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EXPLOSIBILITY TESTS FOR INDUSTRIAL DUSTS

by

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Summary

This report describes the apparatus and procedures for testing suspensions of industrial dusts for explosibility. The results of the tests are expressed either in terms of a standard classification or the measurement of the various parameters that can be used to assess the explosibility hazard of the dusts.

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Introduction

Dust is formed in many industrial processes either as an end product or a by-product and this is particularly so where grinding or milling operations take place or where waste products are formed to any extent. Methods of showing the existence of the dust explosibility hazard of combustible materials and the degree of such hazard are therefore necessary and are described in this report, which gives details of the apparatus and procedures in use at present. The results of tests are used in the specification of safety measures for industrial plant handling explosible dusts.

A Review by Brown[1] in 1951 described the tests in use up to that time, some of which had been used since testing began in 1913 and were originally designed for the measurement of the relative explosibility of coal dusts. More recently there have been certain additions and modifications to the apparatus and the introduction of a further test[2].

Until 1960 the testing of industrial dusts for explosibility was carried out on behalf of H.M. Factory Inspectorate of the Ministry of Labour at the Safety in Mines Research Establishment, Buxton. It was then transferred to the Joint Fire Research Organization and copies of the four main test apparatus were built. The apparatus and test procedures are described in F.R. Note No.464, 1961 (3). Recently further tests of the type in use at the U.S. Bureau of Mines[4] have been added and this report supersedes F.R. Note No.464 with a description of all the tests.

Scope of Tests

Classification tests show whether or not a dust is explosible, and if so, measurements can be made of the minimum ignition temperatures with either a small or a large source of ignition. Further tests can then be made to measure other explosion properties of explosible dusts as follows:-

(a) the minimum explosible concentration
(b) the minimum ignition energy
(c) the maximum explosion pressure and rate of pressure rise
(d) the maximum permissible oxygen concentration to prevent ignition in dust clouds.

Methods of Test

General Procedure.

Before testing a dust sample its toxicity and that of its combustion products is considered and if the material has toxic properties appropriate safety precautions are taken.

Preparation of Dust Samples.

Whenever possible the dust, as received, is tested directly. If, however, the "as received" dust is not readily dispersable because of high moisture content, its dispersability may be improved by drying the sample either in a desiccator or in a liquid jacketed oven at 104°C. If the dust sample contains

large particles, which would not be readily dispersed by the air blast in the tests, the sample may be sieved through a 12 mesh BS sieve to remove the coarse particles which are then discarded and the remainder of the sample is submitted to test.

If ignition does not occur with the dust sample from which the coarser particles have been removed or with the "as received" dust, even after drying, the sample may be sieved through various mesh sizes down to 240 BS and the test procedure repeated on the sieved and dried fractions.

Dust Dispersion.

The essential feature of an apparatus for testing a dust for explosibility is a means of dispersing the material to give a reasonably dense dust cloud in the region of the igniting source. The dusts which are tested have a wide range of dispersability and for the most favourable conditions for dispersion, there has to be considerable variation in the means of producing the dust cloud, by altering the air dispersion pressure, the quantity of dust and the position where the dust cloud is formed relative to the source of ignition.

Apparatus and Procedure for Classification Tests

Four tests are used to determine the explosibility of the dust. The four forms of test apparatus are illustrated in Plates 1-4. A summary of the main features of the different apparatus is given in Table 1. Fuller details of the apparatus and test procedures are given in Figs.1-4 and Appendices 1-4.

Table 1

Types of test apparatus

Apparatus	Direction of dispersion of dust	Igniting source	Illustration
Horizontal tube (Wheeler's test No.1 modified)	Horizontal	Heated platinum wire coil (Small igniting source)	Plate 1
Inflammator (Vertical tube apparatus)	Vertically downwards	Electrically heated wire coil or electric spark (Small igniting source)	Plate 2
Hartmann type (Vertical tube apparatus)	Vertically upwards	Electric spark or electrically heated wire coil (Small igniting source)	Plate 3
Furnace (Wheeler's test No.2 modified)	Vertically downwards	Heated wall of furnace (Large igniting source)	Plate 4

Sequence of Tests

The sequence of tests is usually as follows:-

(1) Horizontal Tube
(2) Inflammator
(3) Hartmann Type Apparatus
(4) Furnace

If the dust ignites and propagates flame in the Horizontal Tube the minimum ignition temperature with a small source of ignition is measured, as this indicates the degree of explosibility of the dust; next the dust is tested in the Furnace which has a large source of ignition and the minimum ignition temperature for that test is also measured. Non ignition in the Horizontal Tube is followed by testing in the Inflammator and if there is no ignition in that test, testing is then carried out in the Hartmann type apparatus before the dust is tested in the Furnace test.

Classification Tests

(1) The Horizontal Tube Test

In this test dust is dispersed horizontally by an air blast of short duration over a small source of ignition. The apparatus consists of a glass combustion tube 4 ft. 6 in. long and 3 in. internal diameter open at both ends with a platinum coil igniter across the horizontal diameter, 18 in. from one end. A small sample of dust is placed in a conical heat 13 in. from the igniting source and dispersed by an air blast which is directed at the base of the heap. With the platinum coil at 1300°C, observations are made as to whether or not propagation of flames away from the source of ignition takes place, when dust clouds of various concentrations are formed in the region of the coil. If flame propagation occurs, the temperature of the igniting source is reduced and the dust concentration varied, until the lowest two temperatures are obtained differing by 10°C, such that the dust cloud ignites at the higher temperature only and this is termed the Minimum Ignition Temperature for Test No.1. When no flame propagation is observed, at least four further tests are carried out in which dust clouds of a fairly high concentration are formed in the region of the igniting source at the appropriate temperature.

This test is suitable for testing all types of carbonaceous materials particularly if the particle size of the dust is small, but dusts which are coarse, or of high density are often not readily dispersable into a uniform dust cloud in it. This test is not used for metal dusts as they might damage the platinum ignition coil.

(2) The Inflammator

In this test dust is dispersed vertically downwards on to a small igniting source. The apparatus consists of a glass combustion tube 3 ft. 6 in. long and 3 in. internal diameter which is mounted vertically. It is open at the top and closed at the bottom by a loose fitting bung. The igniting source, which may be either a small wire coil heated to a bright red heat or a continuous high tension electric spark, is 5 in. from the bottom closed end of the combustion tube. No measurements are made of the temperature of the igniting source in this test. A sample of dust, from a dust holder, which may be introduced at either of three sidearms along the tube, is dispersed by an air blast sufficient to blow all the dust against a deflector plate and form a dust cloud which falls down on to the igniting source. Observations are made as to whether or not flames propagate away from the source of ignition. The dust concentration may be varied by altering both the amount of dust and the pressure of the dispersion air and the dust may be introduced at different positions relative to the igniter.

