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Chapter 67

AN EXPERIMENTAL APPROACH TO THE DETERMINATION OF EXPLOSIBLE LEAN LIMITS FOR COAL DUST AND METHANE MIXTURES

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ABSTRACT

A current program of research on the explosibility of coal dust/methane mixtures is described. During the study an explosion test chamber based on a novel design has been developed. This 20 litre open chamber uses a rotating drum concept for dust dispersion and infra-red sensors for dust concentration measurement. The chamber design allows different initiators to be tested while varying methane gas and coal dust concentrations.

A new approach to the determination of coal dust concentration is included with a description of a dielectric dust probe. The measurement technique is based on the change in dielectric constant as the proportion of coal dust in air between probe capacitor plates increases or decreases.

Characterization of coal dust samples is of vital importance. The particle size distribution, coal proximate analysis and elemental analysis were studied. Coal dust was sourced from airborne collected samples, settled dust from mine sources and seam channel samples crushed and sized.

Explosibility test results indicate that a very low concentration of coal dust can form an explosible mixture when dispersed in methane concentration of just below five percent. With low temperature initiators, the coal dust lean limit concentration rises rapidly as the methane concentration is reduced.

An accurate knowledge of the potential explosion hazards of coal dust and coal dust/methane mixture is necessary to establish safe operating conditions in underground mines. The research results outlined extend knowledge in this area.

INTRODUCTION

In Australia, there have been five major coal mine disasters since 1970. These incidents took place at the Box Flat, Kianga No.1 and Moura No.4 Collieries, in Queensland, and at Appin and West Wallsend No.2 Collieries in New South Wales. These disasters resulted in over 50 deaths, and the permanent loss of a number of the mines.

Methane is the most frequent constituent involved in mine explosions, but extensive explosions such as those mentioned above almost invariably involve coal dust. It is rare for coal dust explosions to occur in the absence of methane, although there are several documented cases. One of the worst mine disasters in the history of mining, at Courrieres Colliery, France in 1906, in which 1099 miners lost their lives, occurred in methane free conditions. A case of prohibited explosives initiated a pure coal dust explosion in this incident (Cybulska, 1981). A more usual scenario is, however, for an initial explosion in a methane/air mixture raising and dispersing clouds of coal dust from roadways and ledges, and initiating a powerful and destructive explosion.

The explosive potential of coal dust depends on a number of factors that include fineness of particles, incombustible (ash) content, volatile content, moisture content, entrained flammable gas, and the strength and duration of the explosion initiator. The presence of methane further increases the explosive potential of coal dust, as does the mining method.

The high production rates associated with longwall mining produce large quantities of fine coal, and in gassy mines, large volumes of methane can be liberated simultaneously. As mining progresses, limestone dusting of the face is not possible, so airborne dust or settled dust layers cannot readily be made inert in this vicinity. High production rates in the vicinity of 16,000 tonnes per day are being obtained on occasion on Australia's newer longwall faces, some of which are worked by bi-directional cutting.

Various researchers have postulated that airborne coal dust may explode under optimal conditions with a lean limit concentration across the range from five to 300 g/m^3. Comprehensive tests by the United States Bureau of Mines identify 135 g/m^3 as a lean limit for Pittsburgh coal (Hertzberg et al, 1979), and general agreement appears to have been reached among many authors that a figure of about 55 g/m^3 is a safe lean limit concentration in air for most coals.

Even low concentrations of methane in the mine air lowers the lean limit concentration of coal dust. Similarly, methane/air mixtures have been found to be potentially explosive at lower methane concentrations when airborne dust is present. The normally accepted lower flammability limit for methane of just below five percent concentration in air no longer applies and attains a lower value. The abundance of hydrocarbons in a

methane/air/coal dust hybrid atmosphere reduces the initiation energy needed to start an explosion, and intensifies the level of that explosion.

The subject of dust explosions is complex. Research has been undertaken in a number of major world mining provinces to establish such parameters as lean limit concentrations and the effects of adding inert dusts, but the results are often misleading or contradictory. There is often wide disagreement from author to author. Mixtures of coal dust in air are inherently difficult to control and even with the same apparatus and experimental methods there may not be reproducibility from one test to the next. Furthermore, earlier workers used explosion chambers and apparatus considered crude by modern standards. Problems including non-uniform dust dispersion, inadequacy of the ignition source, and lack of agreement with large scale mine gallery tests have resulted in the development of more sophisticated and larger explosion chambers. Advances in solid-state electronics have led to the development of apparatus which can now measure accurately the parameters involved in coal dust explosions.

