FLAME ARRESTERS IN INDUSTRY

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National Performance Evaluation Codes for flame arresters, and UK procedures mainly developed at the Fire Research Station are described. The application of arresters to the protection of specialised industrial and commercial explosion risks is discussed.

INTRODUCTION

A flame arrester is a permeable matrix of metal, ceramic or other heat resisting materials, which can cool a moving deflagration flame and the following combustion products below the temperature required for the ignition of the unreacted flammable gas on the other side of the arrester.

In some applications the flame arrester must be able to resist the transmission of premixed flame which may be burning on the arrester surface over prolonged periods of time, such a transmission of flame through the arrester is referred to in the literature as 'flashback'.

Although in the UK there is no British Standard for flame arresters, there are various publications broadly specifying performance and construction. The publication issued by the Health and Safety Executive gives a great deal of guidance on the use and construction of flame arresters[1].

This paper surveys most of the available information on the construction, performance and use of flame arresters in the UK and abroad.

Although flame arresters are widely used in the UK and often protect costly installations, there is no British Standard or Code of Practice covering their construction and mode of usage. This paper will not deal with arresters for gaseous mixtures containing hydrogen or acetylene or any flammable mixture with atmospheres other than air.

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TYPE OF ARRESTER ELEMENTS AND HOUSINGS

Crimped Ribbon Arresters

This type of arrester is probably the most widely used. The great majority of such arrester elements are constructed by winding a flat and crimped metal ribbon around a central metal core and then surrounding this structure by a suitable metal frame, Fig 1. The elements may be housed in a great variety of assemblies which are designed to fit into a pipe line or be mounted at the end of a line or on the vent pipes of storage vessels. The maximum strength of such assemblies varies greatly; as a rule those for mounting in line are more robust than the end of line assemblies. Assemblies exposed to the atmosphere are fitted with a hood or may have other protection against rain and snow. Some crimped ribbon arresters are constructed from straight lengths of alternating crimped and flat ribbons. These are fitted into varieties of rectangular frames which can be very large and consequently very heavy. Many crimped ribbon arrester elements are made either from stainless steel, or cupronickel ribbon: there may be objections to the use of aluminium or its alloys, because they have low melting points and are capable of producing incendive sparks when struck with rusty iron.

Crimped ribbon arresters have good mechanical strength; some models have a reinforcement in the form of metal rods inserted within the element, others may be supported by external steel structures. There are many variants of these methods especially with arresters made for special applications as for instance for marine use, where resistance to corrosion and good mechanical strength are of great importance.

In practice the thickness of flame arresters, sometimes defined as length of aperture, is not less than 18 mm, and may be up to 75 mm. There is no theoretical upper limit to the arrester diameter. In practice a diameter of approximately 500 mm is the maximum. Rectangular shaped arresters can be very large, but the larger size elements may be subdivided by steel elements to add strength and to confine thermal stresses to smaller areas. The dimensions of the aperture are not defined to any standard but a certain range of dimensions is accepted and adhered to in industrial practice.

Experimental evidence indicates, Davies et al[2] that for good performance the crimp height must not exceed half of quenching diameter. The hydraulic diameter is frequently used to relate apertures other than circular. The required length of aperture for various gases had also been standardised, in industrial practice on the basis of available experimental evidence. Table 1 shows the minimum by a commercial manufacturer of crimped ribbon flame arresters, when applied to groups of gases in accordance with BS 4683 pt 2 1971[3].

TABLE 1 - Dimensions of Typical Commercial Flame Arresters.*

	GROUPS			
	I	IIA	IIB	IIC
Crimp height mm	1.13	0.61	0.61	0.43
Length of aperture mm	38	19	38	76

Typical crimped ribbon elements offer 70-80 per cent of cross-sectional area of arrester open for flow, the remainder being taken up by the ribbon. Because of their predictable performance, accuracy of manufacture and robustness, crimped ribbon arresters have been widely used for many years.

Wire Fabrics

There are several types of arrester elements constructed from various wire fabrics.

At one time stainless steel or brass gauze were widely used either singly or in multiple layers, or as a strip wound into a roll and then housed in a cylindrical housing. The single layer gauze arresters have a very limited performance, they cannot arrest flames moving at speeds greater than 10 m/s, they are also fragile. The rolled gauze arrester, although fairly efficient, cannot be manufactured to specified tolerances; therefore unless it can be shown that there is no chance of faulty specimens occurring they may not be acceptable.