Both carbonaceous and metal dusts may be tested in this apparatus and it is particularly useful for testing materials in which the particle size is large or the material is of a fluffy or flocculent nature and cannot be dispersed into a dust cloud in the Horizontal tube test. Dusts which are adherent or of high density are not readily dispersable in this test.

(3) Hartmann Type Apparatus

In this test dust is dispersed vertically upwards over a small igniting source. The apparatus consists of a vertical tube approximately 1 ft. long which is fitted over a hemispherical brass dispersion cup in which the dust sample is placed. The dust is dispersed by an air blast, at pressures up to 40 p.s.i. which is introduced through a pipe in the centre of the dust cup and deflected by a mushroom shaped deflector on top of the pipe. The small igniting source may be either a continuous high tension electric spark or a hot coil like those used in the Inflammator test and the position of the igniting source relative to the dust dispersion cup may be varied. The dust concentration may be changed by varying the quantity of sample and the pressure of the dispersion air.

When the dust under test is dispersed in the region of the igniting source, observations are made as to whether flame propagation through the dust cloud away from the source of ignition, occurs for a range of dust concentrations.

This test is suitable for testing all types of dust particularly materials which are not readily dispersable in either the Horizontal tube or the Inflammator tests.

(4) Furnace Test

In this test the dust is dispersed vertically downwards through a large source of ignition. For this test a small sample of dust is placed in a dust tube which is fitted at a right angle to an electrically heated furnace and joined to it by a pyrex glass adaptor. The furnace is $8\frac{1}{2}$ in. long and 1 7/16 in. in diameter and may be heated to temperatures up to 1000°C. The dust is dispersed through the heated furnace with an air blast and observations are made as to whether flame appears at the bottom open mouth of the furnace. If ignition with flame takes place, the furnace temperature is lowered until two temperatures differing by 10°C are obtained such that ignition takes place at the higher temperature only. Following this the quantity of dust and the air dispersion pressure are varied further over a temperature range until the lowest furnace temperature at which ignition occurs is determined and this is termed the Minimum Ignition Temperature for Test No.2.

All dust samples submitted for a Dust Explosibility Classification Test are tested in the Furnace test and whenever possible, the Minimum Ignition Temperature of the sample is measured.

Classification of Dusts

From the results of the tests the dusts are classified as follows[5]

Class I — Dusts which ignite and propagate flame readily, the source of heat required for ignition being small.

Class II — Dusts which ignite readily with flame but require a larger source of ignition.

Class III — Dusts which do not ignite in the tests.

Dusts which ignite and propagate flame in the Horizontal tube, Inflammator or the Hartmann type apparatus either "as received" or after sieving and drying are placed in Class I.

Dusts which ignite and produce flame in the Furnace test, but not in the other three tests, are placed in Class II.

Dusts which do not produce flame in any test, or dusts which ignite in the Furnace test and produce a very small flame only when the furnace temperature is 1000°C, are placed in Class III.

A classified list of the dusts that have been tested for explosibility is published at intervals(5).

Tests to Measure the Explosibility Hazards of Dusts

When dusts have been tested for explosibility and their classification has been established, if the materials are found to constitute an explosion hazard, further information on the degree of the hazard can be obtained by measuring:

(1) the minimum explosible concentration in air - the lower explosion limit.

(2) the minimum spark energy required for the ignition of a dust cloud.

(3) the maximum explosion pressure and the maximum rate of pressure rise developed in a dust explosion.

(4) the maximum permissible oxygen concentration of the atmosphere to prevent ignition in a dust cloud.

(1) Minimum Explosible Concentration in Air

Experiments to determine this value for a dust are carried out in the Hartmann Type apparatus using the continuous electric spark as the source of ignition. A weighed quantity of the sample is placed in the dispersion cup and a filter paper diaphragm with a 1/16 in. hole in the centre is held over the top of the combustion tube by a locking ring. The dust is dispersed by an air blast of up to 40 p.s.i. and the criterion for indicating an explosion is propagation of flame away from the igniting source; it is usually accompanied by bursting of the filter paper diaphragm. When explosion occurs, the quantity of dust is reduced and testing is continued until no explosion is observed in at least four tests with the same dust concentration. The weight of the smallest quantity of dust with which explosion occurs, is divided by the volume of the tube, to give the value of the minimum explosible concentration in air.

(2) Minimum Ignition Energy of a Dust

The minimum spark energy required for the ignition of a dust cloud in air is measured in the Hartmann type apparatus with the modifications described in Appendix 3. A quantity of dust which is approximately ten times the minimum explosible concentration in air is placed in the dispersion cup and the top of the combustion tube is covered by a filter paper diaphragm held by a locking ring. Electrodes with finer points than those used in the Classification test are fitted and sparks of known value, obtained by charging condensers of capacity (C) with a fixed voltage supply (V) and discharging them through a high voltage transformer, are passed across the electrodes while the dust is dispersed into a dust cloud. Observations are made until the lowest energy value of the spark, ($= \frac{1}{2} CV^2$ joules), at which flame propagation through the dust cloud is

obtained. At least four tests are carried out in which no flame propagation is observed before the minimum ignition energy for the dust is established.

(3) Maximum Explosion Pressure and Maximum Rate of Pressure Rise in a Dust Explosion

This test is carried out in a Hartmann type apparatus which is similar in design and dimensions to that used for Classification tests but has an explosion chamber which is a sealed pressure vessel constructed of steel. The plate sealing the top of the combustion tube is fitted with an electronic transducer, the output from which is used to measure the pressure developed in the explosion of the material for test. The igniting source may be either a continuous high tension electric spark or a hot coil which is positioned $4\frac{1}{2}$ in. above the dust dispersion cup. Windows for observing whether an explosion takes place are fitted diametrically opposite each other 2 in. above the source of ignition. The dust is dispersed by release of air from a 3in.^{3} reservoir at a pressure of 120 p.s.i. by a full port solenoid operated valve. A non return valve, fitted between the solenoid operated valve and the explosion vessel, prevents the combustion gases from escaping when the explosion takes place. Explosion pressures and rates of pressure rise are measured over a range of dust concentrations usually between 0.1 and 5.0 oz/ft^3 or g/l, from which the maximum explosion pressure and the maximum rate of pressure rise can be determined and these often do not occur at the same dust concentration.