An accurate knowledge of the explosion hazards of coal dust in combination with methane is necessary to establish safe operating conditions in underground coal mines. Coal is a highly variable organic derivative and does not lend itself to theoretical calculations of explosive potential based on thermodynamical considerations alone. Further, mining techniques and the mining environment may vary widely and add to the uncertainty in establishing safe conditions. The only effective approach is to monitor what are deemed meaningful parameters during explosions under controlled conditions, and to establish a matrix of many possible combinations of physical and chemical variables. By a systematic approach along these lines, a level of expertise will evolve which will enable the recognition of potentially dangerous combinations of conditions *in situ*. The recent developments and investigations of lean limit concentrations and work on potential sources of ignition, including frictional ignition, are intended to provide the necessary understanding and expertise to recognize potentially dangerous situations before they develop into major disasters involving loss of life and productive capacity.

EXPLOSION CHAMBER

The primary objective of the current program of research is the determination of the lean limit concentrations for several Central Queensland coal types sampled from longwall operations. A 20 litre explosion chamber has been developed which differs in the method of dust dispersion to the chamber used by the U.S. Bureau of Mines (Cashdollar and Hertzberg, 1985), and produces a well dispersed and homogeneous dust cloud which can be maintained for a sufficient period of time to measure experimental parameters accurately. The Chamber (figure 1) consists of a rotating drum with one end plate stationary to accommodate instrumentation. In its development, the curved drum internal surface was lined with horizontal beads of "silicone" sealant to lift and drop coal dust as the drum rotates as part of the dust dispersion mechanism. The system is electrically driven through a variable speed gearbox as preliminary tests showed that the efficiency of dispersion was affected by the rotation rate, the optimal

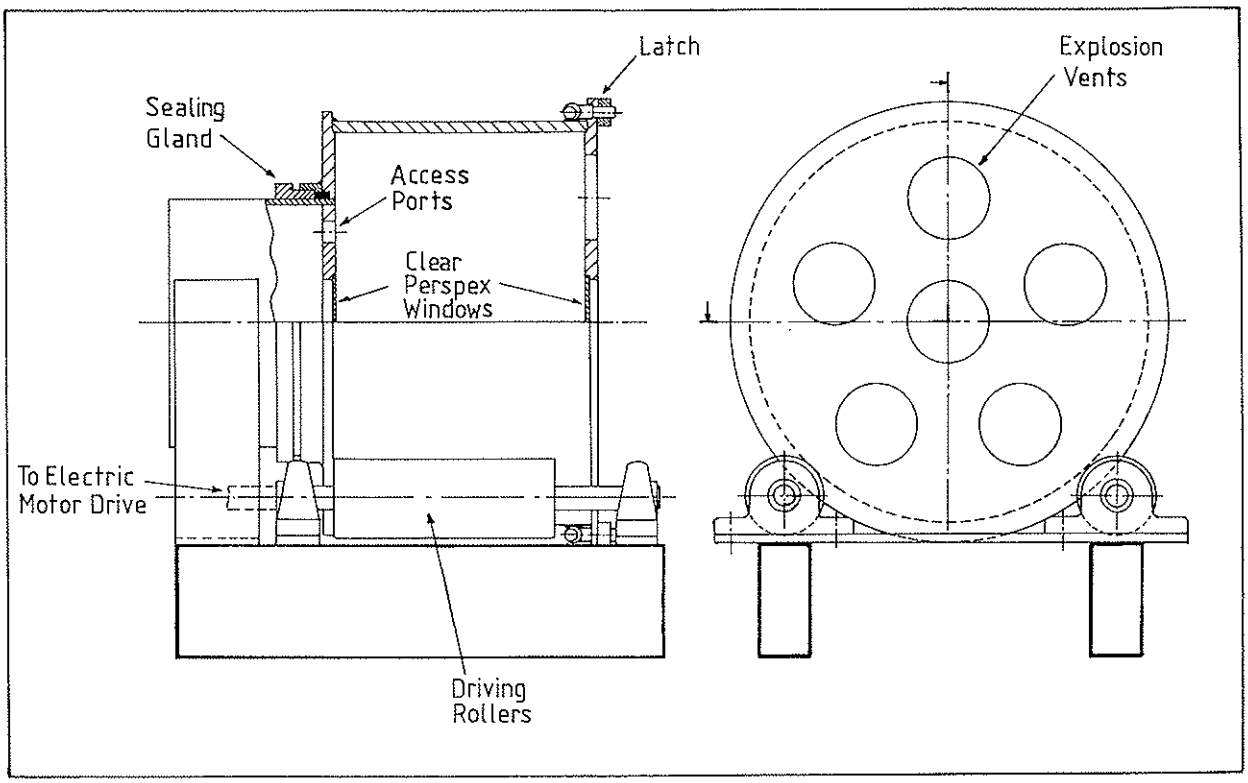

Figure 1 - Explosion Chamber

rate being 52 r.p.m. The interface between the rotating and fixed surfaces of the end plate was sealed with a teflon gasket to provide freedom of movement as well as air-tight contact.

There was no intention of measuring maximum explosion pressures or the rates of pressure rise, and all tests were unconstrained low pressure tests. Explosion pressure release was provided by six vents in the front plate which, during tests, were covered by a sheet of thin transparent plastic taped over this plate to close the system. Methane was introduced by a large graduated gas syringe through a valve in the end plate, with a second valve to release internal pressure during filling.

