THE MEASUREMENT OF QUENCHING DIAMETERS AND THEIR RELATION TO THE FLAMEPROOF GROUPING OF GASES AND VAPOURS

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SYNOPSIS

Minimum quenching diameters have been determined by observing flash-back of flames through circular holes drilled in thin brass plates. For about 20 gases and vapours, ranging from acetylene to ammonia, the order of increasing quenching diameter is substantially the same as the order of increasing flameproof safe gap (maximum experimental safe gap). The application of quenching diameter measurements to assessing the explosion hazard properties of gases is discussed and, in particular, to assessing flameproof requirements.

Introduction

When it is required to assess the explosion hazard rating of a gas or vapour not hitherto handled on an industrial scale it is necessary to know, or estimate, a number of properties (*e.g.* lower flammable limit, self-ignition temperature, maximum explosion pressure, maximum flame speed, maximum rate of pressure rise): before safe electrical equipment can be prescribed it is necessary to know the Flameproof Group and Intrinsic Safety Class of the gas.

Some of these properties are interrelated and it is generally appreciated that if a number of gases are arranged in order of increasing hazard with respect to three of these properties, *viz.* decreasing order of flameproof safe gap, decreasing order of minimum igniting current (the property which determines Intrinsic Safety Class), or increasing maximum flame speed, then these particular orders are roughly the same and hence these three hazard properties must be governed by substantially the same combustion properties of the gases. On the other hand, the orders of increasing hazard with respect to self-ignition temperature, lower flammable limit, or maximum explosion pressure, are quite different and other properties must be involved. Given a gas of unknown properties it would obviously be advantageous if a relatively simple measurement could be made which would place the gas at least roughly within the ranking of gases for the three hazard properties which are related. Let us first consider the criteria for a flameproof enclosure and the method of testing gases for their assignment to flameproof groups.

Flameproof Enclosures and Gas Groupings

There are two main criteria which must be satisfied by a flameproof enclosure:[1]

> "*A flameproof enclosure for electrical apparatus is one that will withstand, without injury, any explosion of the prescribed flammable gas that may occur within it . . ., and will prevent the transmission of flame such as will ignite the prescribed flammable gas which may be present in the surrounding atmosphere.*"

Explosion will not be transmitted to the flammable vapour outside the apparatus if the gaps in the enclosure are flanged and if the distances between flanges are sufficiently small. There is a maximum permissible gap for each gas or vapour; this is derived from measurements made in a special apparatus consisting of a sphere of eight litres capacity divided equatorially, each half being flanged. The two halves are held apart by spacers. Outside the sphere is a mixture of the gas or vapour with air of the composition which is most easily ignited; inside is a mixture of slightly different composition —that which is the most incendive. The inner mixture is sparked and it is observed whether the gas outside is ignited. The gap between the hemispheres is varied and a number of trials made from which is found the largest gap which will not allow ignition outside in 20 attempts. This is called the maximum experimental safe gap (mesg). From the pattern of the results a statistical calculation gives an estimate of that gap which with a high degree of probability gives a $10^6 : 1$ risk against ignition of the gas outside; this is called statistical maximum safe gap (smsg). Gases are placed in groups on the basis of smsg values. For any gas the smsg is less than the mesg roughly in the ratio 3 : 4 although there is a considerable scatter in this ratio.

Gases and vapours are divided into flameproof groups. This is done on the basis of smsg values. Group I is reserved for methane; Group II gases have smsg values above 0·0250 in., Group III between 0·0150 and 0·0250 in. inclusive, and Group IV less than 0·0150 in.

Gases which on this basis fall in Group II all have mesg values 0·033 in. or greater; the Group III gases have mesg values between 0·033 and 0·024 in. The gas with the lowest mesg value in Group III is town gas; since the publication of BS 229 : 1957 town gas has changed and the mesg has increased (see, for example, Ref. 2).

In the testing of apparatus with respect to the different groups there is a test gas for each group: for Group I it is methane, for Group II, pentane, and for Group III, a mixture of hydrogen and methane (85/15). So far as damage to the enclosure is concerned the pressure rises produced by the test gases are measured in the enclosure and the enclosure is then tested to a pressure 50% in excess of this. The maximum pressure generated by pentane is rather greater than that generated by the test gas for Group III but the use of the 50% excess pressure in testing makes the differences between the groups of second importance in this respect.