Dimensional details of this apparatus are given in Appendix 5 and it is shown in Fig.5 and Plate 5.

(4) Maximum Permissible Oxygen Concentration of the Atmosphere to Prevent Ignition in a Dust Cloud

This measurement is carried out in the Furnace Apparatus with the modifications described in Appendix 4. Atmospheres of known compositions are used to disperse the dust and are passed through the furnace while the dust is being dispersed. The temperature of the furnace is maintained throughout the experiment at 850°C.

The minimum ignition temperature of a dust in atmospheres other than air or containing less oxygen than air may be measured for either a Class I or Class II dust

Commissioning the Apparatus

When the apparatus for Classification tests had been constructed at J.F.R.O., a number of dust samples, which had previously been tested and classified at S.M.R.E. were tested in it. Table 2 in F.R. Note No.464[3] gives the results of both series of tests and they show very good agreement both for the Classification and for the Measurement of the Minimum Ignition Temperatures with either a small or a large source of ignition.

For measurement of the Minimum Explosible Concentration, the Minimum Ignition Energy and the Maximum Explosion Pressures, experiments were carried out with a range of materials for which results have been published[6] and found to be in good agreement with them.

Acknowledgements

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the original apparatus and for supplying the dust samples for comparative Classification tests. Thanks are also due to Mr. P. S. Tonkin who originally built the apparatus for Classification tests at the Joint Fire Research Organization and for his advice and assistance with the initial testing.

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(5) H.M. FACTORY INSPECTORATE. Ministry of Labour. Dust Explosions in Factories. Form 830, January 1963, H.M. Stationery Office.

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APPENDIX 1

HORIZONTAL TUBE

(Modification of Wheeler's Test No.1)

Apparatus

A sketch of the apparatus is shown in Fig.1. The 3 in. internal diameter, horizontal, borosilicate glass, combustion tube is in two parts. The left hand part is 18 in. long with a one inch diameter hole in its wall, situated 5 in. from one end and the right hand part is 36 in. long. Both parts are held in adjustable iron supports and butt on to opposite sides of the asbestos wood holder for the ignition coil. The two parts of the tube are held tightly against the asbestos wood by two tie rods acting on brass collars which are clamped externally to the appropriate ends of the tubes. The butt joints are sealed with soft jointing material.

Fig.1(a) shows the ignition coil unit. The igniter consists of a platinum wire coil 0.7 in. long made from an 18 in. length of 32 S.W.G. platinum. The coil is wound around the outside of the centre section of a ceramic tube 6 in. long approximately 0.04 in. bore and 0.1 in. outside diameter. The turns of the coil are spaced to give even temperature along its length. The ends of the coil are connected to the output side of a variable transformer which allows the coil to be heated to 1300°C. The bore of the ceramic tube carries a thermocouple with its butt welded junction at the centre of the tube. The couple is made of pure platinum, 13 per cent rhodium-platinum wire, 26 S.W.G. The ends of this thermocouple are connected, with compensating leads, to a temperature controller which also indicates the temperature of the ignition coil. The igniter is fixed in a groove 3/16 in. deep in the asbestos wood holder. The asbestos wood has a 3 in. diameter hole in the centre and when the apparatus is assembled the ignition coil lies diametrically across the combustion tube in the horizontal plane.

Dispersion of dust around the coil is effected by a blast of air which may be varied in quantity as required. The air is metered at the required flow rate and then diverted for 2 seconds on to the dust in the combustion tube by the operation of a three-way solenoid valve. The valve mechanism is operated by a relay controlled by a cam on the shafting of an electric clock motor.

APPENDIX 2

INFLAMMATOR

Apparatus

The combustion tube, Fig.2 is of borosilicate glass, 3 in. internal diameter and 40 in. long. It is open at the top and closed at the bottom with a loosely fitting rubber bung. The tube has four side arms for alternative positions of the dust holder, each 1 in. internal diameter, 2.5 in. long, at intervals of 10 in. along the right hand side and one side arm of like dimensions diametrically opposite the lower side arm, 5 in. from the bottom of the tube. The ignition coil holder or electrode holders fit into the bottom side arms and a brass dust holder fits into any of the side arms above the igniting source. The dust is blown from the holder with a blast of air from an air reservoir of 28 $in.^3$ capacity. The dispersion of the dust cloud is improved by the deflector plate. To allow filling of the reservoir to the required pressure and the quick release of the air, a spring loaded clamp assembly operates on the rubber tubing between the air reservoir and the dust holder.

The source of ignition may be either a hot coil or an electric spark. The coil is $7\frac{1}{2}$ turns of 20 S.W.G. electrical resistance wire, each turn being 5/16 in. internal diameter, and is heated by a 10 volts 20 amperes A.C. supply. The actual temperature of the ignition coil is not measured in this test. The electric spark is generated from an induction coil with a Ruhmkorff commutator and the energy applied to its primary circuit is about 70 watts.

APPENDIX 3

HARTMANN TYPE APPARATUS

Apparatus

Figure 3 shows the apparatus diagrammatically. It consists of a cylindrical brass block 3 in. diameter 2.5 in. long, the top of which is dished to form a dispersion cup $\frac{5}{8}$ in. deep. The air for dispersing the dust is delivered through an aperture 0.375 in. internal diameter in the centre of the cup terminating in an air deflector. Fitting to the top of the cup, by means of a brass adaptor, is a perspex combustion tube 2.5 in. internal diameter and 12 in. long. The tube has five pairs of diametrically opposed brass electrode holders, fitted into its wall. A pair of brass electrodes is screwed through the appropriate holders and a spark gap of about 0.25 in. is used. A brass locking ring, 2.5 in. internal diameter is mounted on top of the perspex tube. The combustion tube assembly is fixed to the dispersion cup by clamping bolts and the dispersion cup is fixed to the wooden base.

The air blast for dust dispersion is obtained from a reservoir similar to that used in the Inflammator by energising a full port solenoid operated valve. The apparatus used for producing the induction spark is the same as that used for the Inflammator test.

Modifications to apparatus for an alternative source of ignition.

The test apparatus may be modified to use a different igniting source, the source being an electrically heated wire coil. The perspex tube is replaced by a borosilicate glass tube which is of larger outside diameter. Consequently, the dispersion cup is modified by attaching a brass annulus, outside diameter 4 in., on which the glass tube is clamped. The ignition coil holder may be introduced through a side arm above the dispersion cup at heights of 3 in., 5 in. or 1 ft; the coil is on the axis of the combustion tube.

