

THE MAXIMUM EXPERIMENTAL SAFE GAP FOR A SPRAY OF HIGHER FLASH POINT LIQUID

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Summary

An unheated 8-l spherical explosion vessel is used to measure the Maximum Experimental Safe Gap for sprays of liquids whose flash points are higher than laboratory temperature. A simple model is used to calculate the fraction of the liquid volume that is evaporated by the hot combustion products from the gap. The variations between the liquids, mainly caused by their different boiling point and latent heat of evaporation, are illustrated. The effect of the mean drop diameter in the spray is considered.

Introduction

The Maximum Experimental Safe Gap (MESG) for a spray, or mist, in air, may be defined as the maximum distance between the parallel surfaces of an elongated gap in the wall of an enclosure that will prevent the explosion of a specified gas and air mixture at its most incendive concentration inside the enclosure, from igniting the spray on the outside.

Previous measurements of MESG have involved a gas, or vapour, and air mixture, on each side of the gap. Earlier British measurements used an 8-l spherical explosion vessel, with an equatorial flanged gap (flange width 25.4 mm) [1]. The method described by the International Electrotechnical Commission (IEC), employed a 20-ml spherical explosion vessel, with 25 mm flanges [2]. MESGs determined in these two types of apparatus, generally agree. A heated form of the IEC apparatus was used to measure MESGs for the vapours of liquids that form flammable mixtures with air only at higher temperatures (higher flash point liquids) [1,3].

The MESG is important for the design of flameproof enclosures for electrical equipment used in flammable atmospheres. Flammable gases and vapours are placed in different groups according to their MESG, and the design and test requirements for flameproof enclosures depend upon the group involved.

For industrially important gases and vapours, Group IIA includes the least incendive compounds and IIC the most incendive.

A normal temperature spray or mist of a flammable liquid in air, whose flash point is above normal temperature, is also considered to be a flammable atmosphere [4]. Such a spray may be placed in a group, according to the MESH determined for the compound as a gas or vapour in the heated apparatus, but this procedure might not give a correct grouping for a spray.

The present paper describes the measurement of MESHs for sprays of higher flash point liquids, using apparatus at normal laboratory temperature. Calculations of the evaporation rate, using a simple physical model, illustrate the effects of the relevant physical properties of the liquids sprayed. The results are intended to provide further information, which will be useful when assessing the hazard and taking preventative measures, for these sprays.

Measurement of MESHs for sprays

The 8-l spherical explosion vessel (Fig. 1) was filled with 4.4% by volume propane in air mixture to provide a clearly defined incendive condition. The cylindrical external volume of 90 l was enclosed by a sleeve of thin plastic sheet. An air driven spray gun was mounted inside the external enclosure, in a position such that the nozzle of the gun was at the same level as the equatorial gap in the sphere, and the spray axis was horizontal. The direction of the spray was approximately tangential to the circumference of the sphere. The edge of the spray, 150–200 mm from the nozzle, occupied the region close to, but outside, the gap, near to the position of the electrical spark, which ignited the propane in air mixture inside the sphere.

This position of the spray was found, by experiment, to be more likely to give transmission of ignition, than an arrangement where the spray was directed towards the gap, with the nozzle further away.

Butanol, kerosene, hexanol and ethylene glycol were the liquids sprayed;

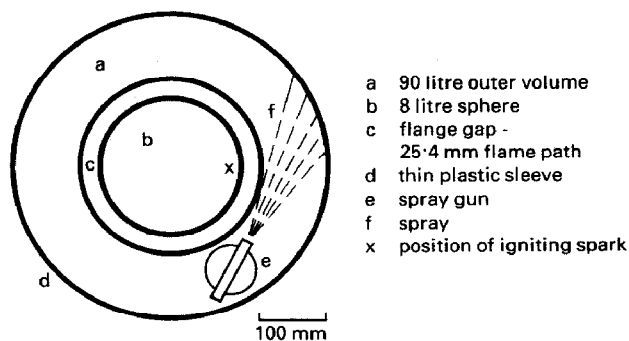


Fig. 1. Location of spray in 8-l MESH apparatus.

TABLE 1

Experimental values for liquids sprayed

	Butanol	Kerosene	Hexanol	Ethyleneglycol
Flash point (°C)	29	38	63	111
Boiling point (°C)	118	150-300	157	197
Latent heat of evaporation (J/g)	589	251	451	798
Density (g/ml)	0.81	0.8	0.82	1.1
Fuel equivalence ratio at nozzle	10	13	—	4
Drop mean diameter in spray (μm)	31	25	—	29
MESG for vapour [1] (mm)	0.91	1.05	0.98	—
MESG for spray (mm)	1.12	1.20	1.14	—

they were selected to include a range of flash points above laboratory temperature (Table 1).