The system of mechanical rotation alone was found to be only partially adequate in dispersing the coal dust. A more energetic system was required to further disperse and homogenize the air/dust mixture and a satisfactory solution was found in using a 1.0mm brass mesh sieve, suspended horizontally on a frame near the top of the drum and vibrated at 50 Hz with a mains power operated electromagnet. This arrangement provided a far more homogeneous "rain" of dust as sheets of material dumped on the screen trickled through under mechanical vibration. It was evident however, that the finer size fractions were still not effectively dispersed. Air-jet dispersion was found to be a simple and effective solution, using a small 1.0m^3/hr diaphragm pump mounted externally. Air was drawn from the drum and returned to a copper tube mounted horizontally against the curved moving internal surface of the drum. Twenty 1.0mm holes were drilled to face this surface. Short lengths of plastic tubing connected the pump inlet and outlet to the drum, and being a closed system, only a small quantity of coal dust was lost through deposition in the tubing. This was readily cleaned between experiments using compressed air. The air dispersion system was effective in establishing a relatively stable dust cloud up to approximately 375g/m^3.

A 2.0m^3/hr pump has replaced the smaller unit to achieve higher dust concentrations.

DUST PROBES

Opto-Electronic Probe

In the study and measurement of lean limit concentrations of coal dust and methane mixtures, accurate determination of coal dust concentration is the singularly most important research priority. There is no probability of expecting that dust dispersion inside the explosion chamber is perfectly efficient and it is therefore not possible to calculate a nominal dust concentration based on the mass of introduced coal dust and chamber volume. Further, it is desirable to test for homogeneity and stability of dust cloud formation during experimentation by directly and instantaneously measuring the concentration over the duration of each test. The methodology employed initially to achieve this was based on the opto-electronic dust probes developed by the United States Bureau of Mines (Cashdollar et al, 1981), and operates on the principle of the relationship between coal dust concentration and light beam attenuation across an optical pathway. By measurement of the intensity of the transmitted light traversing a dust particle cloud of known length and comparing this value to that of the intensity traversing an identical field devoid of particles, it is possible to determine the density of the

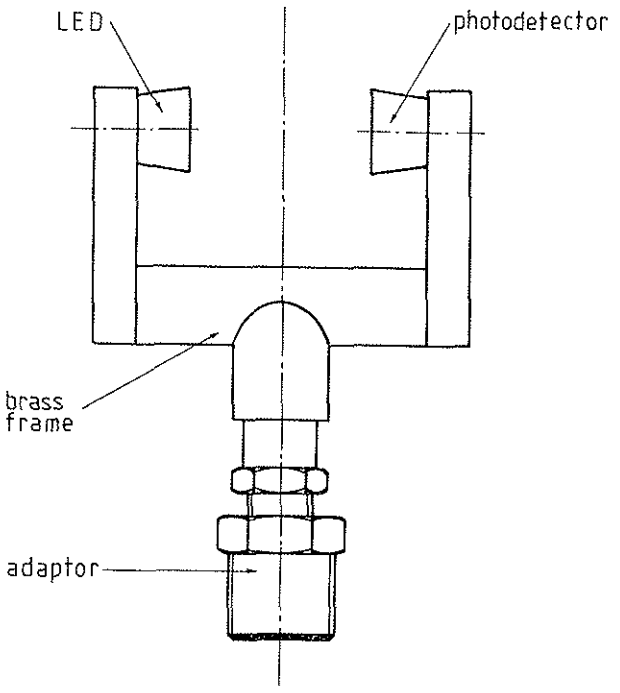

Figure 2 - Optical Dust Probe

particle field. The light intensity was measured electronically and the dust probe used the ARCHER 276-143 high intensity infra-red (880nm) light-emitting diode (LED) and ARCHER 276-142 infra-red phototransistor to form an optical pair mounted on a tuning fork shaped brass frame. Figure 2 shows the basic construction of the probe, and figure 3 the circuitry involved. A separation of 41mm was found to be optimal in terms of measuring range and stability of measurement. An anti-dust solution (Rain-X) applied to the optical surfaces kept dust adhesion to a minimum for the duration of each test (in the order of one minute) as indicated by the output returning to the zero position after a test. All preliminary results for lean limit concentrations were taken using these probes.