Modifications for measurement of the minimum explosible concentration of a dust

A weighed quantity of the sample which is known to be a Class I dust is placed in the dispersion cup. The volume of the combustion tube is measured precisely.

A filter paper diaphragm with a $1/16$ in. hole at its centre is placed over the top of the combustion tube and held in position by the brass locking ring. The continuous electric spark is used as the igniting source.

Modifications for measurement of the minimum ignition energy of a dust cloud

Electrodes with finer points than those used with the continuous electric spark in Classification tests and set $\frac{1}{4}$ in. apart are connected to the output from a transformer, input 240V, output 10 K.V. A range of spark energies between 7 millijoules and 2 joules is obtained by charging paper tubular condensers, of capacity (C) between 0.5 and 30 microfarads, by a constant voltage supply (V) in the range 180-240 volts, and discharging them through the high-voltage transformer. A filter paper diaphragm is fitted over the top of the combustion tube and held in position by the locking ring.

The dust concentration is varied by altering both the quantity of dust and the pressure of the dispersion air.

APPENDIX 4

FURNACE

(Wheeler's Test No.2 modified)

Apparatus

The apparatus is shown diagrammatically in Fig.4 and consists of an air reservoir approximately 28 in^3 capacity, a quick release spring loaded clamp, a dust holder, and a furnace. A pyrex glass adaptor connects the dust holder to the furnace. The furnace tube is of vitreosil $8\frac{1}{2}$ in. long, 1 7/16 in. internal diameter, and the heating element which has a resistance of 13 ohms, is of 20 S.W.G. electrical resistance wire (iron-chromium-aluminium type), wound in external grooves, which are spaced to give even temperature throughout the tube length. The furnace temperature is controlled thermostatically with a temperature controller which is governed by a 19 S.W.G. chromel/alumel thermocouple cemented into the wall of the furnace tube at its midpoint. The entire heating element is covered with aluminous cement and lagged with asbestos tape. The tube is fitted into a furnace box, internal dimensions 6 in. x 6 in. x 9 in., made of asbestos wood and filled with kieselguhr. The furnace box is held in a thin sheet metal casing and is supported vertically on four legs.

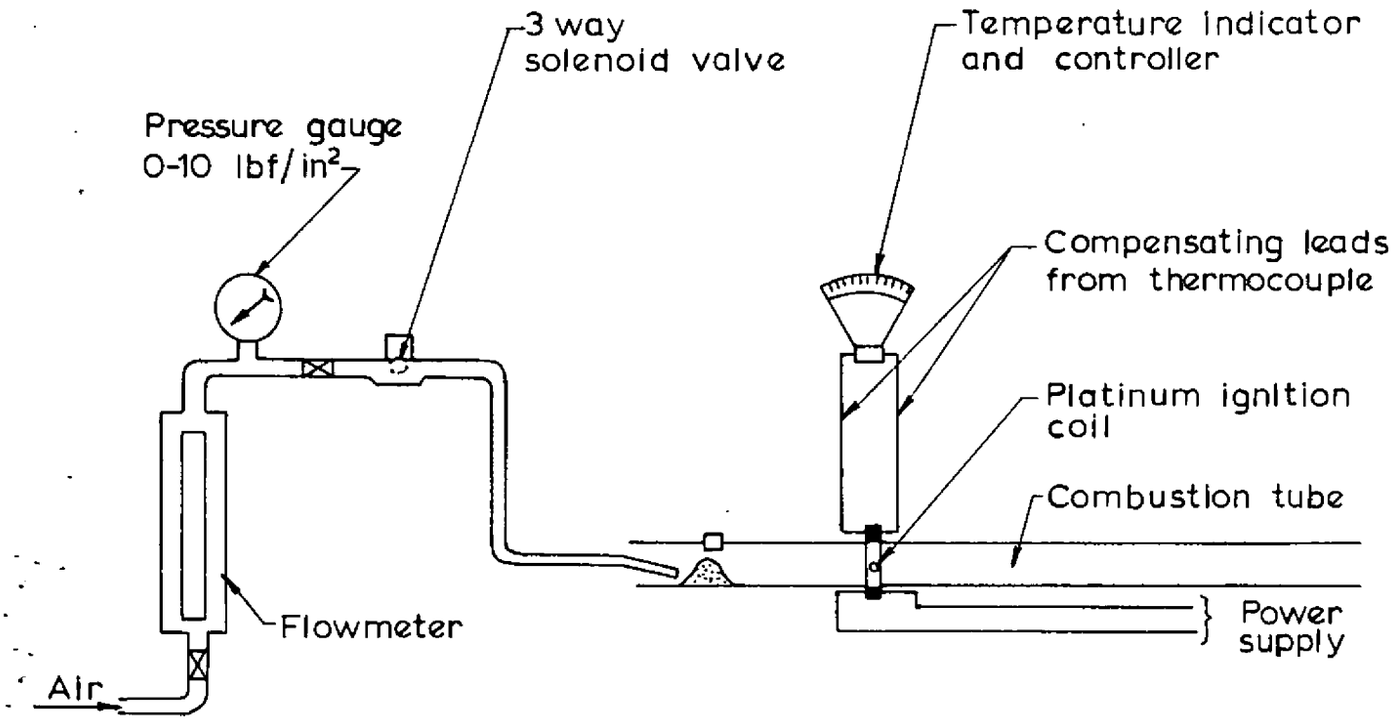
Modifications for tests in atmospheres other than air

