Flame Arrester Performance at Increased Oxygen Concentrations

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1   Introduction

Flame arresters prevent the propagation of a gas- or vapor explosion from one section of a plant to another. Choosing the appropriate flame arrester from a broad variety of types for different scenarios requires knowledge about the technical details of the plant as well as the specific properties of the combustibles that may be present. Inline flame arresters contain so-called flame arrester elements, which allow through-flow of gas or liquid, but suppress potential flame propagation by energy dissipation from the incoming flame front to the material (Figure 1). The performance of various materials and the underlying principles were reported in the literature [1,2] and testing procedures for flame arresters were critically reviewed [3,4]. Commercially available arrestors are currently classified per ISO 16852 [5] by the explosion group of the combustible to be used for. The explosion group of the combustible is deduced from its maximum experimental safe gap (MESG), which is determined in a standard set-up (IEC 60079-20-1) [6]. It is the maximum width of a 25 mm circular gap, through which an ignition in the inner 20 ml volume will not ignite the outer explosive atmosphere in any concentration. Unfortunately, this safe gap cannot be directly linked to the channel dimensions of a flame arrester element. For this reason, the individual flame arrester set-up should be tested experimentally under appropriate reproducible conditions as described in ISO 16852 [5]. While a substance belongs to a specific explosion group, testing can be done with the representative gas mixture of the explosion group instead, which simplifies the procedure for the testing laboratories. The standard testing conditions are the so called atmospheric conditions, which describe the temperature and pressure range usually supposed to be human working conditions (- 20 °C up to 60 °C and 80 kPa up to 110 kPa) with air as the oxidizing gas. As most of the chemical processes are driven beyond this conditions, the MESG as the criterion for choosing the proper flame arrester must be critically reviewed. Is well known from former investigations, how the MESG depends on chemical structure [7], initial temperature and initial pressure as well as the apparatus itself [8-10]. Furthermore, the kind and concentration of oxidizing gas is of major influence [11]. Where no oxidizer is present in the system, flame arrestors are of no practical use,

e.g. at higher pressure conditions around 1 MPa range simulating automotive engine/ aircraft engine fuel pumping conditions. In this study the focus is on the extend, to which the addition of oxygen to ethylene/air-mixtures influences the performance and safety margins of a flame arrester at elevated pressure and whether the changes in performance are comparable to the properties of the MESG.
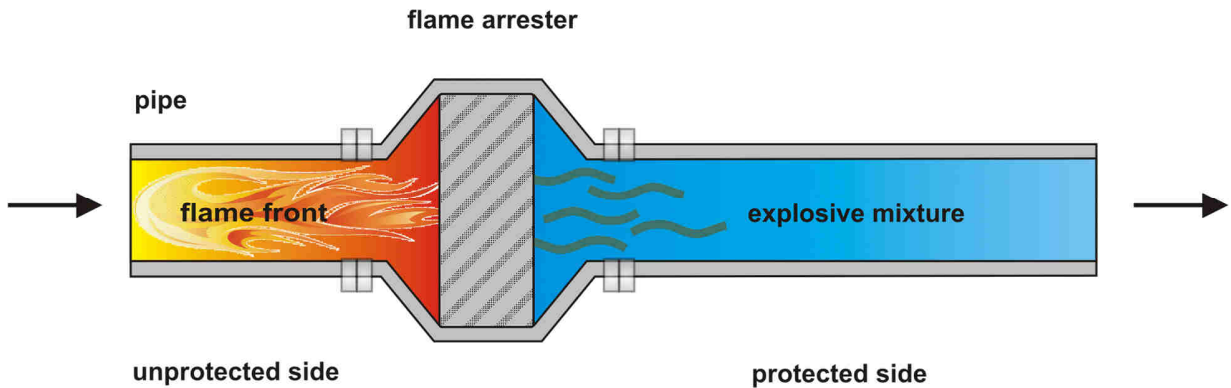

Figure 1. Inline flame arrester assembly

2   Experimental Setup

Mixture preparation

The ethylene/oxygen/air-mixtures were produced by combining the output of three mass flow controllers with a standard uncertainty of 1% relative each. Compressed air with a moisture content of 0.8 g/m^3 was used and the purity of the other gases was 3.0 for ethylene and 3.5 for oxygen. The proper composition was checked via paramagnetic oxygen measurements with an uncertainty of ± 0.3 % by volume in oxygen.

MESG apparatus

The experimental safe gaps of ethylene were measured under increased oxygen concentrations and elevated pressures up to 160 kPa. Validation of the MESG apparatus was done with ethylene under standard conditions to reproduce the reference value of 0.65 mm given in IEC 60079-20-1. Ethylene was also chosen as the testing gas because it is the representative for explosion groups IIB1-3. The standard apparatus in use was constructed solely for atmospheric conditions and was therefore carefully monitored during the experiments regarding tightness and mechanical stability. In the standard procedure, a number of ten non-ignitions has to be performed at the concentration, which is most sensitive to ignition. At 101 kPa this concentration is near the stoichiometric concentration of 6.5 % by volume. Here, the maximum safe gap is determined from 5 non-ignitions at the stoichiometric concentration. This reduction in statistics contributes to the associated standard measurement uncertainty adding up to ± 0.03 mm. The initial pressure inside the apparatus was measured with an uncertainty of 1 % relative.

