Cellular Metals Used in Flame Arrester Design

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Abstract

End-of-line flame arresters are used to protect the inner part of an apparatus or a fuel tank from an external explosion. Sometimes a flow of a flammable vapour/air-mixture through the flame arrester, being present for a longer period of time, can not be excluded in all cases. If so, it is necessary to use an endurance burning flame arrester which has to avoid a flame transmission to the inner side of the tank safely. The immense heat produced by the flame which is burning on the surface of the porous medium reduces the quenching property of the flame arrester element. Therefore the heat exchange with the cooling gas flow as well as the effective radial heat conduction from the porous structure to the surroundings has to be optimized to ensure sufficient cooling. To examine the behaviour of different cellular metals the temperature distribution inside flame arrester elements made of sintered fibres as well as of crimped ribbon structures was determined. The experiment is based on the endurance burning test concerning DIN EN 12874 with several thermocouples recording the temperature development at different locations of the flame arrester element. By means of the temporal and local temperature distribution conclusions concerning the ratio of axial to radial effective heat conduction can be drawn for different cellular metals. Because of this ratio is high for sintered fibre structures compared to other porous materials, especially to the traditionally used crimped ribbon elements, the fibre structures seems to be a very good material for the design of endurance burning flame arrester elements.

1 Background

Flames cannot transmit through a narrow gap which has an effective dimension that is small enough to quench the flame by means of cooling of the reaction zone, removing of intermediates of the chemical reaction and stretching of the flame. This active principle is used for flame arrester elements as well. They are built up by several parallel gaps of arbitrary cross sections. The property of a gap, and therefore also a flame arrester element, changes with temperature. Kim et al. have performed experiments concerning the correlation of the maximum dimension of a gap that safely quenches a flame and the temperature of the quenching walls [4]. Such a correlation is shown in FIGURE 1 for quenching surfaces made of chemical inert material.

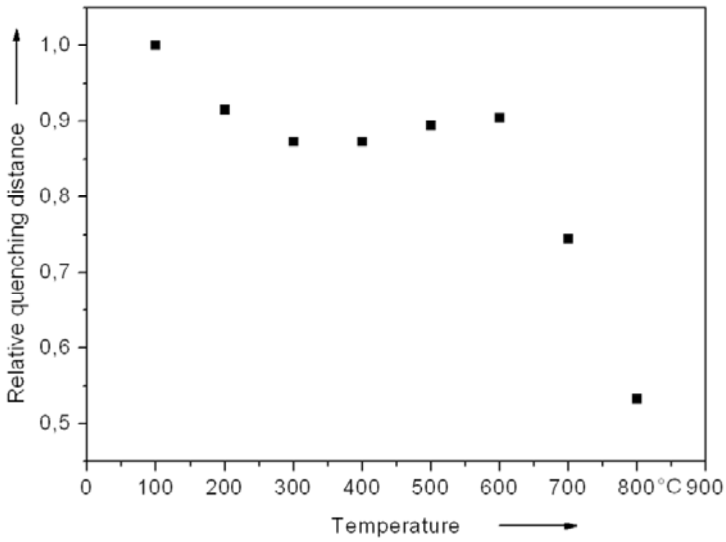


FIGURE 1 Correlation of the maximum dimension of a gap that safely quenches a flame and the temperature of the quenching [4]

It is remarkable that the distance between the walls that is necessary to quench the flame gets much smaller when the temperature excesses 600 °C. This temperature varies for different applications, but the fact that the quenching ability of a gap or a flame arrester element strongly decreases beyond a critical temperature is generally valid. Therefore a sufficient cooling of the flame arrester element is a very important task for the design of endurance burning flame arresters. Traditionally flame arrester elements are made of crimped ribbon structures. This elements are manufactured by spooling up a flat steel ribbon together with a crimped one which is shown in FIGURE 2. By this method a structure with parallel gaps which each have a triangular cross section is manufactured. Using this kind of flame arrester elements, the designer of endurance burning flame arresters try to modify the housing to achieve an optimised cooling.

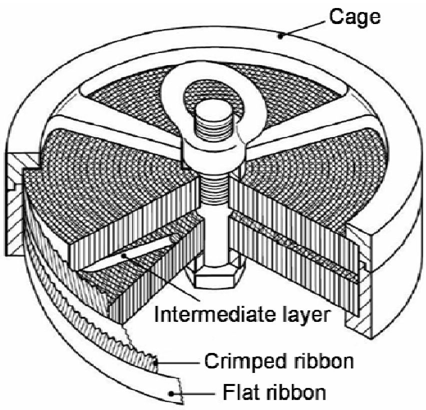


FIGURE 2 Crimped ribbon flame arrester (exemplary) [3]

FIGURE 3 shows two possible methodologies, FIGURE 3a) realises the cooling mainly by natural convection using cooling rips and the housing in FIGURE 3b) minimises the heat transfer resistance between the flame arrester element and the system the flame arrester is installed in by using thick walls of cast iron.