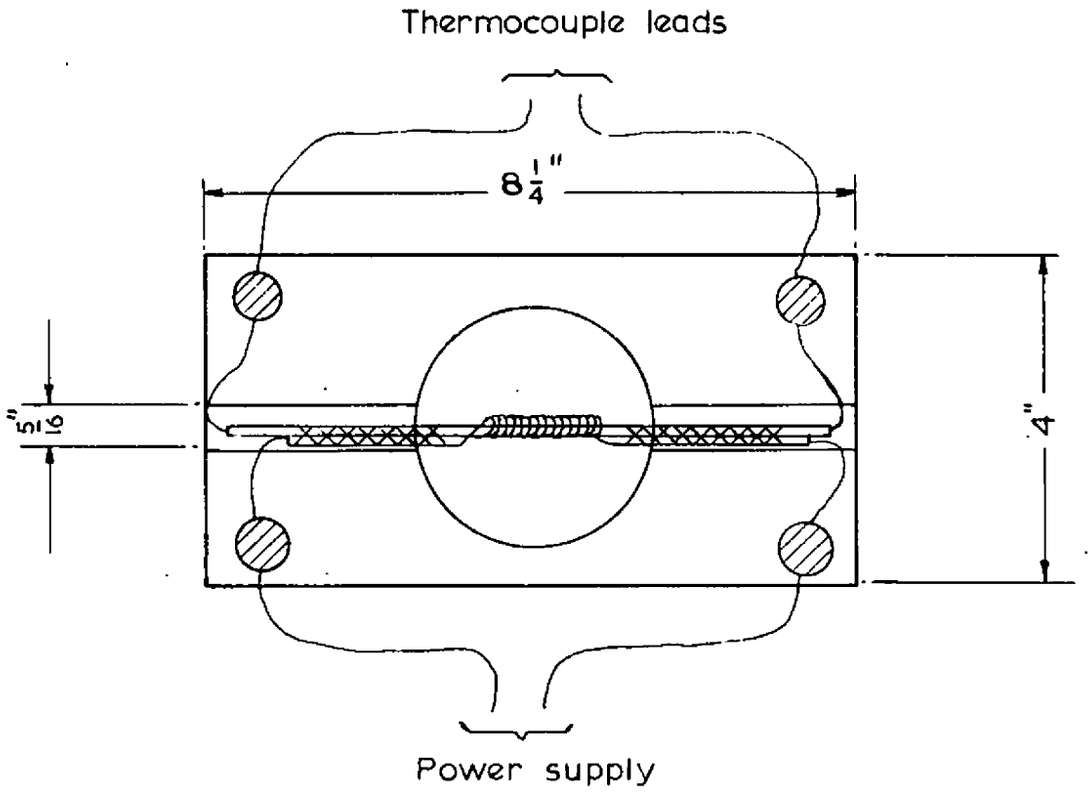
The apparatus may be modified and used to determine ignition temperatures of dust clouds in atmospheres other than air. During testing the whole of the apparatus is filled with the required gas mixture. This is ensured by fitting a pyrex glass adaptor with a side arm, between the dust holder and the top of the furnace, and fixing a borosilicate glass tube, 3 in. internal diameter and 6 in. long, directly under the furnace. While the reservoir is being filled to the required pressure, and throughout the testing period, the furnace tube and the borosilicate glass tube below it are purged by passing the gas mixture through the side arm of the pyrex glass adaptor, so that a flame from the furnace will burn only in the modified atmosphere.

APPENDIX 5

HARTMANN TYPE APPARATUS FOR PRESSURE TESTS

The apparatus is shown diagrammatically in Fig.5. It is a modified version of the apparatus used in Classification tests; a steel combustion tube 2.75 in. internal diameter, 3.25 in. external diameter and 12 in. long replaces the perspex tube. A brass annulus fits over the top of the tube and is held in position by a threaded locking ring. An electronic transducer (range 0-150 p.s.i.) is fitted into the centre of the annulus. A pair of electrode holders with well insulated electrodes are fitted into diametrically opposite side arms $4\frac{1}{2}$ in. above the dispersion cup. This igniting source may be replaced by an electrically heated coil in one side arm, and the second side arm is then blanked off. Windows $\frac{1}{2}$ in. in diameter are fitted in side arms 2 in. above the source of ignition. The dispersion cup assembly is the same as that used in the Classification test except that a non return valve is fitted between the pipe leading to the dispersion cup and the port of the solenoid operated valve, and air at 120 p.s.i. from a 3 $in.^3$ reservoir is used to disperse the dust. The combustion tube, dispersion cup etc., are all chromium plated to minimise corrosion caused by the combustion products from an explosion. The combustion tube is fixed to the dispersion cup with steel bolts which are fixed to the metal base on which the whole assembly stands. The various joints are sealed with washers so that the combustion chamber is capable of withstanding pressures up to 150 p.s.i. When an explosion takes place the output from the electronic transducer is fed to an amplifier and oscilloscope which is photographed by a drum camera so that a pressure time record of the explosion is obtained. In calculating the final explosion pressure a correction is made for the pressure obtained due to the dispersion air.