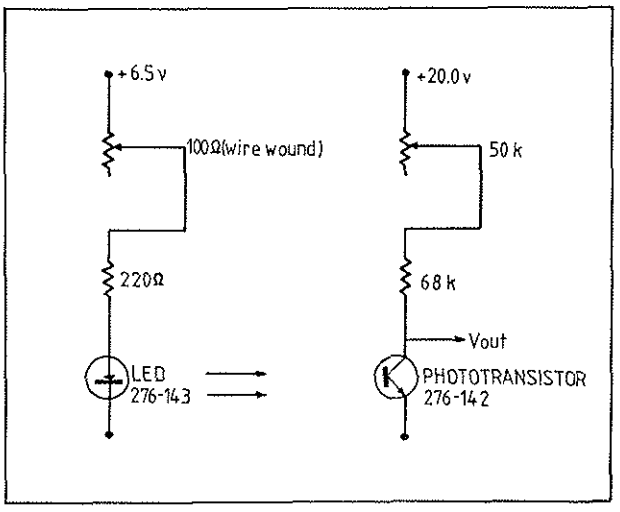

Figure 3 - Circuit Diagram of the Dust Concentration Probe

Dielectric Probe

An objective of the ongoing coal dust explosibility research is the development of an intrinsically safe and portable total dust density meter for use underground. It is intended that development will occur in two stages, the first stage being the construction of a probe for use in the explosion chamber research where coal quality and conditions are readily controlled. The second stage will involve the development of a more sophisticated device for use in underground coal mines. This mine instrument will need to be accurate for a range of coal types with considerable variability in moisture content.

The laboratory chamber probe has been developed and is currently being tested and assessed.

The measurement technique, which has been used by geophysicists (Stacey, 1972; Tuck and Stacey, 1978; Stacey et al, 1988) over the past 20 years, is based on the change in dielectric constant as the proportion of coal dust in air increases or decreases. The equipment incorporates a ratio - transformer bridge for measurement of small capacitances to one part in 10^7.

Theory and Operation. The dielectric dust probe operates on the principle that the capacitance across two metallic plates in parallel opposition depends on the value of the dielectric constant of the insulating materials separating the plates, according to the formula

$$C = k\frac{\varepsilon A}{d} \qquad (1)$$

where C is the capacitance in picofarads
A is the cross-sectional area of the plates in centimetres^2
d is the distance separating the plates in centimetres
ε is the dielectric constant
k is a constant equal to 0.0885

The dielectric constant of air is close to that of free space, namely, 1.0006, and the constant for coal approximately 5.5. It follows that as coal dust is introduced between the capacitor plates, the capacitance increases proportionally. The dielectric layer is now a composite layer of coal and air mixture, and the capacitor may be treated as a series combination of partial capacitors with capacitance

$$C = kA/(d_1/\varepsilon_1 + d_2/\varepsilon_2) \qquad (2)$$

where d_1 is the relative "thickness" of air
ε_1 is the dielectric constant of air
d_2 is the relative "thickness" of coal
ε_2 is the dielectric constant of coal

According to equation 2, the dielectric constant, and hence the capacitance, varies directly with the relative concentration of each component. Measurement of the capacitance, then, provides a measure of the relative concentration of coal dust between the plates.

Equation 1 describes a theoretically ideal example where the distance between the plates is very small in relation to their thicknesses and the electric field lines are perpendicular to the plane of the capacitor plates. In a practical dust probe it is necessary to separate the plates by a relatively large distance in order to measure a significant volume of coal dust/air mixture, and the prototype antenna assembly has a separation of 20.0mm. At this separation the electric field lines tend to stray outwards at the edge of the capacitor plates as shown in Figure 4(a). As a result of this 'fringe effect', equation 1 is not valid and is expressed in the more complex form

$$C = k\varepsilon A/d + k\varepsilon r[-1 + \ln\{16\pi r/d(1 + t/d) + 4\pi t\ln(1 + d/t)/d\}] \qquad (3)$$

where r is the radius of the plates
and t is the thickness,

as coal dust particles in the vicinity of the poorly defined stray field will affect the capacitance. This effect is undesirable because the volume in which the capacitance is affected needs to be accurately known to calculate an absolute concentration.

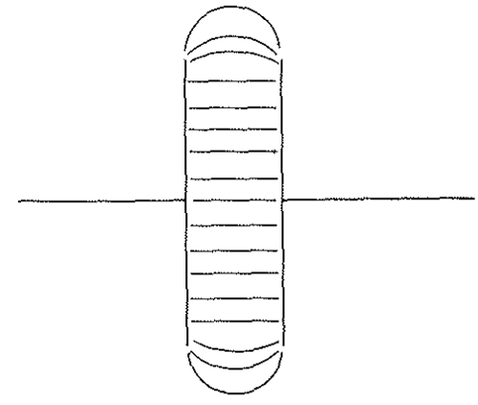

FIGURE 4(a) FRINGE EFFECT - ELECTRIC FIELD

To solve the fringe effect problem, guard electrodes were designed and positioned outside the main capacitor plates as shown in figure 4(b). The earthed guard plates capture stray field lines and clearly delineate the electrical field between the plates.

With reference to figure 4(c), using guard electrodes with dimensions of the assembly satisfying the criteria

$$w > 2d$$
$$y = d$$
$$d = 2r/10$$

then the difference between the measured values of capacitance and those calculated from the equation

$$C = k[\varepsilon\pi(2r + y)^2/4d] \quad (4)$$

is less than 1 percent. The effective diameter of the capacitor plates is increased by half the separation to the guard electrodes (Scott and Curtis, 1939).

