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FLAME ARRESTERS FOR INDUSTRIAL USE

by

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Types of arrester

Most flame arresters or flame traps consist basically of a solid matrix containing a group of small narrow passages or apertures through which gases or vapours can flow, but which are intended to be too small for a flame to pass through. Thus as the flame enters the arrester it is subdivided into flamelets, and it is obvious that all of these should be quenched if the explosion is not to propagate through to the other side of the arrester. The various types of flame arrester differ mainly according to how the subdivision is obtained and the number and size of the apertures produced. A selection of the more common types of flame arrester is listed in Table 1, which shows that all the types except the hydraulic arrester contain a solid matrix. The tabulated list is not meant to be exhaustive, or to give more than a general description of each type of arrester.

The various arresters listed in Table 1 differ considerably in their resistance to gas flow. This resistance is an important consideration because in many industrial applications a flow of gas is required through the arrester and where, for instance, the gas is propelled by a fan the maximum pressure drop that can be tolerated across the arrester may be only one or two inches water gauge. On the other hand, where gas is withdrawn from a cylinder, or is pumped, a much higher pressure drop across the arrester is often permissible. The demands for high flame-quenching ability and low resistance to gas flow are to some extent incompatible, but by taking measures such as widening a duct at the arrester this difficulty can often be overcome.

TABLE 1

Types of flame arrester

Type	Main characteristics
Wire gauze.	Can be used singly or in packs.
Perforated sheeting or blocks.	Usually metal. Can be used in a wide range of thicknesses.
Crimped ribbon.	Also obtainable in a wide range of sizes
Packed tower or pebble box.	Can be large items of plant, and with fillings of a wide range of sizes.
Parallel plate.	Assembly of closely separated plates, usually metal.
Sintered metal or ceramic.	Apertures can be very small and may have a high resistance to gas flow.
Hydraulic.	Water-sealed non-return valve, which breaks up gas flow into separate bubbles.

Not all flame arresters contain a porous solid matrix; for instance the hydraulic arrester is basically a non-return valve sealed by a layer of water through which the gas bubbles. If properly designed there is never a continuous passage of gas through the water in the arrester; the bubbles break up the flow. The arrester can be effective as long as the flame is only propagating above the water layer and in order to ensure this the arrester is most often used in situations where the point of ignition is known e.g. in a supply line to a burner.

A similar principle to that of flame arrester is used in the design of electrical apparatus for use in flammable atmospheres. For this apparatus to be designated "flameproof" the gaps between joint surfaces and the diametral clearance for operating rods, spindles, shafts, etc. must not exceed the permissible maximum, as determined by the official standard testing procedure [(1)]. The main function is different from that of flame arresters and it will not be considered here in greater detail.

Use of flame arresters

Historically, the first systematic use of a flame arrester was the wire gauze in Davy's miners' safety lamp, developed early in the 19th century. This application was followed, over a century later, by the specification of a wire gauze containing at least 28 meshes to the linear inch for protection of the vent pipes of storage tanks containing petroleum. The other types of arrester were usually also developed with specific applications in mind.

The types of plant and equipment in which flame arresters are now used cover such a wide range that a complete classification cannot be attempted. The following are some of the more common uses, but they are only a selection from a much wider range.

1. In solvent vapour recovery systems.

2. In the vent pipes of storage tanks for flammable liquids.

3. Preventing flash-back in gases supplied to burners or furnaces.

4. Preventing ignition from the exhaust of internal combustion engines working in flammable atmospheres.

5. Quenching the decomposition explosions of acetylene.

Although the types of plant and equipment using flame arresters vary widely, they tend to have certain common features. It is unusual for the system to be completely closed, so that if an explosion occurs the pressure would build up without any release, but it is far more usual for a part of the system to be open to atmosphere either through a duct opening, or a restricted opening such as a nozzle, or through a vent which opens when the gas pressure changes from the normal working range. Thus if an explosion occurs there is usually a preferential direction for the gas to move as soon as the pressure begins to increase. The existence of this preference affects the performance required of the flame arrester. Figures 1-3 show three simplified systems, represented by a duct sealed at one end and open to atmosphere at the other and containing a flammable gas mixture on both sides of the flame arrester;

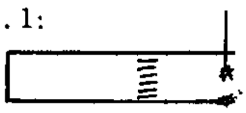
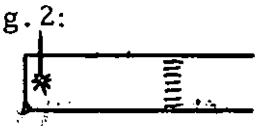
similar considerations would apply to more compact systems, but the behaviour in ducting is simpler to visualise.