DETAILS OF IGNITION COIL

FIG.1. THE HORIZONTAL TUBE APPARATUS

Not to scale

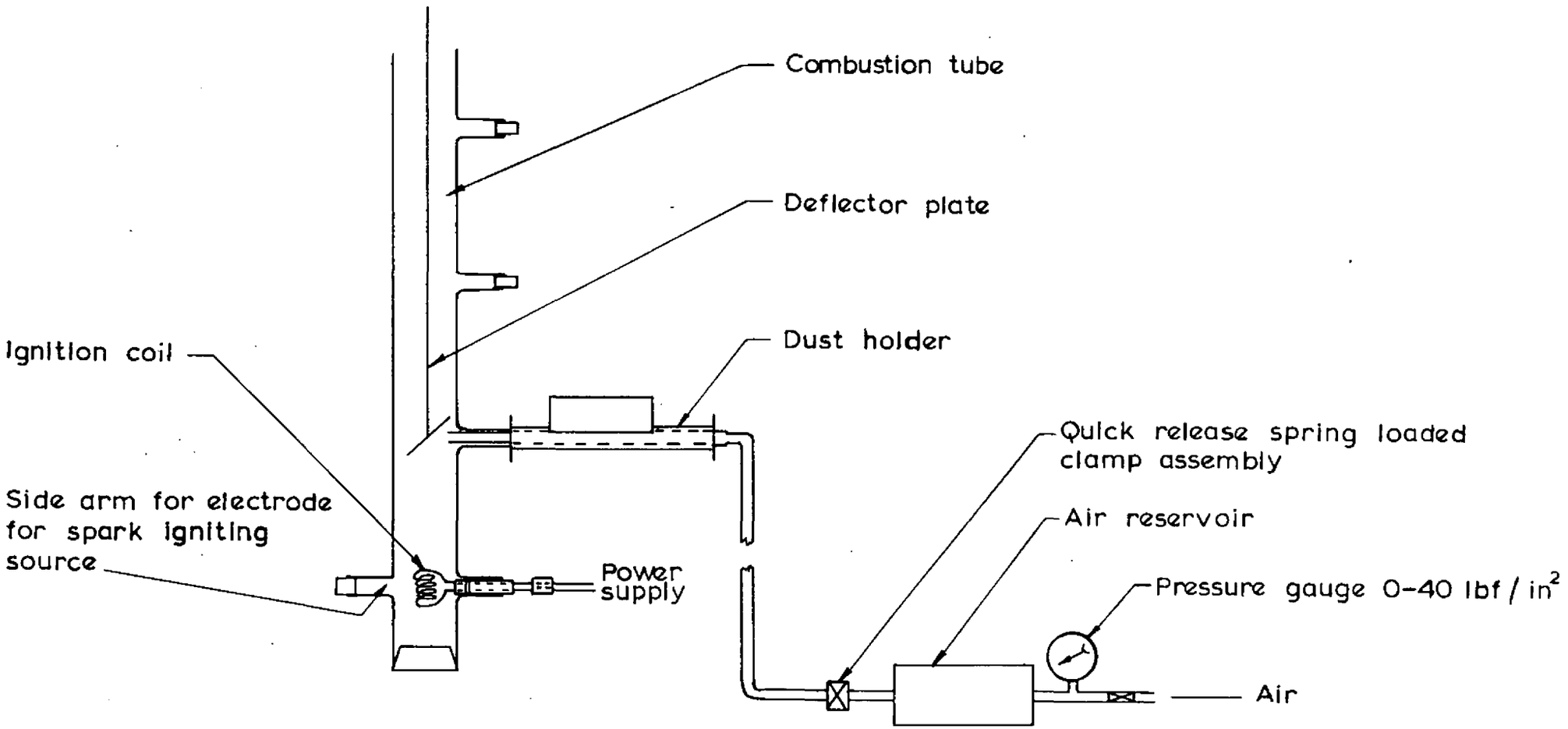


FIG. 2. THE INFLAMMATOR APPARATUS

Not to scale

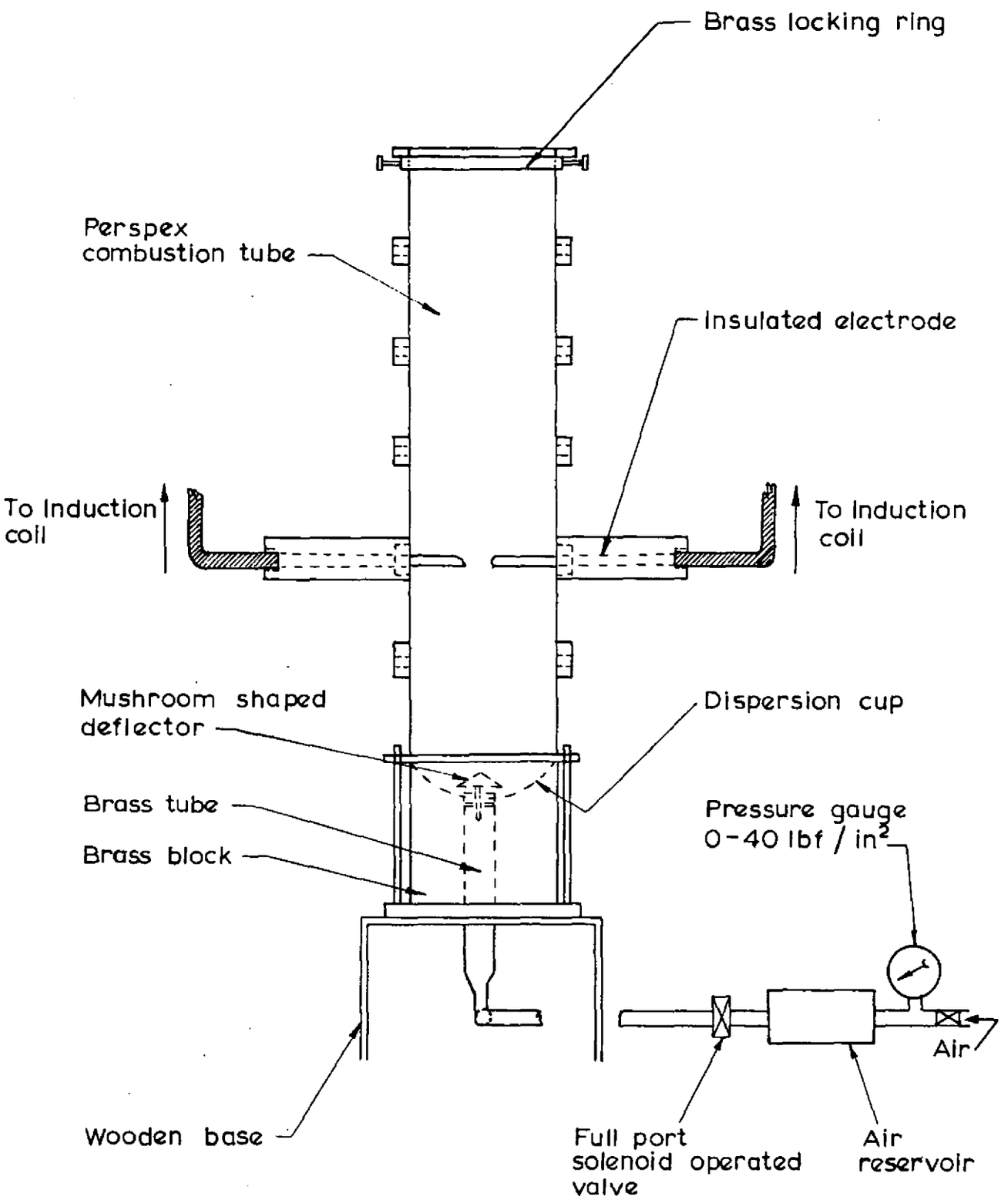