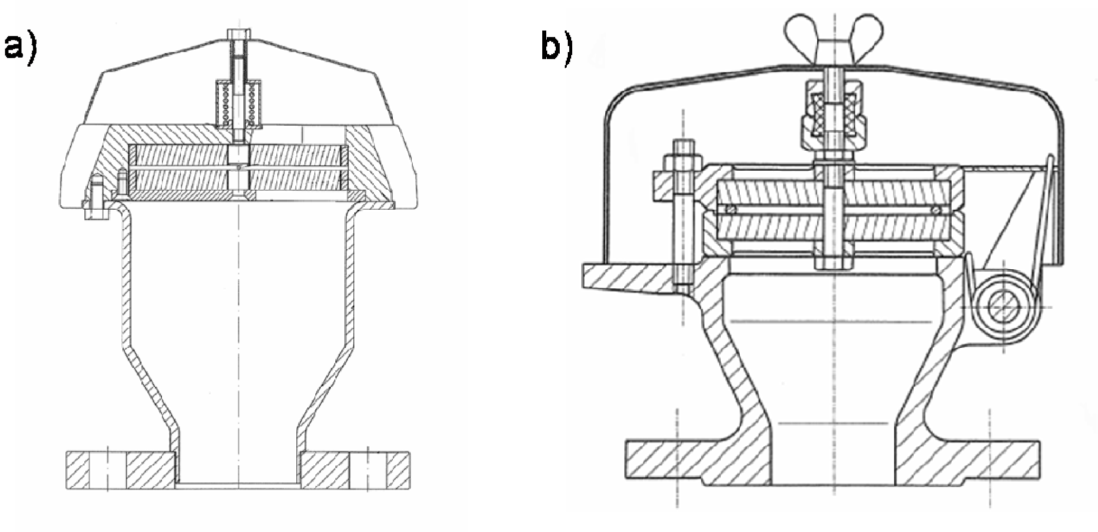


FIGURE 3 Possible designs of endurance burning flame arresters

The idea of this paper, in contrary to these existing designs, is to develop a new design for the flame arrester element itself.

2 Design of flame arrester elements

During the endurance burning test a flame stabilizes itself on the surface of the upper flame arrester element. This combustion induces heat energy into the flame arrester. To guaranty a sufficient quenching the flame arrester element must be cooled, but the heat must not be transported towards the inner side of the element. So the heat conductivity in radial direction must be as good as possible whereas in axial direction it should be as small as possible. As can be seen in FIGURE 2 the solid parts in the crimped ribbon structure are directed from top to bottom which leads to an disadvantageous ratio of radial heat conductivity to axial heat conductivity. In sintered fibre structures the orientation of the solid phase is the other way around. The fibres are orientated in radial layers and are connected by a sintering process in axial direction [1]. The performance of the sintered fibres used in endurance burning flame arresters will be analysed experimentally in the following.

3 Experimental set-up

The set-up consists of a modified flame arrester allocated by the German “Flammer GmbH”. The experiment was executed in accordance with the endurance burning test in EN 12874 [2]. That is to say the flame arrester gets passed through by a well defined combustible/air-mixture which gets ignited on top of the flame arrester element. The volume flow has to be adjusted in such a way that the temperature of the flame arrester element is maximized. The experimental set-up is shown in FIGURE 4.