It follows that for a composite dielectric layer, equation 2 transforms to

$$C = k[\pi(2r + y)^2/4(d_1/\varepsilon_1 + d_2/\varepsilon_2)] \quad (5)$$

In practice, the prototype antenna assembly was not constructed to entirely conform to these criteria as suitable material could not be found. The final prototype has 60.0mm diameter main capacitor plates machined from solid brass blocks. The thickness of the plates is 2.0mm and the separation between plates is 20.0mm.

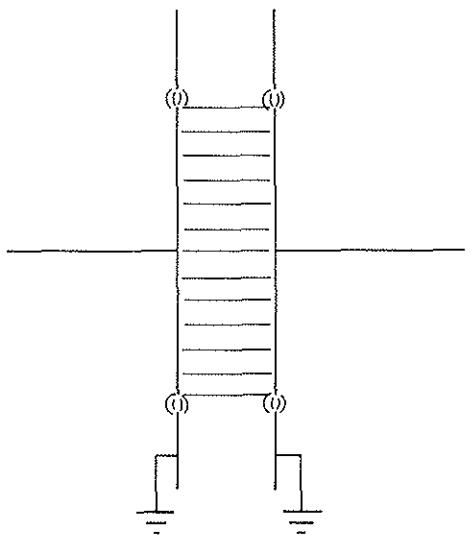

FIGURE 4(b) ELECTRIC FIELD WITH GUARD ELECTRODES

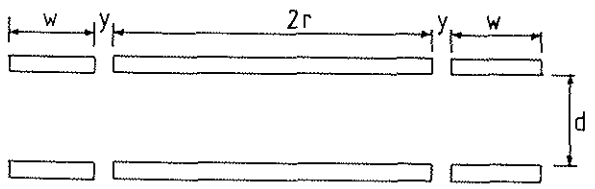

FIGURE 4(c) GUARD ELECTRODE ARRANGEMENT

They are fixed in position inside the guard plates by a 3.0mm band of ARALDITE. The guard plates are 17.0mm wide and 2.0mm thick, and are extended back 20.0mm to form a mount for a 2.0mm thick back plate. Thus each assembly is completely sealed from coal dust contamination and from stray capacitance effects (see figures 5 and 6).

Internally a thin copper wire forms the electrical connection from the main capacitor plate to a BNC socket mounted in the side of the guard plate of each assembly. A miniature preamplifier to match the impedence of the capacitor plates, approximately 40MΩ, to the impedence of the main circuit, 10kΩ, is mounted inside one capacitor assembly. Connection to the main circuit is through lengths of 75Ω coaxial cable.

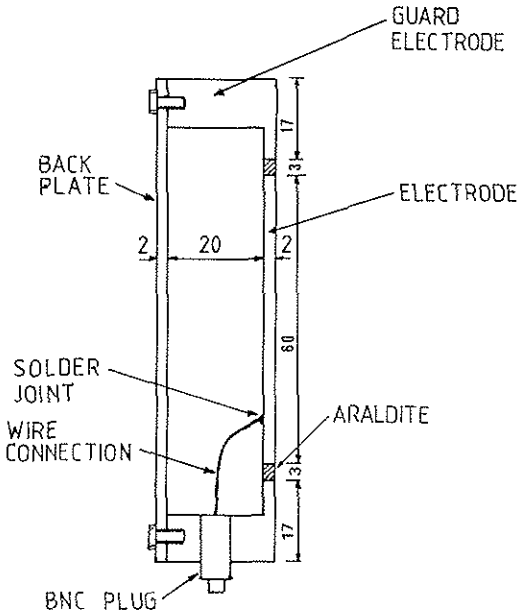

FIGURE 5 DIELECTRIC ANTENNA ASSEMBLY

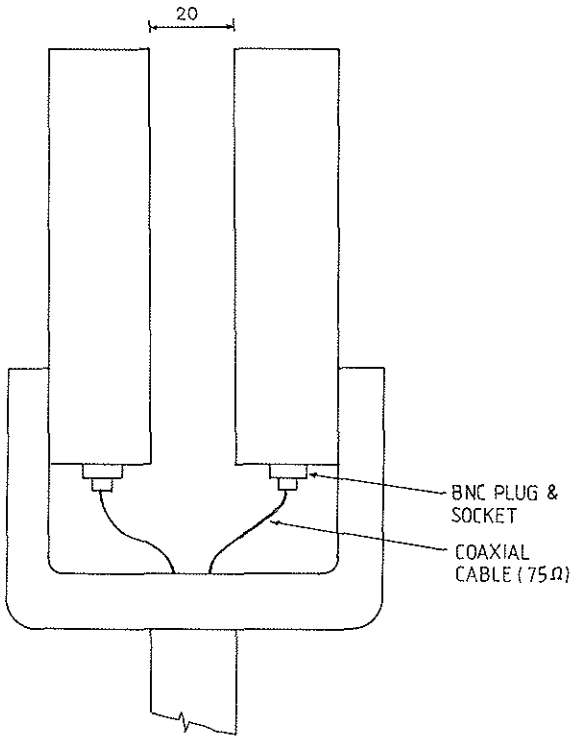

FIGURE 6 DIELECTRIC DUST PROBE

The two assemblies are mounted in opposition on a tuning fork shaped bracket and adaptor which can be screwed into position within the explosion chamber.