There are other types of wire arresters. One is knitted wire fabric which is compressed within a metal die, the other is a narrow knitted wire strip which is wound to form a flat disc. Both elements were designed to be incorporated into assemblies suitable for vent pipes of storage tanks holding flammable liquids, and are marketed as complete assemblies for such applications. The density of these elements is rather high, and they show a correspondingly high flow resistance, which makes them unsuitable for other applications. Their performance in stopping moving flame fronts and flashback performance is moderate, higher density arresters giving better performance.

* Information from Amal Ltd.

Metal Foam Arresters

A more recent material employed for the construction of arresters is a metal foam, which has a structure similar to an open pore plastic foam, but it may be made from a variety of metals. However current production arresters are made from nickel/chrome alloy with a chrome content of not less than 15 per cent and not more than 40 per cent.* The apparent density of the arrester is not less than 0.5 g/cm^3.

The metal foam is manufactured in three grades related to flame stopping properties. The flame stopping properties of metal foam can be improved by rolling the metal. Fig 2 shows an enlarged photograph of metal foam.

Because of the method of manufacture of metal foam it is not possible to specify all tolerances nor is it possible to ascertain the presence of internal cavities which may be present within the foam. Therefore unless it can be shown that some form of examination is available capable of detecting any cavities which affected the performance of metal foam then general acceptance of this material might be difficult.

Experiments have shown that any internal cavities which could have a deleterious effect on the performance of the arrester can be readily detected by visual examination. Metal foam at present is marketed in form of a sheet and the user has to provide suitable mounting. The chief advantages of the material is the ease with which it can be shaped, and variety of mountings which may be produced. Metal foam has a good arresting performance for moving flames.

Parallel Plate Arresters

Parallel plate arresters are applied in selected industrial areas. Their main advantage is high mechanical strength and ease of cleaning. They are however very heavy and expensive to manufacture because they are made from stainless steel. A typical use for such an arrester would be the exhaust system of a diesel engine of a truck designed to function in hazardous areas. Such arresters are constructed from plates in the form of stainless steel rings with spacers to provide 0.6 mm clearances between the rings. Provision can be made for dismantling the rings when cleaning is required. More recently a new flame arrester was developed, which consisted of a number of straight stainless steel foils with indentations to achieve the required separation. A pack of such foils is located within a suitable frame. Such arresters are sold only as in-line arrester assemblies. They have good moving flame arresting performance. They were not tested for flashback performance.

Metal Sphere or Pebble Arresters

This type of arrester has a restricted use because of its weight and rather high flow resistance. It is rarely used in the UK, the main applications being exhausts or air inlets of diesel engines of trucks which enter hazardous areas. Because they can be made very robust, they are well suited to these applications. They can be designed and constructed in a way which makes them resistant to fouling by soot, thus they can function over long periods of time without cleaning.

* Information from Dunlop Ltd.

Another use for sphere arresters is the relief of gaseous explosions in cubical vessels. Such explosions generate a great deal of heat, and arresters must be capable of absorbing substantial quantities of heat without thermal damage.

Pebble arresters when sprayed with water are used on acetylene lines, this specialised application is outside the scope of this paper.

Hydraulic Arresters

Hydraulic arresters contain liquid, usually water which may have anti-freeze added. They operate by breaking up the gas stream passing through into discrete bubbles. Hydraulic arresters may also incorporate a mechanical non-return valve, to prevent the displacement of the liquid and are usually effective in quenching flames propagating in one direction.

PERFORMANCE OF VARIOUS TYPES OF ARRESTERS

There are two important aspects of arrester performance. One is the ability of the arrester to stop the propagating flame front within the pipe. The other aspect of performance concerns the situation where a premixed flammable gas/air mixture flowing through the arrester matrix is ignited and a stationary flame is established on the arrester surface, in effect the arrester becomes a burner.

In some applications it is essential that the arrester should be capable of holding such a flame for an extended period (1–2 hours) without igniting the upstream gas. In all applications arresters must be strong enough to withstand the impact of the moving flame front; in some applications arresters must tolerate corrosive and dirty gases without a substantial drop in performance. All aspects will be discussed in turn.