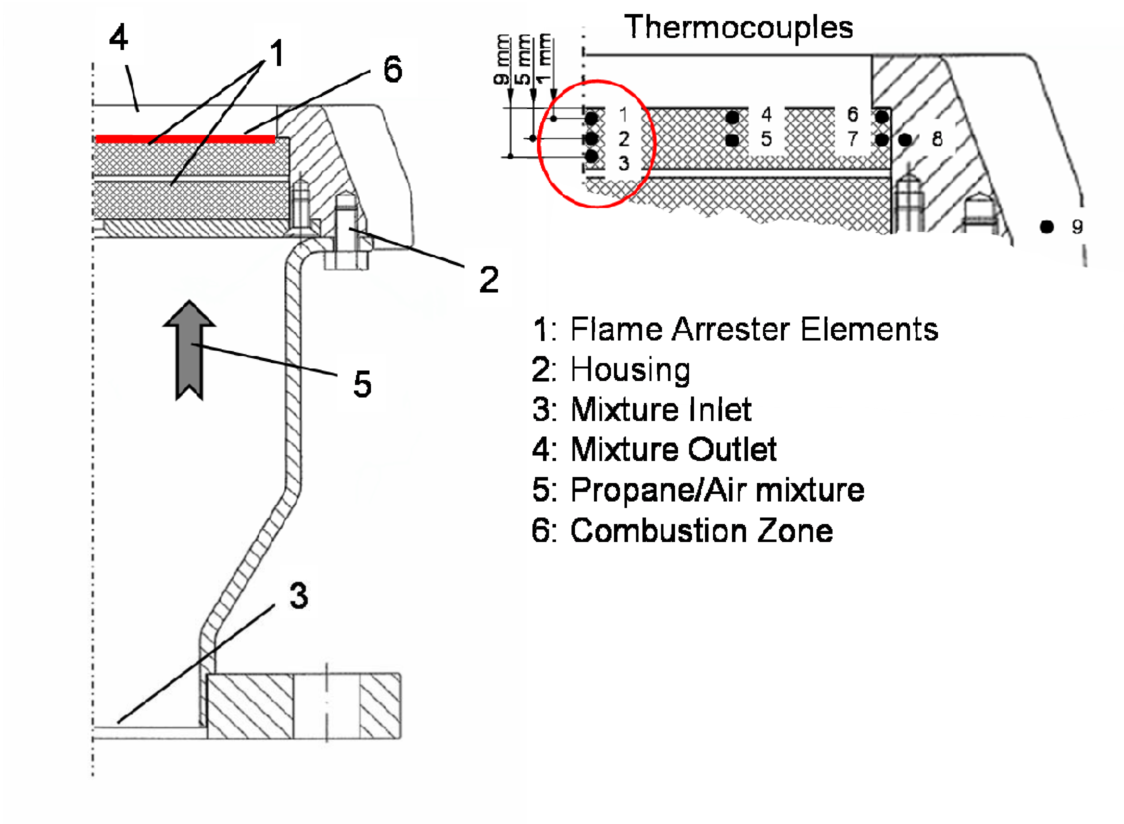


FIGURE 4 Experimental set-up

To estimate the temperature distribution inside the flame arrester the upper flame arrester (Thermocouples 1-7) as well as the housing (Thermocouples 8 and 9), are equipped with thermocouples. The thermocouples are placed inside the flame arrester element in such a way, that the temperature distribution in axial as well as in radial direction of the flame arrester element can be determined. The combustion experiment was executed using a stoichiometric propane/air-mixture. To start the experiment the propane/air-mixture gets ignited on top of the first flame arrester element and the temperature profiles are determined by means of the thermocouples.

4 Results

The temporal development of the temperature inside a flame arrester element made of crimped ribbon as well as one made of sintered metal fibres is shown in FIGURE 5. The used fibres have an average length of 25 mm, a diameter of 150 µm and a porosity of 70 %. After ignition, the temperature rises. Depending on the position of the thermocouple, different slopes and different maximum temperatures are visible. The maximum temperatures can be seen 3800 s after the ignition as well at the crimped ribbon as at the fibre structure. The most remarkable difference in the temperature profiles between the crimped ribbon and the fibre structures is the axial temperature gradient. These temperature gradients (crimped ribbon structure ΔT = 65 K, fibre structure ΔT = 355 K) are shown in FIGURE 5.