In the case where there is no continuous flow of unburnt gas into the system the gas is stationary at the instant that ignition occurs. When ignition occurs near the mouth of the duct (Fig. 1), or a flame flashes back into the duct, the flame propagates up to the arrester through a stationary or relatively slowly-moving gas. If the arrester quenches the flame the hot products of combustion are mostly discharged to atmosphere through the open end of the duct. The arrester therefore has to quench a flash of flame but the total amount of heat to be transferred to do this is not large, although the rate of transfer of heat must be high because the time available when the flame is in contact with the arrester is short. When ignition occurs at a position remote from the mouth of the duct (Fig. 2) the expansion caused by the combustion causes the unburnt gas ahead of the flame to move down the duct through the arrester. As the flame arrives at the arrester it is propagating through a fast-moving gas mixture tending to carry it through the arrester. Because the gas is streaming rapidly an appreciable pressure drop may develop across the arrester, which must of course be sufficiently strong mechanically not to disrupt. If the flame is quenched by the arrester most of the hot products of combustion will not pass through it, but will remain between the igniter and the arrester and will cool to the walls of the duct. Thus under the conditions represented in Figure 2 the arrester must be able to quench a fast-moving flash of flame and be sufficiently strong to withstand the pressure arising from the motion of the gas. In the case where ignition occurs near the arrester, and the gas tends to exhaust through the arrester (Fig. 3), the flame propagates in two directions. Soon after ignition a slowly-moving flame arrives at the arrester and should be easily quenched. Meanwhile another flame propagates towards the closed end of the duct and the hot combustion products that it generates are exhausted to atmosphere through the arrester. The arrester has to be of substantial thermal capacity to withstand the hot exhaust and must also be sufficiently strong mechanically to withstand the pressure due to the moving gas.

In most practical systems, however, the flammable gas mixture will be in motion when ignition occurs, and the gas may continue to flow during and after an explosion. If, in Figures 1-3, the gas flows from left to right then the possibility of the flame stabilising in the duct modifies the performance required of the arrester. In the case represented by Figure 1, if the gas is flowing at a high speed the explosion may not be able to propagate back against the stream; it will then either be swept out of the duct entirely or may stabilise on the mouth of the duct, like a burner, or on a protruberance in the duct. If the gas velocity is lower, so that the flame can propagate back against the flow, the flame will stabilise on the arrester and heat it, unless the gas flow is quickly turned off. In Figure 2 the flame could stabilise either on the inlet port of the gas stream or on a protruberance in the duct; in either case a flow of hot combustion products would pass through the arrester. A similar situation can arise in the arrangement shown in Figure 3. Thus whenever a flame arrester is installed in a system in which a flowing gas stream can ignite, the possibility of the arrester heating must be studied. There are available on the market automatic detectors which will operate a valve to cut off the gas flow as soon as a flame stabilises, and these detectors can minimise damage to the arresters. The properties required in arresters installed in various systems are summarised in Table 2. The requirement of fine structure usually means that the passages through the matrix in the arrester should be small, or that the components of this matrix should be of small size, and this requirement has often to be combined with mechanical strength. The required mechanical properties and the thermal capacity are both influenced by the mass of the arrester; the thermal capacity can however be increased without increasing the mechanical strength by wetting or greasing the arrester.

TABLE 2

Characteristics required of arresters installed in various ducting systems

Ducting arrangement	Requirements for arrester			
	Fine structure	Mechanical strength	Thermal capacity static gas	Thermal capacity flowing gas
Fig. 1: 	✓			✓
Fig. 2: 	✓	✓		✓
Fig. 3: 	✓	✓	✓	✓

It should be emphasized that the systems shown in Figures 1-3 represent simplified versions of actual plant, the behaviour of which may be more complex. In particular it is often not obvious where ignition is likely to occur, so that an arrester installed in an actual plant may have to face a combination of the conditions of Figures 1-3 and Table 2.

Design and installation of arresters

With the amount of information available at present, it is frequently impossible for the most economic design of flame arrester to be specified for a given installation. With arresters containing solid matrices the specification would include the cross-section and length of the passages through the arrester, and possibly also the mechanical strength and thermal capacity. If the diameter of the apertures in the arrester is too large a flame would be able to pass through the arrester. If the apertures are unnecessarily small, then the pressure drop across the arrester will be unduly large and power will be wasted in driving the system. In addition the clogging of the arrester by dust etc. may become unnecessarily troublesome. As flame arrester of various types have been in use for a long time. knowledge of safe designs for particular systems has accumulated; but whether these designs are the most economic, or give adequate guidance for the procedure to be adopted with new installations and flammable materials, may not be clear.

