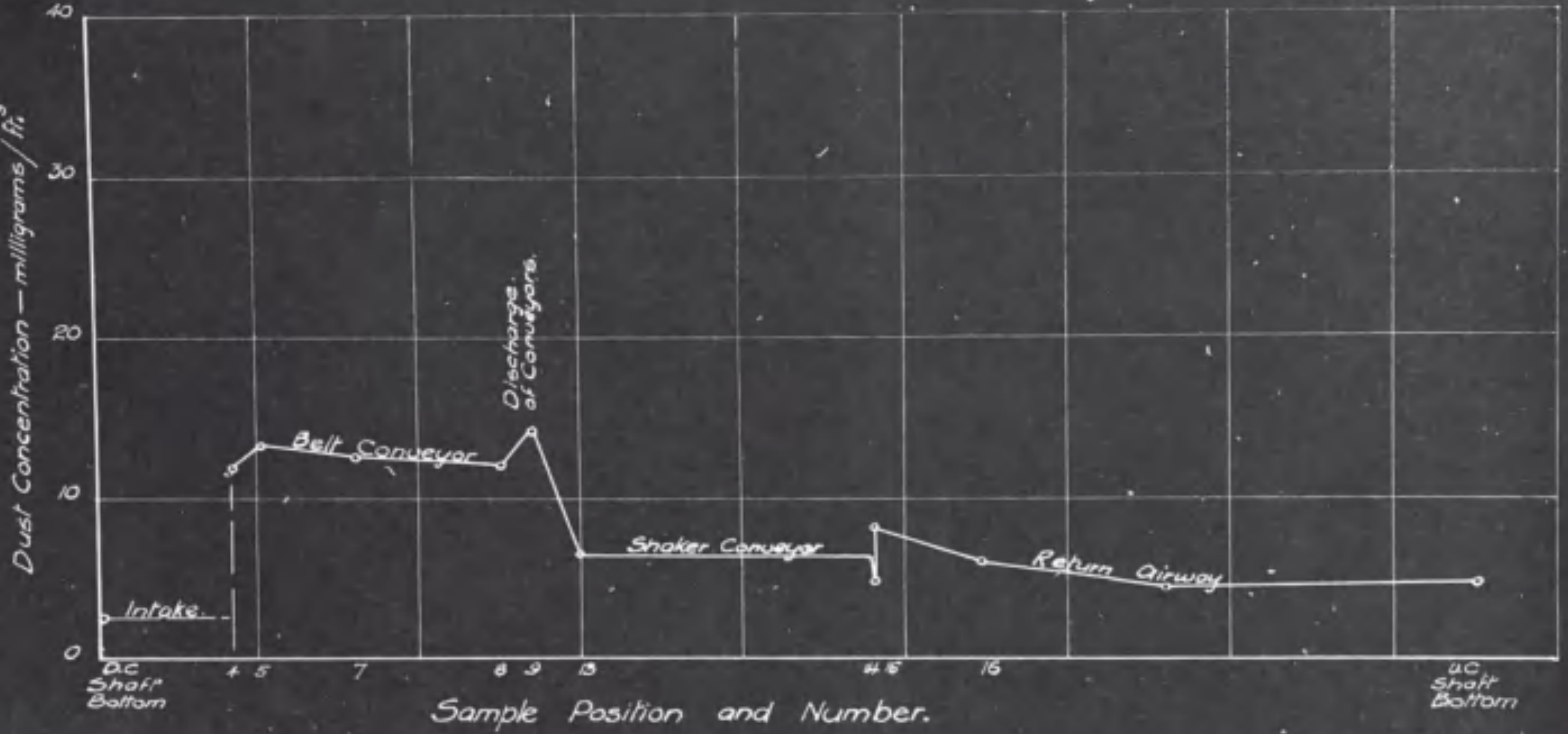

Dust Concentration — milligrams / ft.³
0
10
20
30
40
D.C Shaft Bottom
4
5
7
8
9
13
14
15
16
U.C Shaft Bottom
Sample Position and Number.
Intake.
Belt Conveyor
Discharge. of Conveyors.
Shaker Conveyor
Return Airway