FIG.3. THE HARTMANN TYPE APPARATUS

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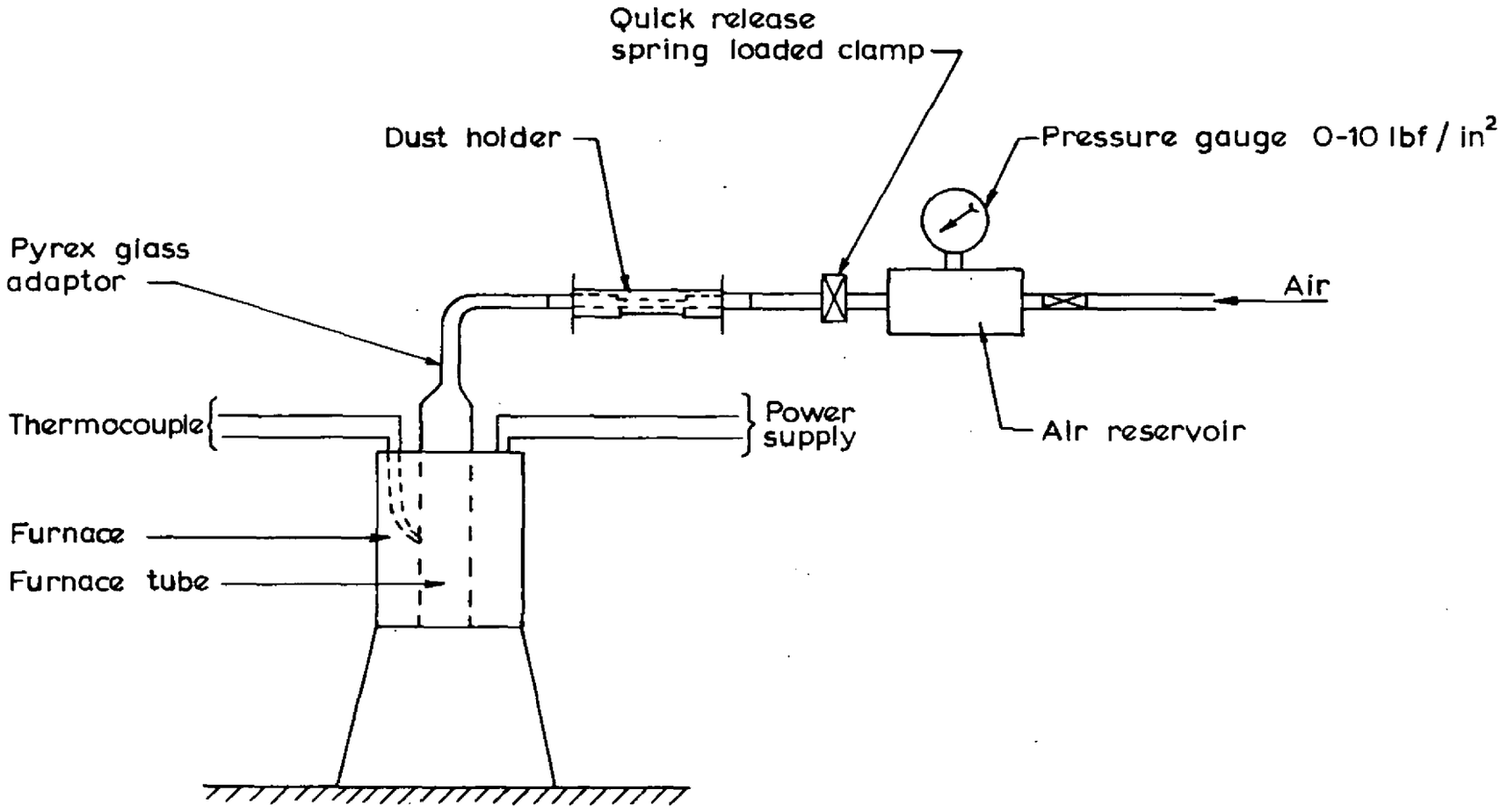
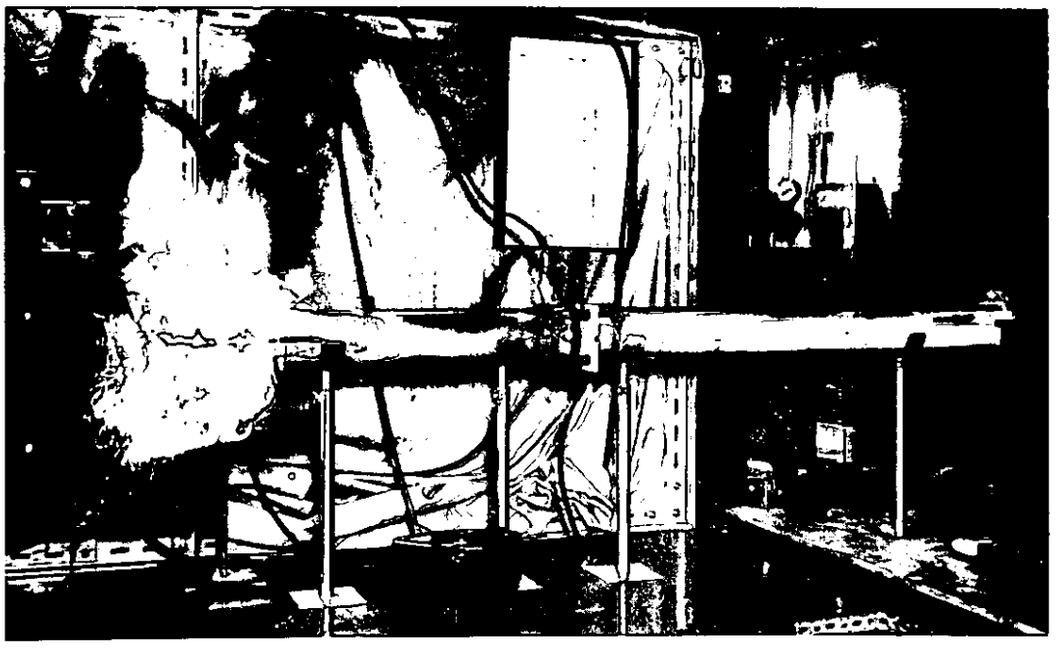