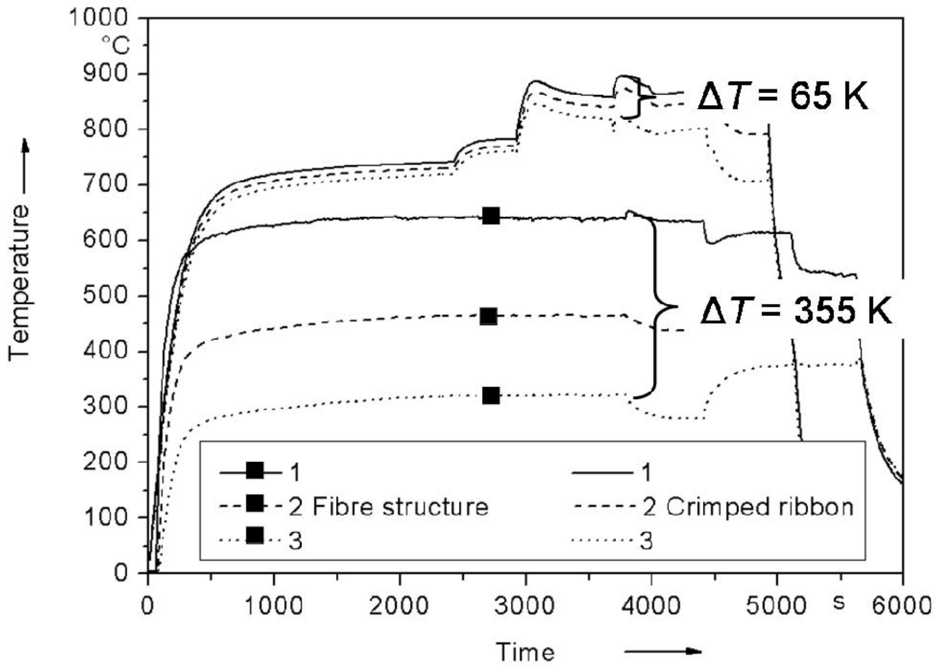
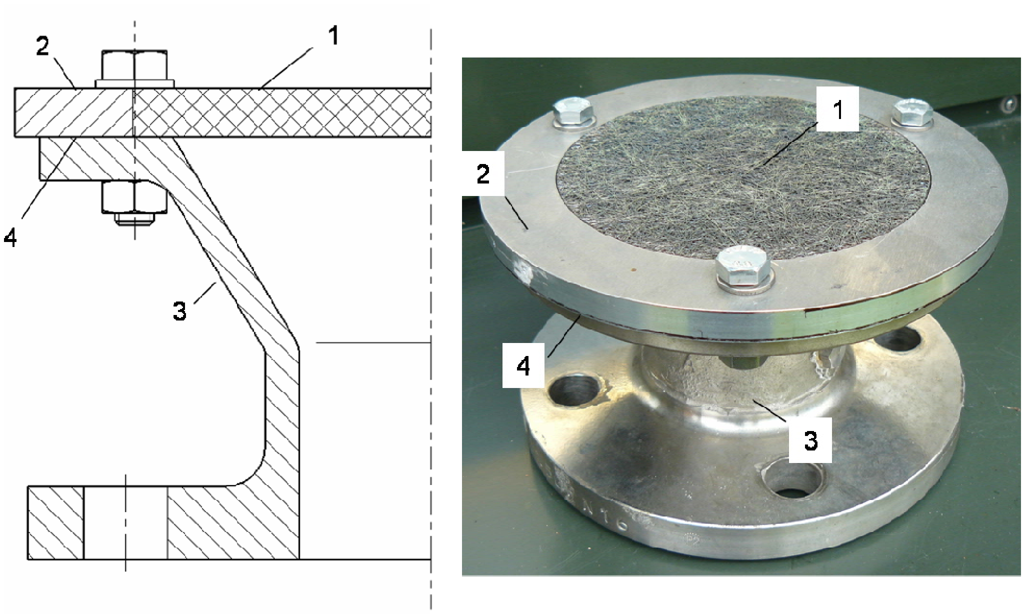


FIGURE 5 Temperature profiles of a flame arrester made of crimped ribbon and sintered fibres, respectively

5 Conclusions

The small axial heat conductivity of the sintered fibre structures results in a relatively low temperature at the inner surface of the flame arrester element. Therefore the risk of an ignition at the hot surface as well as the risk of burning through of the flame arrester element at a critical situation in the testing procedure is small. Because of this it is possible to design endurance burning flame arresters with only one single flame arrester element using sintered fibre structures instead of crimped ribbon elements. An additional advantage of the fibre material is its mechanical strength, which enables a design without a central screw like shown in FIGURE 3. As the central screw is made of solid metal, it cannot be passed through by the propane/air-mixture and therefore cannot be cooled by convection effectively. So a central screw transports heat into the inner part of the flame arrester. This risk can be avoided by using a flame arrester element made of sintered fibres without a central screw.

Taking these results into account, a prototype of an endurance burning flame arrester using sintered fibres was designed and manufactured. This prototype, which is shown in FIGURE 6, has a much more simple design than the traditional flame arresters shown in FIGURE 3. Its safety performance, nevertheless, is very good, which was proven experimentally.



1: Flame arrester element 2: Retainer 3: Housing 4: Flat aluminium seal

FIGURE 6 Prototype of an endurance burning flame arrester using sintered fibres as the flame arrester element

The high performance of sintered fibre structures concerning their usage in endurance burning flame arresters have been shown in this work. To fulfill the convey to an industrial usage, a quality management system concerning the production process of the sintered fibre structures has to be developed.

Acknowledgement

The authors would like to thank the German Federation of Industrial Cooperative Research Associations "Otto von Guericke e.V." which has supported this work through the federal programs for innovation competence in medium-sized enterprises (PROINNO II), Grant KF 0043902LF4.

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