Fig. 67

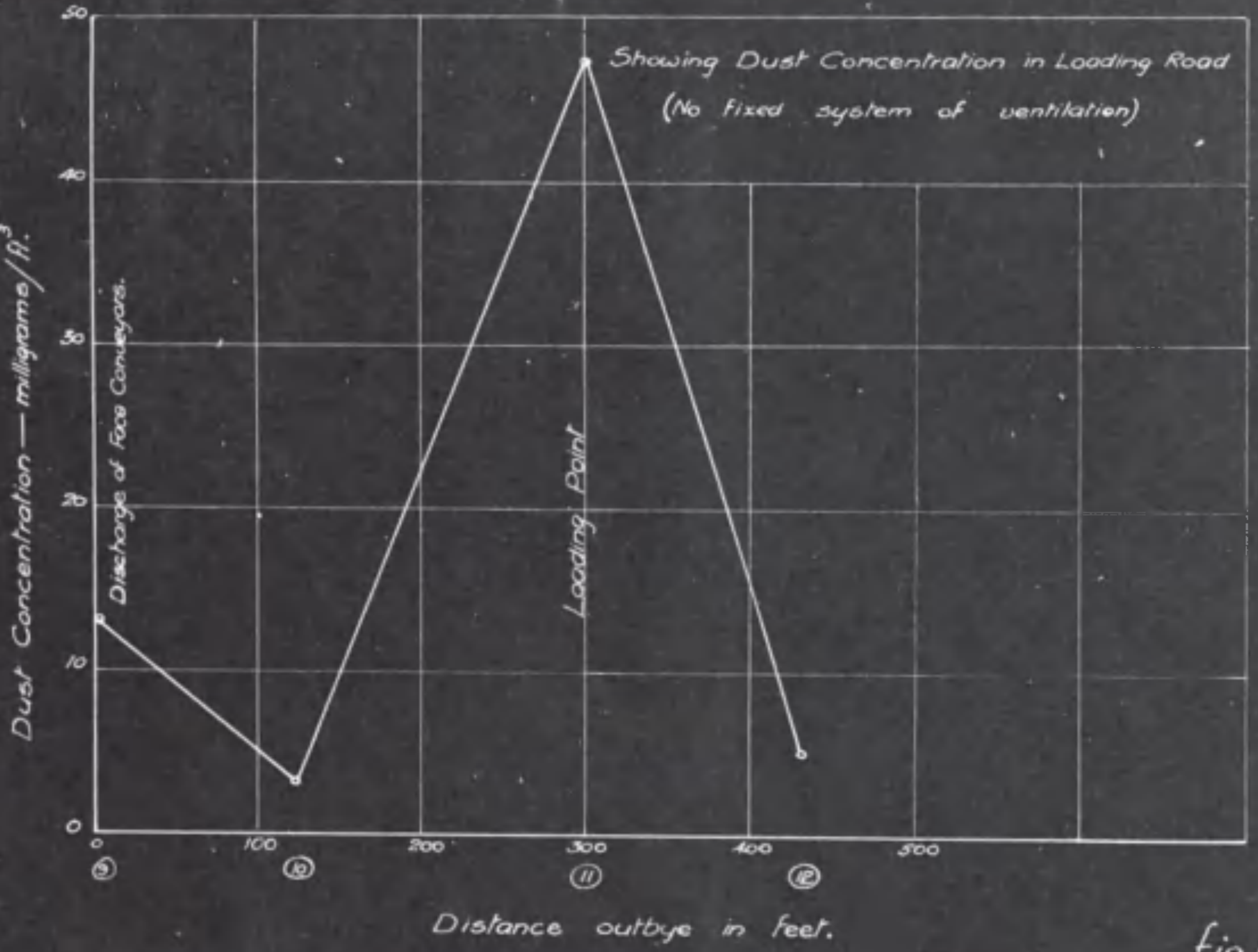

Showing Dust Concentration in Loading Road
(No fixed system of ventilation)
Dust Concentration — milligrams/ft.³
0
10
20
30
40
50
Discharge of Face Conveyors.
Loading Point
0
100
200
300
400
500
⑨
⑩
⑪
⑫
Distance outbye in feet.

Fig. 68

Dust Survey Data.