Performance While Stopping Moving Flames

When an arrester element is exposed to a moving flame front, the flame will arrive at the arrester apertures at a certain speed. At ambient temperature the dimensions of the apertures being substantially less than the quenching distance (or diameter), will not allow the flame to continue. Therefore the reaction ceases and the hot gaseous combustion products may be driven into the arrester matrix. Their reaction may continue within the element with some heat loss to the matrix. At some stage the hot combustion products will be expelled from the arrester. These hot combustion products after passing on through the arrester will mix with the unburnt gas and it is possible that this mixture will then be within the flammable limits and also above the ignition temperature. When these conditions arise reignition may take place. Fig 3 shows a streak photograph of such a reignition. Generally during explosions in pipes there is little movement of burnt gas once the flame front is extinguished, and thermal damage to the arrester element seldom takes place. If however arresters are mounted on cubical or spherical containers, substantial volumes of hot gas may flow through the arrester element and unless the arrester area is adequate, the element may sustain thermal damage[4].

Flashback Performance

Flashback defines a condition where a stationary premixed flame burning on the arrester surface ignites gas entering the arrester. Such flame can only arise when flammable mixture is flowing through the arrester element. Rogowski et al[5,6] Schampel et al[7]. Within a certain range of gas velocities the flame front can undergo flashback and then stabilise on the arrester surface.

Once this occurs the arrester behaves as a burner. At high flow rates, the flame will lift off, and at low flow rates it will burn near the arrester element surface. There is a flow rate at which the heat transfer to the arrester is at its maximum, and arrester surfaces may reach temperatures of approximately 1000°C. Because this temperature is higher than the ignition temperature of the flammable gas the arrester can no longer quench the flame and all arresters fail. The flame front enters the arrester element and once this occurs the flame proceeds quickly through the arrester apertures and the unburnt gas upstream becomes ignited.

Fig 4 shows a time/temperature curve of a flame arrester, while tested for performance in resisting flashback the flame did not flashback. If arresters are mounted in a pipe line, their performance while resisting flashback is not good because of acoustic oscillations and most arresters will resist flashback for a few minutes only. If such pipe geometries cannot be avoided, a flame detector must be installed, and any flame which may stabilise on the downstream surface of the arrester extinguished. The detectors can be commercially available thermo-elements, when in use they are arranged to operate at a preset signal level. The level of the signal is important, because any alarm or extinction device must complete its operation within a relatively short period of time.

THEORY DESIGN DATA AND PERFORMANCE

Palmer[8] experimented with metal gauzes and he formulated a simple theory based on heat loss to the arrester and concluded, that for good performance gauzes must have apertures substantially smaller than the appropriate quenching distance. In further studies[9] he suggested that generally the critical length required for quenching was proportional to the flame speed. Palmer also suggested for crimped ribbon arresters a correlation.

$$L \sim V D_H^2 \qquad (1)$$

L - length of aperture
V - flame speed
D_H - hydraulic diameter

An empirical equation for crimped ribbon arresters was subsequently developed.

$$V = 0.38 \frac{ay}{d^2} \qquad (2)$$

where - V is the flame speed at which the arrester failed (m/s)
a is the fractional free area of arrester surface
y is the thickness of the arrester (cm)
d is the diameter of the aperture (cm)

This equation is valid for square and triangular apertures, an appropriate dimension being chosen for the latter. If used for elongated openings flame speed will be underestimated. The results which were used as a basis for this equation were obtained with an arrester element of diameter equal to that of the test pipe.

Davies et al[2] describe some experiments with metal foam, equation (2) was confirmed with a correction for explosion pressure applied by the factor (po/p)

$$V = 0.95 \, n \, y \left(\frac{po}{p}\right) \qquad (3)$$

where po atmospheric pressure
p explosion pressure when the flame front reaches the arrester
n number of apertures per unit area of arrester surface (cm^{-2})

Results for metal foam were in reasonable agreement with this equation. The authors took streak photographs of explosions in which arresters failed to stop transmission of flame and these have shown that at higher flame speeds arresters quenched the flame but hot gases re-ignited the unburnt flammable gas downstream of the arresters. Fig 3 shows an example of such a streak photograph.

The formula can be applied only for explosion within the deflagration regime for both crimped ribbon and metal foam arresters. Once flame reaction enters the pre-detonation regime most arresters fail. In practice a crimped ribbon arrester assembly with an element 38 mm thick and crimp height appropriate to the gas mixture will stop flames moving at the speed of 300 m/s. Metal foam of the appropriate grade, 13 mm thick will give similar performance, once this flame speed is exceeded performance is variable.