If it is required to prescribe flameproof equipment for a gas which has not been assigned to a group, therefore, one essential piece of information is an estimate of the safe gap for the gas. The rigorous determination of safe gaps requires specialised equipment and techniques and a good deal of a

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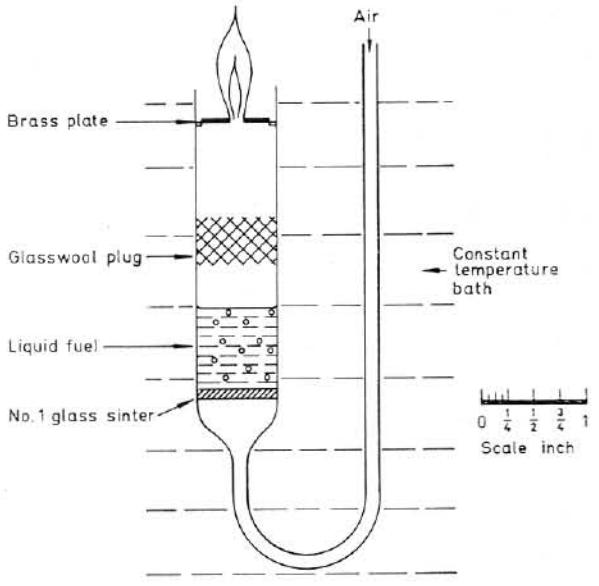

Fig. 1.—*Diagram of the apparatus to determine quenching diameters of liquid fuels*

time. It is worth considering whether there is some easily measured property of a gas which may be directly related to its flameproof safe gap. If the gas falls in a homologous series, the adjacent members of which have been tested and fall into the same flameproof group, then clearly the gas in question is likely to fall into this same group (even so there does not appear to be a detailed systematic relationship between, for example, the number of carbon atoms and the safe gaps in the paraffin series of hydrocarbons). Phillips has shown how to calculate a function which gives a good correlation with mesg for a number of gases.[3] This function is the maximum rate of entrainment of fresh combustible–air mixture into a jet of hot gas emerging from a flanged gap which allows the maintenance of a high temperature in the jet and hence allows development of ignition; it can only be applied to other gases when certain data for the gases are available which are consistent with those used to obtain the correlation.

Another correlation is between mesg and the logarithm of the minimum igniting current.[2] The latter is the basis of Intrinsic Safety Classification, but its determination is hardly easier than the direct measurement of safe gap.

The simplest laboratory measurement which might be directly related to safe gap is the quenching distance between parallel plates or the geometrically related property, quenching diameter. Quenching diameters have therefore been measured for a number of gases and vapours.

Experimental

Quenching diameters have been determined by observing flash-back of flame through single holes drilled in brass plates $\frac{1}{32}$ in. thick. The holes were drilled with standard twist drills. Fig. 1 is a diagram of the apparatus. Gas–air mixtures were made up by metering gas streams with Rotameters; vapour–air mixtures were made up by bubbling air through the liquid and the composition varied by varying the liquid temperature. The procedure was to stabilise a flame above the brass plate for one second, after which the gas flow was stopped and it was observed whether the flame flashed back through the hole or was quenched; this was repeated 20 times. The size of the largest hole through which the flame did not pass in 20 attempts and the smallest size of hole to pass the flame at least once in 20 attempts were each determined for a series of compositions. The pairs of critical hole sizes were plotted against composition; minimum values were read off from these plots and the minimum quenching diameter was taken to be the mean of these.

With this experimental procedure any heating of the brass plate by the flame was insufficient to affect the result. Where the temperature required to give the desired composition range of vapour–air mixtures was above ambient temperature the whole experiment was conducted at an elevated temperature; otherwise the quenching diameters were determined at 25°C. No correction for temperature has been made to those quenching diameters determined above ambient temperature since the mesg values for these materials must also have been determined at elevated temperatures.

For ammonia and methane–nitrogen mixtures larger versions of the apparatus were used. In the case of ammonia a short flame tube was used: a flame was stabilised two inches above the brass plate at a heated orifice; when the gas supply was stopped the flame travelled down to the cold brass plate and either passed through or was quenched in the usual way. (The plates in these two cases were $\frac{1}{25}$ in. thick.)

Determinations have been repeated for several gases at different times by different workers using different gas supplies, and the results agreed within one hole size.

The effect of disc thickness was investigated. Increasing the thickness to $\frac{1}{16}$ in. and $\frac{1}{8}$ in. increased the quenching diameters only slightly and in roughly the same degree for all the gases and vapours tested.