Flame arrester testing rig

An inline deflagration flame arrester, which prevents the propagation of explosions caused by combustibles of type IIB3 (MESG ≥ 0.65 mm) up to 160 kPa initial pressure, was used throughout the investigation (PROTEGO FA-CN-50-IIB3-P1,1; kindly ceded for use by Braunschweiger Flammenfilter). The flame arrester (DN 50) was mounted between to pipes of 50 mm inner diameter and 2.5 m in length. Both ends of the setup are closed by flanges equipped with the gas in- and outlet. This ratio of length and diameter (L/D)

prevents the occurrence of detonation, which may be expected for L/D > 50. The pipe temperature was kept at 20 °C as well as the gas temperature. Three crimped ribbon type flame arrester elements of 0.5 mm gap size and 10 mm height were inserted to the arrester, separated by thin mesh layers. Humidity and oxygen concentration were measured at the exit of the pipe. Thermocouples, pressure transducers and photodiodes are located at different positions to detect the incoming flame velocity, explosion pressure and the potential ignition on the protected side.

3   Results

Maximum safe gaps for ethylene/oxygen/air-mixtures were measured at atmospheric and elevated pressures and different concentrations. The results for ethylene/air-mixtures are given in Figure 2. The minimum of the parabolic curve denotes the maximum safe gap of the combustible at any concentration. It slightly shifts down by about 0.2 % by volume when the pressure is increased from 101 kPa up to 150 kPa. As the Ethylene curve is relatively flat, the shift results in a maximum deviation of 0.005 mm, which is already included in the associated measurement uncertainty. For other combustibles, such as Ethane the curve is more narrow and the effect would be more prominent. As adjustment of the concentration with pressure rise is recommended then, in this investigation the measurements on ethylene were carried out at the stoichiometric concentration.
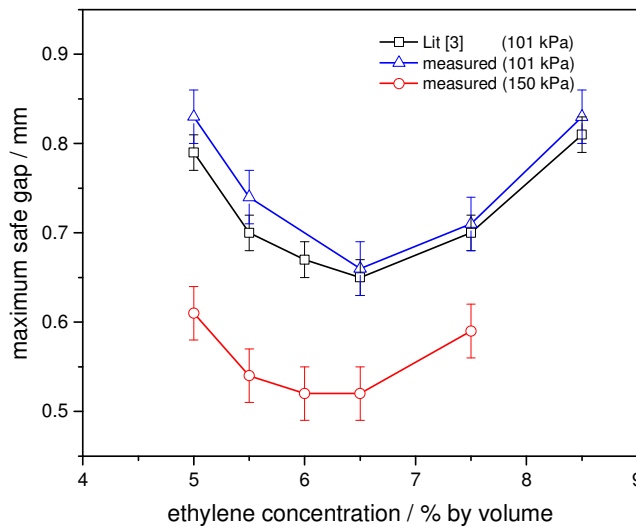

Figure 2. Concentration curves of the safe gaps depending on the initial pressure.

The maximum safe gap determined on the stoichiometric mixture at different contents of oxygen and the dependence on pressure is given in Figure 3. In general, the maximum safe gap is lowered at higher pressure. A linear dependence on 1/p was already reported in the literature [8]. The effect is strongest for ambient air as the oxidizing gas. The higher the oxygen concentration, the weaker is the effect of pressure, but the smaller is the safe gap in general. At atmospheric pressure the oxygen addition shows the strongest effect on the maximum safe gap while at 160 kPa the maximum safe gap is only slightly decreased.

Performance tests on the flame arrester were carried out with stoichiometric mixture for a given oxygen concentration. The results are shown in Figure 4. The flame arrester was originally approved to be safe for an operational pressure of 160 kPa. This was confirmed by the tests. However, a small increase in the oxygen content of the gas-mixture from 19.6 % to 21 % by volume forced the arrester to fail. Here, its protective function is only ensured up to 140 kPa. Further increase of the oxygen content up to 24 % by volume results in severe failure of the arrester already at ambient conditions.
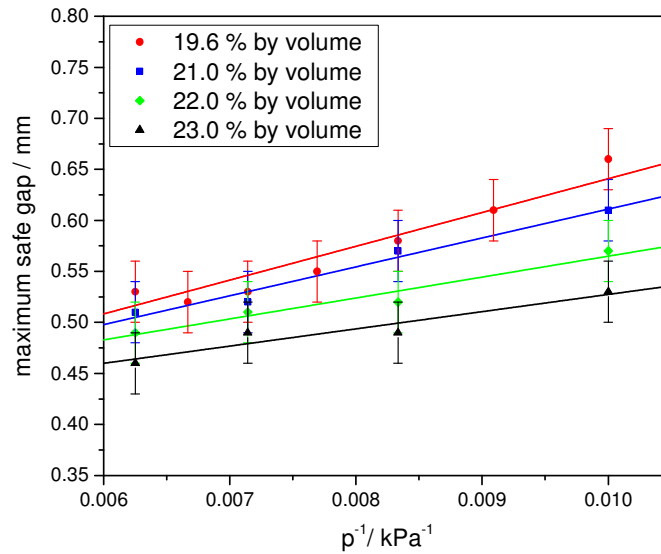
Figure 3. Pressure dependence of the maximum safe gap for different oxygen contents.

Figure 4. Test series with ethylene/oxygen/air mixtures on type IIB3 flame arrester, which was originally approved for 160 kPa.

4   Conclusions

A small increase of the oxygen content in an explosive ethylene/oxygen/air-mixture leads to severe restrictions on the use of flame arresters. The safety margins from higher test pressures are quickly depleted at lower operational pressures. The maximum safe gap at the pressure which is only just safe in the arrester tests does not seem to be constant for different oxygen concentrations. This means, that the reliability of arresters in oxygen enriched atmosphere cannot simply be deduced from MESG at atmospheric conditions. It is strongly recommended to test the individual arrester under real application conditions.

Ongoing testing and data analysis addresses the dependence of arrester failure on flame velocity, pressure rise rate and energy density. The question, whether the explosion groups are applicable to flame arresters under non-atmospheric conditions or whether specific types of compounds might switch to a different group due to changes in reaction path and kinetics.

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