Pozharnaya Technica[10] quotes a formula arriving at the critical diameter of the arrester apertures made from a wire gauze pack, or a bed of spheres 3-4 mm diameter of depth not less than 150 mm.

$$d = \frac{x}{v} \frac{E\,(Tp - Tw)}{RT^2} \qquad (4)$$

where d – critical diameter of the arrester aperture
x – coefficient of thermal conductivity of the aperture wall
v – flame speed
E – activation energy for overall reaction
Tp– temperature of combustion products
Tw– temperature of arrester wall
R – gas constant
T – flame temperature

If the thermodynamic data are not available another formula is quoted (Cf. Holm[11]) also based on heat transfer from the flame.

$$d = \frac{4\lambda\,(t - T_o)}{v\,(Q - S_r\,(T - T_o))} \qquad (5)$$

when d – quenching critical diameter
λ – coefficient of conductivity of unburnt gas
t – flame temperature ^{o}C
T_o – temperature of unburnt flammable mixture
v – speed of flowing gas cm/s
Q – heat of reaction cal/mol
S_r – mean heat capacity of combustion products cal/^{o}C
T – flame temperature ^{o}C

Both formulae are said to be based on the constant Peclet number Pe[11] and indicate maximum diameter

$$Pe = d\,Su/\alpha$$

where Su – burning velocity
α – the thermal diffusivity of the unburnt gas mixture

d – tube diameter

which will extinguish the flame front. It does not take into account the re-ignition of hot gases downstream from the arrester. Hulanicki[12] confirmed experimentally the validity of this formula for arresters made of spheres, sintered metals, ceramics, and glass wool for flame speeds not exceeding 15 m/s. At higher flame speeds where re-ignition by hot combustion products downstream of the arrester may take place this formula is not applicable.

INDUSTRIAL REGULATIONS IN VARIOUS COUNTRIES

In the UK there are no mandatory Regulations or National Standards, governing the construction and use of the flame arresters. Nevertheless the Factories Act Petroleum Act 1928 does imply that in some situations flame arresters must be applied, especially in storage tank vent pipes.

General advice on performance and on application of flame arresters may be found in Health and Safety Executive Booklet No 34 [1].

More recently Rogowski[13] produced a manual specifying testing of flame arresters which is being submitted for standardisation. This document specifies tests for performance of flame arresters while stopping moving flames and resisting flashback. Test procedures, apparatus and flammable gases are specified. The document does not apply to hydrogen and acetylene. All arresters are required to pass a performance test for stopping flames moving in pipes. This test does define the limit of performance capability and is also a very useful test for strength of arrester element.

In the USA the usage and construction of flame arresters for surface industries is not mandatory. However the Underwriters Laboratory[14] specifies construction and testing requirements for flame arresters forstorage tanks. The compliance with this standard is one of the conditions of the conditions of the continued listing of the product by Underwriters Laboratories. The standard specifies tests for performance while stopping moving flame fronts. These tests are carried out using at least 5 ft long pipeline attached to the arrester assembly. A flammable petroleum/air mixture is used. The standard also specifies a test for flashback resistance, the arrester assembly is required to hold a stabilised petroleum vapour/air flame for not less than 1 hour. During this test the temperature of the assembly is measured.

In West Germany flame arresters tests are mandatory by Government order and prototypes are tested for gases other than hydrogen and acetylene and listed by the PTB. Selected references give information on their structure, application and testing[15,16,17,18,19,20]. The flame arresters may be broadly divided into four groups.

I. Explosion resistant arresters
II. Flashback resistant arresters
III. Detonation resistant arresters
IV. Special arrester for dip tubes and level gauges on tanks and tankers, for cable glands and for overflow devices.

There is no Code of Practice for use of flame arresters in all applications. But arresters are mentioned in various Codes of Practice, which are too numerous to be discussed in detail in this paper.

Arresters mounted on storage tanks having a capacity larger than 1000 l must be explosion and flashback resistant. To comply with flashback resistance requirements, an arrester element must be capable of holding premixed flame of an appropriate gas mixture for two hours. Detonation resistant arresters are housed in assemblies which break up the detonation wave before it arrives at the arrester element.

Arresters in pipe lines which contain flowing gases, must be protected by temperature sensitive devices, which sound alarm, extinguish the flame or interrupt flow.

All arrester elements in West Germany are 1 cm thick and there may be two or three elements in one assembly. Some European countries which have no National Codes may use Codes of other countries, this may be more common in petroleum industries.

ACKNOWLEDGEMENT

This paper forms part of the work of the Fire Research Station, Building Research Station, Department of the Environment. It is contributed by permission of the Director, Building Research Establishment.