Sample Number	Pump Strokes	Wt. in gms.	Dust Concentration gms./cub.ft.	Konimeter Count per c.c.	Position and Remarks on Sample
I	40	.0002	.00I0	36	Taken at surface level at D.C. shaft.
2	I0	.000I	.0020	Uncountable	On pithead between the shafts.
3	50	.0007	.0028	I0	Pit bottom. At intake to section. Coal winding proceeding
4	50	.003I	.0I24	26	Intake airway 20 ft. from face. 3/4 mile inbye. Many fibres and hairs.
5	27	.00I8	.0I33	Uncountable	At lower end of face. Dusty.
6	Sample spoiled			I80	
7	50	.0032	.0I28	Uncountable	Centre of belt conveyor face. Mostly coal dust. A few coke particles.
8	40	.0024	.0I20	-do-	I0ft. from discharge of of belt conveyor.Nine workmen on intake side.
9	35	.0025	.0I43	-do-	8ft. outbye of belt discharge. Shaker not discharging. Stagnant ventilation.
I0	40	.0006	.0030	-do-	40 yds. from belt discharge. Air stagnant. Many fibres and hairs.
II	30	.007I	.0474	-do-	At gate-road conveyor discharge.Very dusty. Many large, angular particles.
I2	50	.00I2	.0048	-do-	I00 ft. outbye of loader. Air stagnant. A few wood fibres.
I3	40	.00I3	.0065	-do-	Bottom end of shaker conveyor. No coal discharging. Shot recently fired. A few coke particles.
I4	30	.0007	.0046	Spoiled	In fast corner of face. Miner using pick. Much fibrous material present.
I5	30	.00I2	.0080	Uncountable	In return airway at face. Conveyor working. All very fine dust.
I6	30	.0009	.0060	-do-	At bend in return airway. Velocity 55ft./min.
I7	40	.00I0	.0050	740	Upcast shaft bottom.

Results

The results of the survey are typical of a dry and dusty mine and it is evident that the most dense concentrations prevail at the points where coal is discharged, i.e. at conveyor ends and loading points. The effect of a more or less stagnant ventilation in the loading road has the effect of rapidly reducing the dust concentration in a very short distance (fig.68). The conditions near the loading point, however, are far from pleasant.

Limits of concentration of dust in air for moderately dusty coal mines, as obtained from the foregoing survey and other tests, may be summarised briefly in the following table:-

Showing the Limits of Dust Concentration in the air of moderately dusty coal mines.

Operation or Position		Dust Concentration in milligrams/ cub.ft.
Behind coal-cutters		I8 -55
In the vicinity of Loaders and conveyor discharges		IO - 47.4
On machine-cut conveyor faces		4.4 - I4.5
After ripping shots		4.0 - I4.8
In airways, haulage roads and travelling roads		2.0 - I2.4
In shaft bottoms	Upcast	I.0 - 5.0
	Downcast	I.0 - 2.8
On pitheads		I.0 - 2.0

Concentrations are relatively great during coal-cutting, loading, and immediately after shot firing, but it must be remembered that the duration of the concentration is of some importance. Whereas the shotfiring concentrations quoted exist only for a comparatively short time, those for coal-cutting and loading are continuous. When assessing the hazard to which any workman is exposed, the time of exposure to the definite concentration must be given due consideration. The incidence of the diseases brought on by the inhalation of dust appears to be a function of the product of time of exposure and the concentration.

The values of the table show generally that, if the present dust conditions in our mines are to be ameliorated, methods of dust reduction and systems of control will be most profitably applied in the operations of coal-cutting, loading and discharging from conveyors and, to a lesser degree, in blasting.

Acknowledgments

In conclusion I wish to express my sincere thanks to Professor A.M.Bryan, B.Sc.,M.I.Min.E. for his supervision and guidance throughout the research. His advice and criticisms were appreciated at all times.

To the following companies I also tender my indebtedness:-

Messrs. Wm.Baird and Co. Ltd., Jas. Dunlop and Co. Ltd. and The New Cumnock Collieries Ltd. for facilities granted at their collieries for experimental work.

The Imperial Chemical Industries Ltd. for supplies of Perminal W.

The South Hetton Coal Co. Ltd. for supplies of shale dust.

APPENDIX I.

General Regulations, 30 July, 1920.
(S.R. and O., 1920. No. 1423)

Part I. - Precautions against Coal Dust (Section 62)

1. The following Regulations shall apply to all mines in which coal other than anthracite is worked.

2. The floor, roof and sides of every road or part of a road which is accessible shall be treated in one of the following ways, either:-

(a) they shall be treated with incombustible dust in such manner, and at such intervals, as will ensure that the dust on the floor, roof and sides respectively shall always consist throughout of a mixture containing not more than 50 per cent. of combustible matter; or

(b) they shall be treated with water in such manner, and at such intervals, as will ensure that the dust on the floor, roof and sides respectively is always combined throughout with 30 per cent. by weight of water in intimate mixture; or

(c) they shall be treated in such other manner as the Board of Trade may approve.