The ratio transformer bridge and electronic system for measuring capacitance changes is shown schematically in Figure 7. An essential component of the instrument, a five decade ratio transformer, is an inductive voltage divider providing an output voltage which is a precise ratio of the input voltage. This is achieved by windings which are tapped in decades on a very high permeability core giving a high inductance with a low winding resistance. The voltage division is then directly proportional to the number of windings since the core flux is precisely common to all windings.

A Ratio Transformer R/T driven from a low impedance voltage source is connected to capacitances C_1 and C_2. Neglecting stray capacitances, balance of the bridge is given by:

$$R/(1-R) = C_2/C_1 \qquad (6)$$

The maximum sensitivity for the bridge occurs when

$$R/(1-R) = C_2/C_1 = 1 \qquad (7)$$

that is, when the setting of the ratio transformer is R = 0.5.

Accurate bridge calibration is achieved by using a source of very low impedance which is fed from a 3 kHz low distortion sine wave oscillator. It provides, through an Isolation Transformer I/T, the signal for the ratio transformer and the reference signal for the synchronous detector. The probe and standard capacitor are connected to the instrument by long lengths of coaxial cable which are rigidly attached to a fixed surface to keep stray and lead capacitances constant.

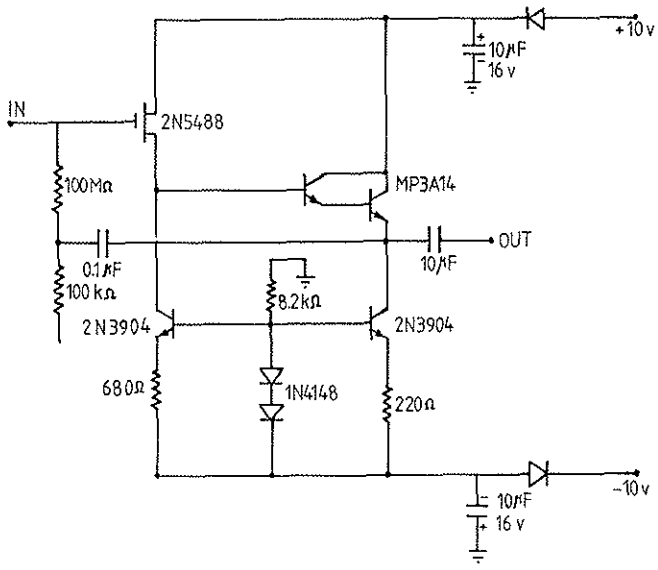

Figure 8 - 50 MΩ Preamplifier

At 3kHz the impedance of the cell is about 40 MΩ so the usual precaution to minimize the out-of-balance signal of mounting the preamplifier (figure 8) as close as possible to an electrode is followed.

The remaining electronic circuitry follows conventional practice for detecting signals which may be obscured by noise. It uses a synchronous detector which is basically a specialised AC voltmeter using phase sensitive detection to recover inphase or quadrature low level signals of the same frequency as the driving frequency. Its output is connected to an RC low-pass filter with selectable time constants thus setting the electronic frequency response. This results in a detector with a very narrow bandwidth typically less than 1 Hz and capable of extracting a signal which is a factor of two orders of magnitude smaller than the noise.