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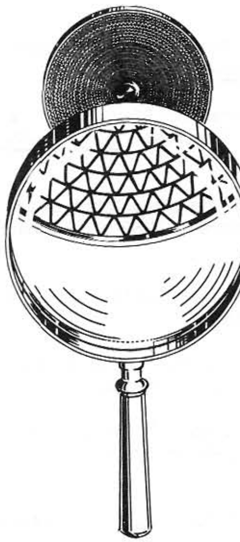

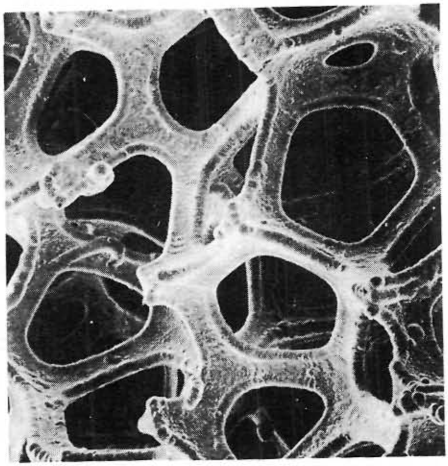

Figure 1 Crimped ribbon arrester element

Figure 2 Metal foam (X50)

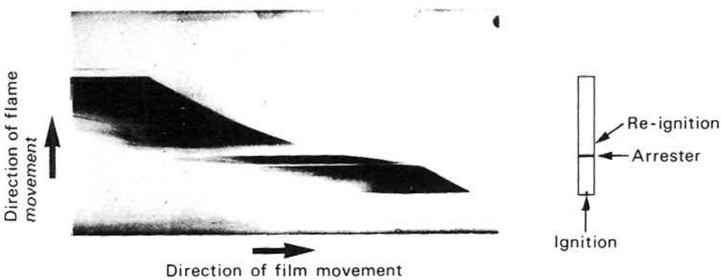

Figure 3 Re-ignition of ethylene/air mixture downstream arrester

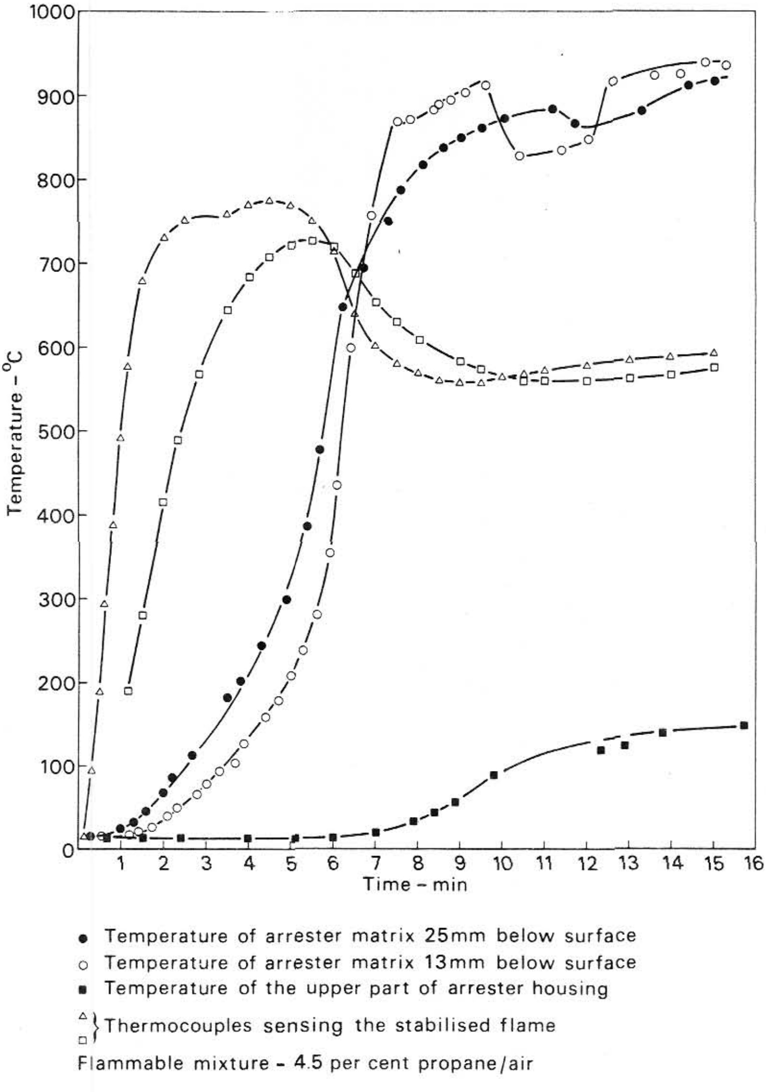

Figure 4 Time-temperature curves for a flashback test with crimped ribbon arrester