Provided that the percentage of incombustible dust required under this Regulation may be reduced by an amount equivalent to the percentage of water present in the mixture.

Provided also that the obligation imposed by this Regulation shall not apply in respect of any road or part of a road, either

(a) in a seam in which anthracite only is worked, or

(b) if, and so long as, the natural conditions thereof as regards presence of incombustible dust and moisture are found by tests made in accordance with these Regulations to be such as to comply with the foregoing requirements.

3. The incombustible dust used for the purpose of the preceding Regulation shall contain not less than 50 per cent. by weight of fine material capable when dry of passing a sieve with 200 meshes to the linear inch (40,000 to the square inch). Provided that if a larger proportion of incombustible dust is used than is required under the foregoing Regulation, the percentage of fine material aforesaid contained in the incombustible dust may be reduced proportionately, but shall not fall below 25.

4. For the purpose of testing the composition of the dust mixture in any part of a road, the following procedure shall be adopted:-

(a) Representative samples of the dust shall be collected from the floor, roof and sides respectively over an area of road not less than 50 yards in length.

(b) Each sample collected shall be well mixed and a portion of the mixture shall be sieved through a piece of metallic gauze having a mesh of 28 to the linear inch.

(c) A weighed quantity of the dust which has passed through the sieve shall be dried at 212 degs. Fahrenheit and the weight lost shall be reckoned as moisture. The sample shall then be brought to a red heat in an open vessel until it no longer loses weight. The weight so lost by incineration shall be reckoned as combustible matter for the purposes of the test.

Provided that in the case of dusts to which the foregoing test would not be applicable, the test shall be such as may be prescribed (Appendix II); if any dispute arises as to the test which should be applied it shall be determined in the manner provided by the Act for settling disputes.

Tests of samples of dust, so taken as to be representative of the normal composition of the dusts throughout the roads of the mine on the floor, roof and sides respectively, shall be made as often as may be necessary but not less frequently than once a month.

The results of the tests shall be posted at the pithead and recorded in a book to be kept at the mine for the purpose in accordance with the provisions of Section 24 of the Act.

Provided that if the representative tests show in respect of any mine or of any part of a mine that the natural conditions as regards presence of incombustible dust and moisture are such as to comply with the requirements of these Regulations, it shall suffice thereafter to make representative tests in respect of that mine or that part of a mine at intervals not exceeding three months or at such longer intervals as may be approved in writing by the Inspector of the Division.

5. No dust shall be used for the purpose of complying with these Regulations of a kind which may be prohibited by the Board of Trade on the ground that it would be injurious to the health of persons working in the mine. Provided that if any dispute arises as to whether the dust is injurious, it shall be determined in the manner provided by the Act for settling disputes.

APPENDIX II

SPECIAL TESTS FOR DUST MIXTURES.

(a) Dust Mixtures which contain Carbonates

I. A weighed quantity of the dried dust shall be heated to a temperature X high enough to ensure complete decomposition of the carbonates, in an open vessel, until it no longer loses weight: and the percentage loss of weight shall be determined.

2. A weighed quantity of the dried dust shall be treated with dilute acid in a suitable apparatus and the percentage loss of weight due tothe evolution of carbonic acid gas shall be determined.

3. The difference between the two percentage losses of weight so determined, shall be reckoned as the percentage of combustible matter for the purpose of the test.

X

Note. - "The high temperature of the blow-pipe flame is required, and heating has to be continued during about an hour to ensure complete decomposition of the carbonate". (Sixth Report of the Explosions in Mines Committee)

(b) Moist Dust Mixtures which cannot be Sieved.

I. The samples collected shall be well mixed and a weighed quantity of the mixture shall be dried at 2I2 degs. F. The weight lost shall be reckoned as moisture.

2. The dust so dried shall be treated in the manner described by paragraph(b) of Regulation 4 and the percentage of combustible matter shall then be determined in the manner prescribed by paragraph(c) of the Regulation.

(c) Dust Mixtures which contain Gypsum.

I. A weighed quantity of the dust which has passed through the sieve, as prescribed by paragraph(b) of the Regulation, shall be dried at a temperature not exceeding 275 degs.F., and the weight lost shall be reckoned as moisture. The sample shall then be brought to a red heat in an open vessel until it no longer loses weight. The weight so lost by incineration shall be reckoned as combustible matter for the purposes of the test.

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