Recent reviews [2, 3] have given accounts of experimental work on different types of flame arrester, but in the main these experiments were aimed at studying the behaviour of the arresters in particular installations rather than discovering how the arresters functioned and the relation of the effectiveness of the arrester to the properties of flames and the dimensions of the systems in which they were produced. Accordingly, emphasis will be given here to recent work that throws light on some of these aspects, although the work covered in the reviews and the tests carried out on various types of arrester are also of considerable practical value.

First, however, it is important to realise that the cross-section of the passages through the arrester must not exceed a certain size, no matter how thick the arrester is. For circular passages this distance is known as the quenching diameter, and it is dependent upon the gas mixture composition. Values of quenching diameters for different gas mixtures are given in Table 3. If the passages are not circular, the quenching diameter can be taken approximately equal to the equivalent hydraulic diameter

$$\left(\text{i.e. } \frac{4 \times \text{area of cross-section of passages}}{\text{perimeter of passage}}\right)$$

although with long narrow slits it is probably more accurate to take the maximum permissible width of a slit to be 0·61 x quenching diameter. A clear distinction is to be drawn between the quenching diameter in which there is a relatively slow propagation of flame and the smaller apertures required to quench fast flames e.g. in the permissible safe gap for flameproof electrical apparatus.

TABLE 3

Quenching diameters for various gas mixtures

Gas mixture	Quenching diameter	
	centimetres	inches
Methane -air	0·32	0·125
Propane -air	0·27	0·105
Ethylene -air	0·19	0·075
Hydrogen-air	0·1	0·039
Propane -oxygen	0·04	0·015
Hydrogen-oxygen	less than 0·03	less than 0·011

The relationships between the structure and efficiency of various types of flame arrester are being investigated at the Joint Fire Research Organization. Work has been carried out with wire gauze, perforated sheeting and blocks, and crimped ribbon flame arresters installed in simple duct systems where overheating of the arrester does not occur (as in Figures 1 and 2). With these arresters there was a velocity of approach of the flame below which it was quenched and above which it passed through the arrester, provided that the apertures in the arrester were smaller than the quenching diameter. This critical velocity increased as the size of the aperture was reduced, and generally when the thickness of the arrester was increased. An exception to the latter was observed when packs of coarse wire gauze, having the meshes accurately aligned, were tested; the effectiveness of the pack levelled off after about 4 layers and did not increase when further layers were added. The behaviour of different types of arrester against stoichiometric propane/air flames (4 per cent by volume propane) are illustrated in Figure 4, which is intended as a rough guide only. The relative effectiveness of the different types rather than discovering how the arresters functioned and the relation of the effectiveness of the arrester to the properties of flames and the dimensions of the systems in which they were produced. Accordingly, emphasis will be given here to recent work that throws light on some of these aspects, although the work covered in the reviews and the tests carried out on various types of arrester are also of considerable practical value.

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The results represented in Figure 4 are for arresters mounted in a $2\frac{1}{2}$ in. internal diameter tube without any bends, restrictions, internal projections, or expansion at the arrester, and with ignition at either the open end (Fig. 1) or the closed end (Fig. 2). To a first approximation the velocity of the flame that was just quenched by a given arrester was the same for ignition under both sets of conditions. The flame velocity was altered in different experiments by varying the distance between the igniter and the flame arrester, the 'run-up'; in general the flame velocity increased with the run-up, but the increase was not in proportion, and with 20-40 ft lengths of pipe ($2\frac{1}{2}$ in. in. diameter) a limiting range of flame velocities occurred. The flame velocity developing after ignition at the closed end of the system (Fig. 2) was considerably greater than after ignition at the open end (Fig. 1) in a tube with the same run-up distance (Fig. 4). The flame velocity also depended upon variables other than the run-up, e.g. the gas composition, and the presence of bends or obstructions. Means of reducing flame velocities, so as to reduce the fineness of the flame arrester required, are discussed in the paper by D. J. Rasbash on the venting of gas and vapour explosions. Current work at the Joint Fire Research Organization on flame arresters includes a comparison of the behaviour of flames of different solvent vapours against perforated metal arresters, and the effect on the behaviour of the arrester of increasing the diameter of the duct in which it is installed. Some of this work is being demonstrated. Accounts have been published of tests on wire gauze arresters [4, 5], and a correlation was obtained between the flame arresting abilities of the arresters and the heat transfer from the flame to the wires.