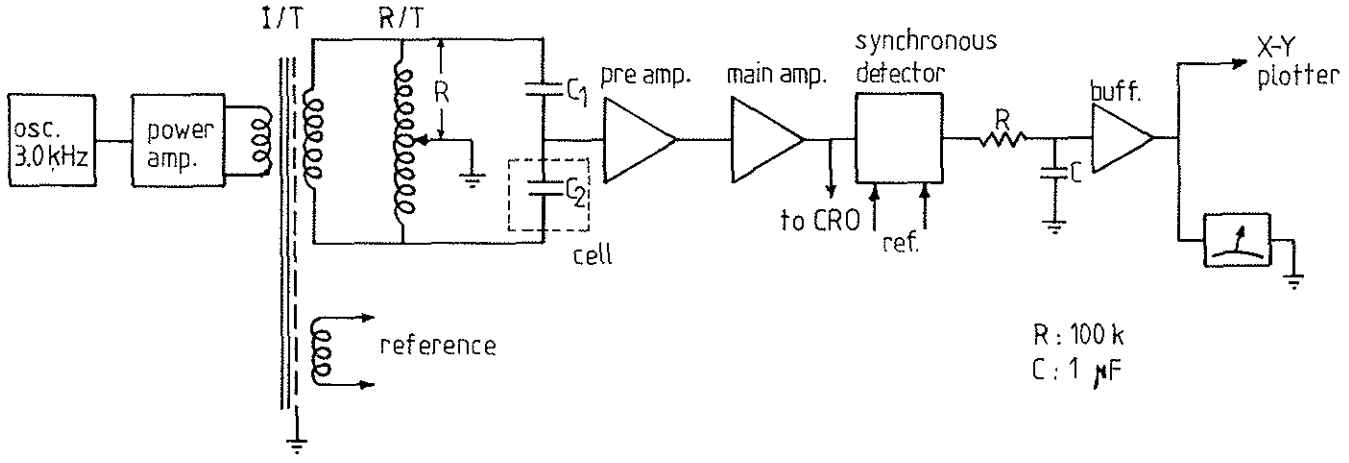

Figure 7 - Schematic of Cell and Electronic Circuitry

IGNITION SOURCE

The ignition sources used throughout the experiments were in the form of tightly wound coils of electrical resistance wire, centrally mounted within the explosion chamber. A variable and high current power supply was provided by a three-phase VARIAC connected to a 240V to 50V step-down transformer. This arrangement allowed the coil temperature to be either adjusted, or set at a specific level.

Two coils were wound from KANTHAL A1 16 B & S furnace element wire, with 10 and 14 turns respectively.

METHANE ADDITION

Compressed pure methane was transferred to the explosion chamber in a 2 litre gas syringe calibrated in units of 0.02 litre. Gas was transferred to the drum via an inlet valve on the rotating portion of the drum base plate.

COAL DUST CHARACTERIZATION

Experimental work was based on coal dust from longwall face collected by channel sampling . Coal samples were subsampled and mixed according to Australian Standard methods. The dust was prepared by oven drying at 102°C, jaw-crushing and hammer-milling. The final sample was stored in drums and used as required over the duration of the project, the literature indicating that storage for this period was acceptable (Cybulski, 1975).

A second comparison set of samples was 'naturally generated and settled dust' in the vicinity of the longwall cutting head. The samples were collected by brushing from ledges on the coal face chock supports. This natural dust sample was collected purely for comparison with the artificially produced dust.

Coal samples were analysed in terms of proximate analysis, crucible swell number, specific gravity and size distribution. Size analysis was by sizing with a Malvern Instruments MASTER Particle Sizer M3.1.

Table 1 shows the proximate results from one mine including comparable data for the natural settled dust.

Table 1

Proximate analysis results for German Creek Seam - artificially produced and naturally settled dusts

Analysis	Artificial	Natural
C.S.N.	7.5	3.5
Ash%	21.2	40.8
Moisture%	1.6	1.2
Volatile Matter%	17.4	15.4
Fixed Carbon%	59.8	42.6

The Malvern sizing (Table 2) details the size distribution for the artificial German Creek dust, and shows that 84.5 percent of the sample is less than the 75µm size fraction. This is an interesting result in that it compares well with the standard d85 sample (85 percent less than 75µm) used extensively in the Polish *Experimental Mine Barbara* explosibility tests (Cybulski, 1975).

The sizing analysis indicated several important characteristics of this coal dust. Firstly, the median diameter, the diameter above and below which contains 50 percent of the mass of the sample respectively, as shown by the Malvern sizing,is 26.7µm for the artificially made sample.

The specific surface area is equivalent to 395cm^2/g (0.06m^2/cc). This is a surprising and unexplained result considering that Cybulski (1975) obtained values ranging between 3850 and 1000 cm^2/g for dusts of similar size distribution. It is evident that more work is needed to clarify the discrepancy.

SIZE MICRONS	% UNDER	% IN BAND
188.0	100.0	0.5
162.0	99.5	1.5
140.0	98.0	2.2
121.0	95.8	3.0
104.0	92.7	3.4
89.9	89.3	3.9
77.5	85.4	4.2
66.9	81.2	4.5
57.7	76.7	4.8
49.8	71.9	5.1
42.9	66.8	5.2
37.1	61.6	5.4
32.0	56.2	5.2
27.6	51.1	4.8
23.8	46.3	4.5
20.5	41.8	4.2

SIZE MICRONS	% UNDER	% IN BAND
17.7	37.6	4.0
15.3	33.6	3.9
13.2	29.8	3.6
11.4	26.1	3.4
9.8	22.7	3.1
8.5	19.6	2.9
7.3	16.7	2.8
6.3	13.9	2.8
5.4	11.1	2.6
4.7	8.4	2.3
4.1	6.1	2.1
3.5	4.0	1.5
3.0	2.5	0.9
2.6	1.6	0.7
2.2	0.9	0.3
1.9	0.6	0.2

Specific surface area 0.06 sq.m./cc.