The operating conditions (air supply pressure, air and liquid flow rates) for the spray gun were varied to optimize conditions for transmission of ignition.

A relatively low pressure (0.7 bar above atmosphere) giving lower flow rates, was found to be best, and the fuel equivalence ratio at the nozzle (the ratio of the actual amount of fuel injected to the stoichiometric amount for the air supplied through the nozzle) when the MESG was measured, is shown in the table. The injected mixture was fuel rich, and a separate air supply (at twice the air flow rate through the spray gun) was flushed continuously through the external volume. A spray duration of 20-30 s before ignition of the propane and air, without stopping the spray, gave transmission of ignition at the smallest gap.

When transmission occurred, the spray ignited, and the mist in the external volume exploded. If the spray was turned off, immediately before igniting the propane and air, transmission of ignition to the mist was not achieved; and this was still the case, for longer spray durations, up to 2 or 3 min.

The MESGs for sprays of butanol, kerosene and hexanol are shown in the table. The ethylene glycol spray did not ignite with the maximum available gap of 2.6 mm. The ignition of the external volume filled with 4.4% by volume propane in air, did not ignite the ethylene glycol spray.

A Malvern Instruments apparatus for measuring particle size was used to determine the mean drop diameter in the unenclosed spray. A helium-neon laser was directed across the spray, and the small angle light scattering was detected by annular photodiodes. The instrument computer calculated the mean diameters, shown in Table 1, assuming a Rosin-Rammler distribution of drop diameters.

Evaporation of the spray

The hot combustion products from the gap evaporate the liquid drops in the spray, before further combustion takes place. A calculation of the evaporation rate, which depends upon the liquid properties and the average drop size, gives insight on the ignition behaviour of the different sprays.

A simplified model is used to calculate the fraction, f , of the liquid volume evaporated from the spray initially at laboratory temperature T_0 , when the drops are mixed with gas at a constant high temperature T_∞ , for a time τ .

The Rosin-Rammler distribution of drop diameters, for a sharpness index 2, is

$$F(D) = \frac{D}{2(D_m)^2} \exp\left[-\left(\frac{D}{2D_m}\right)^2\right] \quad (1)$$

where D is the drop diameter and D_m is the number mean drop diameter.

The fraction evaporated is then given by

$$f = (I_1 + I_2) / I_3 \quad (2)$$

where

$$I_1 = \int_0^{D_e} D^3 F(D) dD, \quad I_2 = \int_{D_e}^{D_b} (D^3 - D_f^3) F(D) dD, \quad (3)$$

$$\text{and } I_3 = \int_0^{\infty} D^3 F(D) dD$$

D_e is the maximum initial diameter of drop that is completely evaporated, and D_b is the maximum initial diameter of drop that reaches boiling point, in time τ . A drop of initial diameter D , such that $D_e < D < D_b$, is partly evaporated in time τ , and D_f is the final diameter of this drop.

In the calculation of D_b , the approximate value $T_\infty - \frac{1}{2}(T_0 + T_b)$ is used for the temperature difference between the gas and the drop, below its boiling point T_b . The heat transfer coefficient is $h = K Nu / D$. K is the thermal conductivity of the gas, and Nu is Nusselt's number. For slowly moving drops, assumed in this model, $Nu = 2$.

Equating the heat transferred to the drop in time τ , to the heat required to raise the temperature of the drop to boiling point, gives

$$D_b = (\tau / G)^{\frac{1}{2}} \quad (4)$$

where

$$G = \frac{\rho s (T_b - T_0)}{6 Nu K [T_\infty - \frac{1}{2}(T_0 + T_b)]} \quad (5)$$

ρ is the density, and s is the specific heat, of the liquid.

For the calculation of D_e and D_f , the following expression for the rate of change of drop diameter by evaporation is used:

$$-\frac{d}{dt}(D^2) = C \quad (6)$$

where the evaporation rate constant is

$$C = \frac{8K}{\rho C_p} \ln \left[1 + \frac{C_p}{L} (T_\infty - T_0) \right] \quad (7)$$

L is the latent heat of evaporation of the liquid, and C_p is the specific heat at constant pressure of the surrounding gas [5].