There are clearly differences between the conditions of quenching diameter and mesg determination. In the case of the quenching diameters the composition of the gas into which the flame flashed back was controlled and varied but the gas burning above the plate was inevitably diluted by entrained air. This is different from the mesg determination where the most incendive mixture is often slightly richer in fuel than

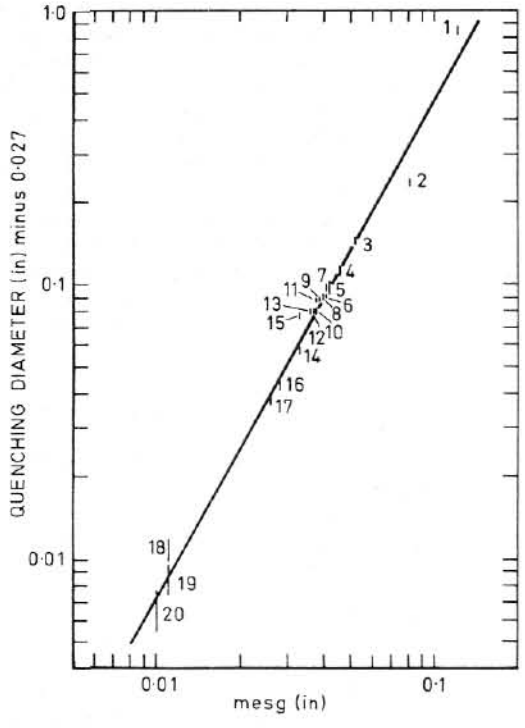

Fig. 2.—*mesg plotted against [quenching diameter (in inches) —0·027]. The lengths of the vertical lines represent the differences between the observed smallest holes for passing flames and the largest for quenching*

the most easily ignited mixture. The biggest difference however arises from the fact that in the quenching diameter determination the flame is burning back into still gas whereas in the mesg determination hot combustion products are being forced by pressure into the unburnt gas.

Discussion of the Experimental Results

The results are given in Table I.

TABLE I.—*Experimental Results*

		Mean minimum quenching diameter (in.)	*mesg (in.)	Minimum igniting current (A)
1†	Ammonia	0·869	0·125 (*a*)	1·07
2	25% Methane 75% nitrogen	0·259	0·081 (*b*)	
3	2-Chloropropane	0·171	0·052 (*b*)	
4	Methane	0·139	0·046	0·195
5	Xylene	0·122 (39°C)	0·042	
6	*iso*-octane	0·117	0·041	
7	Ethyl acetate	0·123	0·041	
8	Ethanol	0·117	0·040	
9	Amyl acetate	0·116 (48°C)	0·039	
10	Vinyl chloride	0·107	0·038	0·180
11	*iso*-butanol	0·114 (40°C)	0·038	
12	*n*-butanol	0·106 (45°C)	0·037	
13	Methanol	0·106	0·036	0·167
14	Butadiene	0·084	0·033	0·129
15	Ethyl ether	0·103	0·033	0·145
16	Ethylene	0·069	0·028	0·108
17	Ethylene oxide	0·054	0·026	0·101
18	Water–gas	0·0375	0·011 (*a*)	0·080
19	Hydrogen	0·0354	0·011 (*a*)	0·075
20	Acetylene	0·0335	0·010 (*a*)	0·060
21	Ethyl chloride	0·127	—	0·20
22	Acetic acid	0·22 (61°C)	—	0·39

* mesg values are from B.S. 229 : 1957 except for

(*a*) Ref. 2

(*b*) " Safety in Mines Research," 1965. (London: H.M.S.O.)

† The numbers on the left-hand side refer to the numbers on Fig. 2.

Fig. 2 shows a log/log plot of mesg *versus* (quenching diameter $-0{\cdot}027$). The equation of this line is:

$$\log_e M = -1{\cdot}8934 + 0{\cdot}5484 \log_e (Q - 0{\cdot}027).$$

No special significance is attached to the precise form of this relationship except that it gives a sufficient approximation to a straight line to apply statistical treatment. The important point is that over a very wide range of quenching diameter values, quenching diameter and mesg increase for the most part together. (Some of the results have already been published[4] but not the three largest quenching diameters.) No further property of the gases was found which when taken into account improved the correlation; thus, at an early stage of the work covering only the Group II and III gases, no improvement in the correlation with mesg was found by considering the explosion pressures or the rates of pressure rise of the various gases.

Fig. 2 therefore allows some inference to be drawn about the likely mesg of a gas if its quenching diameter is known.

It is suggested that a gas of unknown properties may be examined in the following way. The quenching diameter should be determined in a manner similar to that described above. It should then be possible to choose several gases whose mesg values have been determined which will give quenching diameters, determined in the same apparatus, lying either side of the quenching diameter of the gas being examined. If the quenching diameter of the gas can be bracketed by Group II or Group III gases in this way the maximum explosion pressure and maximum rate of pressure rise of the gas should be examined since capacity to withstand damage is a requirement of a flameproof enclosure. If these are satisfactory then it should be possible to say that the gas would be covered by flameproof equipment appropriate to the gases with similar quenching diameters.