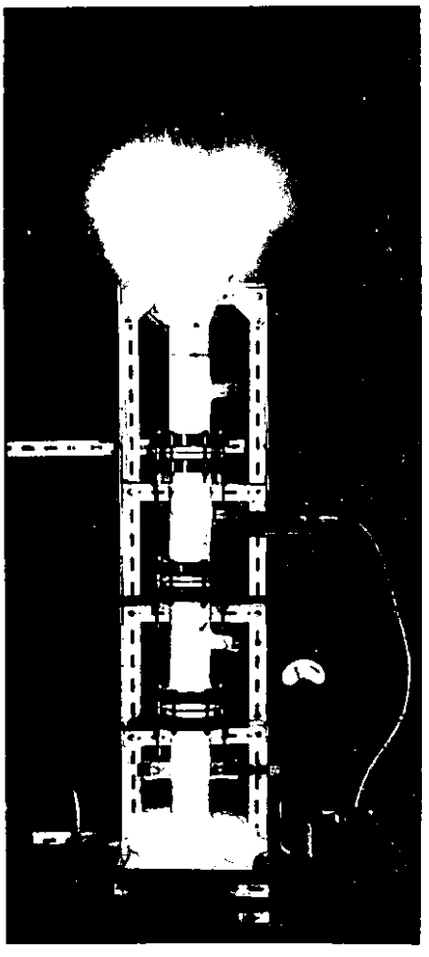
FIG. 4. THE FURNACE APPARATUS

Not to scale



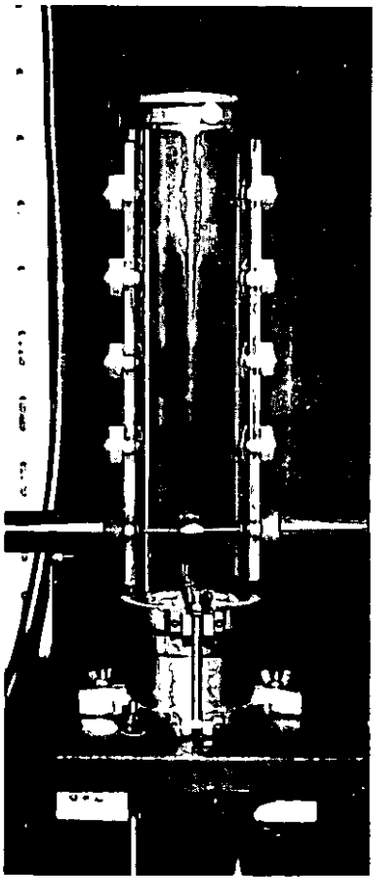
Ignition of cork dust

PLATE 1 THE HORIZONTAL TUBE TEST



Ignition of aluminium dust

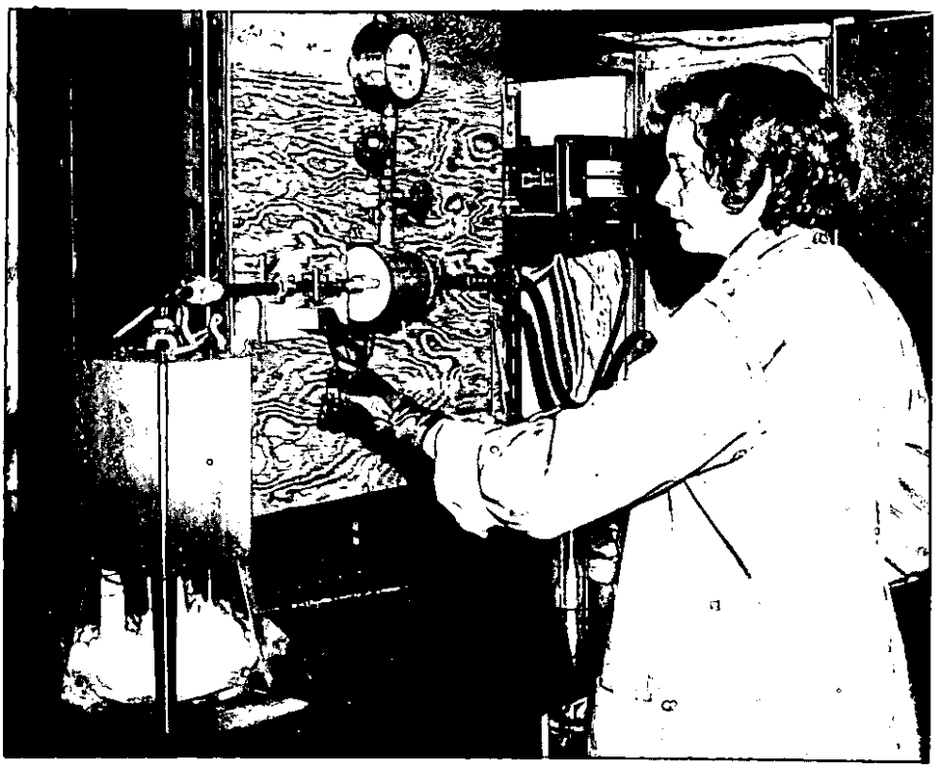
PLATE 2 THE INFLAMMATOR TEST



(a) Showing continuous electric spark

(b) Ignition of aluminium dust

PLATE 3 TEST IN THE HARTMANN TYPE APPARATUS



Ignition of cork dust

PLATE 4 THE FURNACE TEST

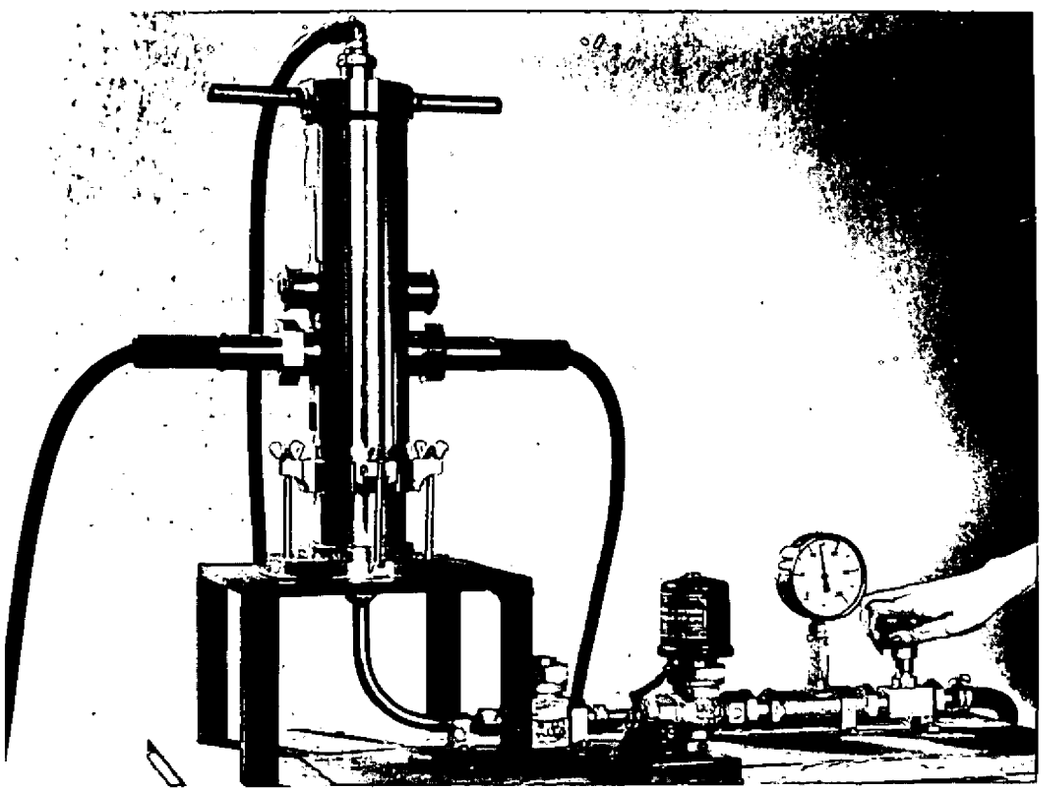


PLATE 5 THE PRESSURE TEST APPARATUS