MESH	APERTURE µm	% UNDER	% IN SIEVE
10	2000.0	100.0	0.0
12	1700.0	100.0	0.0
14	1400.0	100.0	0.0
16	1180.0	100.0	0.0
18	1000.0	100.0	0.0
20	850.0	100.0	0.0
25	710.0	100.0	0.0
30	600.0	100.0	0.0
35	500.0	100.0	0.0
40	425.0	100.0	0.0
45	355.0	100.0	0.0
50	300.0	100.0	0.0

MESH	APERTURE µm	% UNDER	% IN SIEVE
60	250.0	100.0	0.0
70	212.0	100.0	0.0
80	180.0	100.0	0.0
100	150.0	98.8	1.1
120	125.0	96.3	2.5
140	106.0	93.2	3.2
170	90.0	89.3	3.8
200	75.0	84.5	4.8
230	63.0	79.4	5.1
270	53.0	73.9	5.5
325	45.0	68.4	5.5
400	38.0	62.5	6.0

D(v,0.5) = 26.7 µm
D(v,0.9) = 92.4 µm
D(v,0.1) = 5.1 µm
D(4,3) = 38.6 µm
D(3,2) = 13.0 µm

TABLE 2 - SIZE DISTRIBUTION BY MALVERN SIZING

EXPERIMENTAL PROCEDURE

The experimental goal was the determination of the lean limit concentrations for German Creek coal dust/methane mixtures, and the methodology was one of gradually reducing the concentrations of both components from an explosive mixture to the point where an explosion could no longer be initiated. Trials began with a series of tests on pure methane from a 10 percent mixture with air and decreasing by 1 percent in each

consecutive test. When the lean flammability limit had been established, coal dust was introduced and again the coal dust/methane mixture became explosive. The coal dust density was gradually reduced to again find the lean limit. In the next step, the methane concentration was further reduced, and ignition was attempted by the addition of a larger quantity of coal dust than had been used for the immediately higher methane concentration. Again the coal dust was reduced in steps until the lean flammability limit was established.

In each test, the rotating explosion chamber was thoroughly cleaned with compressed air, as were the air lines of the air jet dispersion system. The optical surfaces of the dust probes were cleaned with tissue paper. A weighed quantity of standard German Creek coal dust was distributed on the bottom surface of the drum. A rough approximation of the weight required could be made from the finding that the drum was consistently between 10 and 20 percent efficient in dispersing the sample. The front plate of the chamber was re-lined with plastic sheeting and bolted in position to make an air-tight chamber. The measured volume of methane was introduced with the 2 litre syringe. At this point the ignition source was supplied enough current to reach approximately 600°C as measured by a thermocouple, well below the explosive temperature. The dust probe outputs were checked, and the chart recorder switched on. The explosion chamber, vibrating mesh and air dispersion compressor were simultaneously switched on at the instrumentation desk. The dust concentration was given a short time to stabilize, and the ignition source current slowly increased, the thermocouple indicating the rising temperature. At the moment an explosion was registered on the chart recorder, this temperature was read and recorded.

PRELIMINARY RESULTS

An example of results obtained is shown in Table 3. The concentration of the coal dust sample required to initiate a well defined explosion is shown against the methane concentration present

Table 3

CH_4 conc.(%)	Coal dust conc(g/m^3)
6.00	0
5.50	3
5.13	68
5.10	100
5.05	163
5.00	170
4.90	261
4.80	>375

The lean limit concentrations show a clear upward trend even for small decreases in methane concentration to 4.9 percent. A concentration of 375g/m failed to initiate an explosion at 4.80 percent methane concentration, and it is possible only to record that the required concentration is in excess of this figure. Limitations of the explosion chamber design at the time of obtaining these results made it impossible to achieve dust concentrations in excess of $375g/m^3$.

Of the 34 tests resulting in explosions, all were initiated at ignition temperatures less than 882°C, as indicated with the electronic thermometer. The lowest recorded temperature was 670°C. The remaining tests were with mixtures which were found to be non-explosive despite the ignition source temperature being elevated to 1100°C. In one non-explosive test, the ignitor current was increased to the point of fusion, at about 1600°C.

CONCLUSIONS

The development and laboratory usage of the 20 litre rotating explosion chamber has led the authors to conclude that this approach to coal dust formation and experimentation is valid, and overcomes the limitations associated with the "instantaneous" dust chambers used elsewhere. The system generates a dynamic dust cloud which rapidly reaches stable equilibrium, thus allowing testing for homogeneity and stability of formation. Limitations in the maximum dust concentration attainable were initially a problem which have been addressed by the replacement of the original air jet dispersion system with a larger unit.

The solid state dust probes proved to be invaluable in being able to operate in the hostile environment within the chamber. However, the tendency of coal dust to adhere to the optical surfaces if used for longer durations, and the dependence of the calibration curves on particle size and shape have lead the authors to conclude that a probe based on the dielectric principle will be more accurate and reliable.

It is evident that the method for measuring ignition source temperature with thermocouple and electronic thermometer was unsatisfactory. Consequently, the results from this aspect of the research must be read as estimations only. A realistic approach to the area of ignition dynamics, namely, studies of the shape, size, temperature, and total energy input of an ignition source will require the use of a suitable pyrometer or infra-red camera.

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