The behaviour of crimped ribbon arresters is being investigated by Cubbage [6] in connection with the arresting of town gas/air detonations in pipelines. These explosions are more rapidly-moving than those covered by the results in Figure 4, but it appears that suitable crimped ribbon arresters can be made.

Where a considerable amount of hot explosion products is ejected through the arrester, as in the arrangement in Figure 3, the experimental results of Mansfield [7] are available. He showed that coating gauze arresters with oil or grease increased their efficiency as arresters, but whether the action was solely that of cooling or whether some chemical effect was involved was not settled.

Conclusion

As a result of work already carried out, or in progress, it should be possible to put the provision of flame arresters for ducting systems having only a low resistance to gas flow on a reasonably quantitative basis. With straight, smooth, ducts the problem of flames travelling at speeds up to detonation has been covered and arresters can be specified for these installations. If the ducts have bends or restrictions it may be necessary to instal vents to keep explosion pressures and flame speeds to safe levels, and the required information is available or is being obtained. The requirements for flame arresters in ducts of 1 ft in section are being investigated, but the effect on the flame of enlarging the duct near the flame arrester still requires more study than it has so far received. There may be important industrial uses for wire gauze, perforated metal, or crimped ribbon arresters that differ markedly from those considered above, and which are not covered by the experimental work. If these exist it is hoped that the present symposium will bring these matters to light, so that the research can be extended where necessary.

The types of arrester that cause a higher resistance to gas flow have not been investigated so fully as those of lower resistance. For instance, with sintered metal or packed tower arresters, the flame quenching ability has not been related to the particle size or thickness of the arresters. However, it may be that these arresters are not used sufficiently widely to warrant detailed examination. Opinions on this point are invited.

The installation of flame arrester requires consideration of the lay-out of the containing system, as well as knowledge of the gas or vapour involved, and hence individual installations may need individual consideration. In particular it is not possible to specify an arrester that would be both safe and economic for all plant containing a given gas or vapour. The designing of a flame arresters for an installation is always likely to involve technical details if the most economic working is desired.

References

1. MINISTRY OF POWER. Testing Memorandum Nº.4. Test and Certification of the Flameproof Enclosure of Electrical Apparatus. H.M.S.O. 1958.