$$[D(t)]^2 = D^2 - Ct \quad (8)$$

giving

$$D_e = [\tau/1 + 1/C]^{\frac{1}{2}} \quad (9)$$

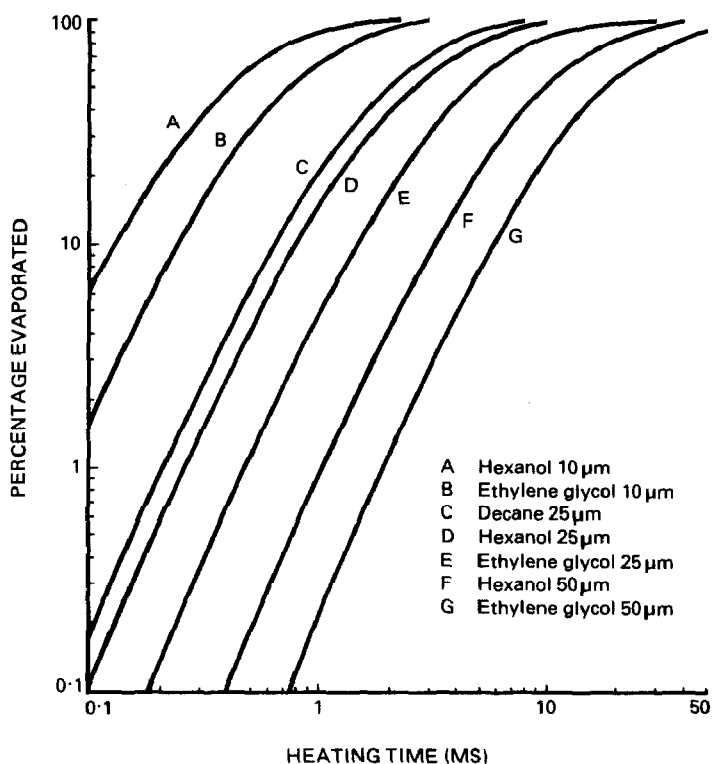


Fig. 2. Calculated evaporation from a spray in an atmosphere at 1650 K.

and

$$D_f = [D^2(1 + CG) - C\tau]^{\frac{1}{2}} \quad (10)$$

The integrals are evaluated numerically for sprays of butanol, decane, hexanol and ethylene glycol. Decane is included in the calculations, as a compound of well-defined properties, to represent kerosene. The upper limit taken for I_3 is $4 D_m$. The value used for T_∞ is 1650 K, taken from calculations in Ref. [6], for the temperature of combustion products of propane and air issuing from the gap, at the MESG.

Figure 2 shows the calculated percentages evaporated from sprays with different drop mean diameters, for heating times from 0.1 to 50 ms. The curves for decane and hexanol, at the same D_m , lie fairly close together, and the curve for butanol, which lies between these two, is not plotted, in order to avoid congestion on the figure. The curve for ethylene glycol at the same D_m is, however, lower; for example at $\tau = 1$ ms and $D_m = 25 \mu\text{m}$, the percentage evaporated differs by a factor of 3 or 4, between decane, butanol and hexanol on the one hand, and ethylene glycol on the other. The effect of drop mean diameter is very marked, $D_m = 10 \mu\text{m}$ giving fast evaporation, and $D_m = 50 \mu\text{m}$ giving relatively slow evaporation.

Discussion and conclusions

The measured values of MESG for the sprays of butanol, kerosene, and hexanol, are some 15–23% higher than the MESGs for vapours of the same liquids. Group IIA of the IEC classification contains compounds for which $\text{MESG} \geq 0.9$ mm, and the results confirm that butanol, kerosene, and hexanol, are correctly classified in this group, whether considered as sprays or vapours.

These results indicate that a number of other compounds, which have been placed in Group IIB ($0.9 > \text{MESG} \geq 0.5$ mm) on the basis of the MESG for their vapour, would be in Group IIA on the basis of the MESG for their spray. This gives no cause for concern, in that the existing grouping is on the safe side, as regards the spray.

Transmission of ignition to the ethylene glycol spray was not achieved, at the highest available gap (2.6 mm).

Results with methane and air mixtures in Ref. [6] showed that for gaps close to the MESG, ignition occurred within about 1 ms of the combustion products leaving the gap. The results shown in Fig. 2 indicate that, for the values of D_m given in Table 1, and with a heating time of 1 ms, the percentage of the liquid evaporated is from 10 to 20% for butanol, decane and hexanol, but is only 4% for ethylene glycol. This is a consequence of the higher boiling point, density, and latent heat of evaporation for ethylene glycol. The measured fuel equivalence ratio for the injected liquid spray is lower for the ethylene glycol, compared with butanol or kerosene. It is probable that the low concentration of

ethylene glycol vapour is an important reason for the difficulty found in igniting the spray of that liquid.

Conditions making the ignition of a spray of ethylene glycol more likely would be adequate fuel equivalence ratio and smaller mean drop diameter. For example, at $D_m = 10 \mu\text{m}$ and a heating time of 1 ms, Fig. 2 shows 60% of the ethylene glycol spray evaporated, providing a higher concentration of vapour for combustion.

Sprays of other high flash point liquids are also expected to ignite more readily when the mean drop size is smaller.

A general conclusion is, that a spray of flammable liquid can be ignited by the mechanism being considered, however high the flash point, provided that the fuel concentration is sufficient, and the mean drop size is small enough. Whether or not these circumstances are likely to occur in practical conditions, is a matter for consideration in each particular case.

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References

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