Looking at the problem in another way, in the prescription of flameproof equipment the vital distinction is between Group IV and the rest. This is because there is no British equipment available for Group IV gases; but on the other hand much equipment is now certified with respect to both Group III and Group II. We may consider the division between Groups III and IV to be defined by mesg value of 0·020 in. Statistical analysis of the relationship shown in Fig. 2 shows that if the quenching diameter of a gas determined as described here is greater than 0·057 in., corresponding to a predicted mesg of 0·023 in., then the true mesg will

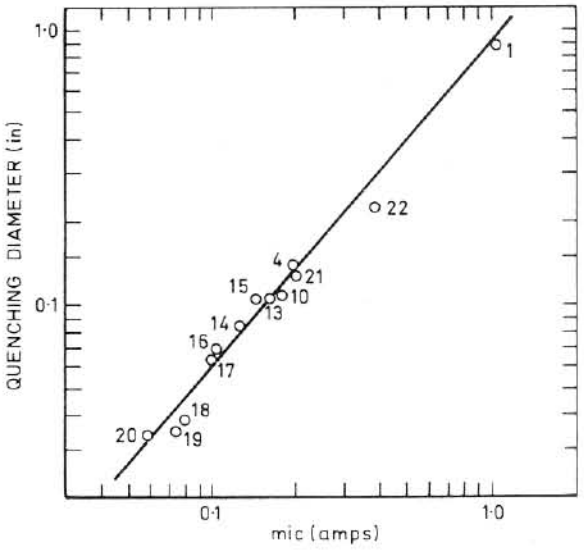

Fig. 3.—*Minimum igniting current (Ref. 2) plotted against quenching diameter*

be greater than 0·020 in. with a confidence of 10^3 to 1. If the quenching diameter is greater than this value then it should be possible to regard the gas as covered by Group III flameproof equipment. Again it would be advisable to check the maximum pressure rise and rate of pressure rise of the gas to ascertain that these are not substantially more severe than those of the flameproof test gases.

A further possible limitation is that although the relationship in Fig. 2 covers a wide range of chemical structures, it is possible that it does not hold for molecules which do not contain hydrogen (see Ref. 4 for a discussion of the case of carbon monoxide).

Since there is a correlation between mesg and minimum igniting current,[2] a correlation may be expected also between minimum igniting current and quenching diameter. A log/log plot is shown in Fig. 3. This includes two gases for which minimum igniting current has been determined, but not the mesg.

Acknowledgments

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References

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2 Slack, C. and Woodhead, D. W. *Proc. Instn elect. Engrs*, 1966, **113**, 297.

3 Phillips, H. *Combust. Flame*, 1962, **8**, 129.

4 Grove, J. R. *Combust. Flame*, 1966, **10**, 308.

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DISCUSSION

Mr. H. G. RIDDLESTONE said that it was very interesting to see that this correlation had been made between the flameproof groups and quenching diameters. Slack and Woodhead have already shown that there is good correlation between igniting currents and safe gaps for flameproof equipment (Ref. 2 of the paper).

Grove mentioned the difficulty of the engineer wanting to know which group a particular gas was in. In B.S.1259: "*Intrinsically Safe Electrical Apparatus*," the number of gases classified was about 140, which was about 100 more than in B.S.229: "*Flameproof Enclosures*." There was therefore a good chance that the gas one wanted to know about was in the intrinsic safety classification. The correlation found by Woodhead and Slack could then be used to obtain the appropriate flameproof group. Only about 40 of the gases had been classified by measurement. The others had been classified by a group of experts on the chemical and combustion properties of gases, including Dr. Burgoyne. The two systems, of correlation and chemical comparison, should together make it possible to classify the majority of the more common gases used in industry.

Mr. GROVE said that quenching diameter measurement was a way of getting an appreciation of a gas which was either too toxic or too corrosive to contemplate using in the usual apparatus without a lot of preparation.

Mr. H. PHILLIPS said that in his department they too had done some correlation work in trying to estimate the value of safe gaps from flame properties. It was interesting to note that Grove had found a very good correlation so far as hydrocarbons were concerned. He thought that if one wanted to improve on this and include mixtures such as carbon disulphide and carbon monoxide, *etc.* one needed to go further back into the theory of combustion and find a correlation which relied on chemical properties such as the activation energy of the combustion reactions.

Mr. GROVE pointed out that Mr. Phillips' calculation of maximum entrainment rate required absolutely self-consistent values, particularly for the energy of activation for all the gases in question. However, that was obviously a more fundamental approach in principle.