2. PALMER, K. N. J.Inst.Fuel 1956 29 293-309.

3. MASSEY, B.S., LINDLEY, B.C. J.R.Aero Soc 1958, 62 32-42

4. PALMER, K.N. 7th Symposium (International) on Combustion. Butterworth, London, 1959. 497-503.

5. PALMER K.N. Engineering 1958, 185 (4804) 438.

6. CUBBAGE, P.A. Flame traps for use with town gas/air mixtures. Institution of Gas Engineers. (To be published).

7. MANSFIELD, W.P. Proc.Inst.Mech.Engrs 1956, 170 (24) 811-62.

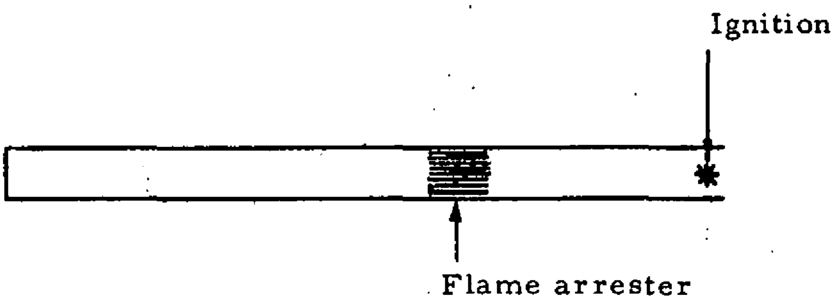


FIG. 1. Ignition at open end of duct

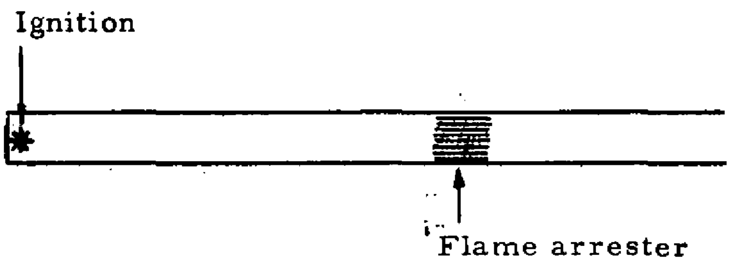


FIG. 2. Ignition at closed end of duct

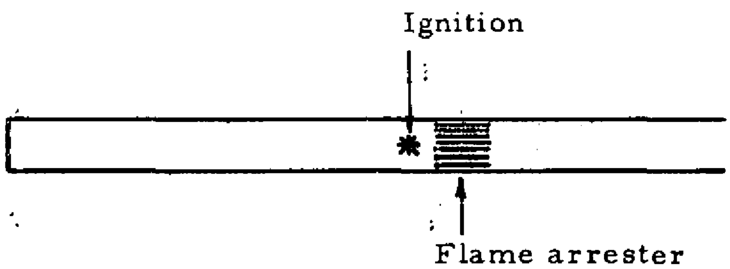
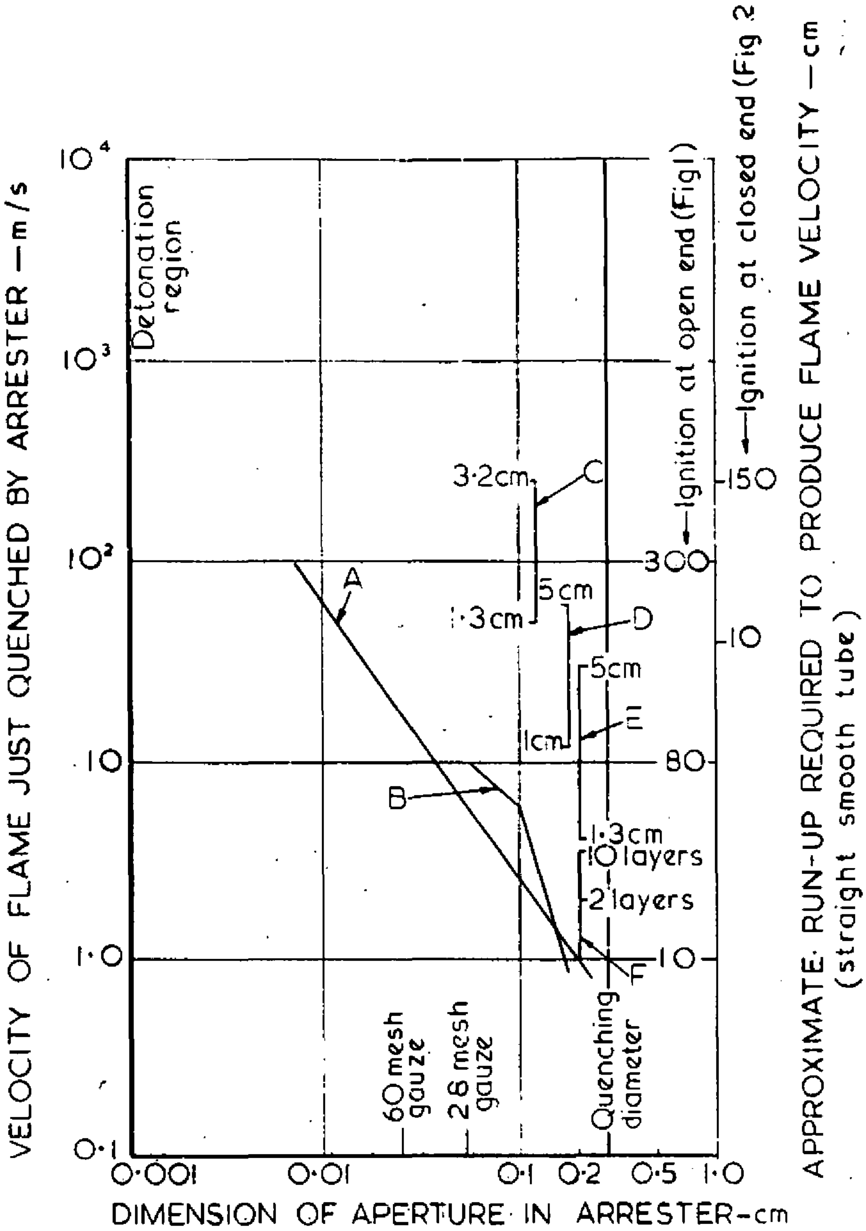


FIG. 3. Ignition near flame arrester



A–Single layers of wire gauze
B–Perforated metal sheet
C–Crimped ribbon
D–Perforated metal block
E–Crimped ribbon
F–Gauze pack

DETAILS OF PERFORATED SHEET

Diameter of hole cm.	Thickness of sheet cm.	Area of hole in unit area of sheet
0·175*	0·073	0·37*
0·100	0·072	0·31
0·055	0·046	0·24

* These values also apply to the perforated metal block

FIG. 4. FLAME ARRESTERS FOR FOUR PER CENT PROPANE-AIR MIXTURES

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