

## FLAME ARRESTERS FOR PLANTS HANDLING ACETYLENE AND ETHYLENE OXIDE

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Both acetylene and ethylene oxide are highly flammable gases that have a range of important uses in the chemical and process industries. They tend to exothermic explosive decomposition if energy is supplied (e.g. heating from flashback from a combustion unit). In their pure form they are chemically unstable and can spontaneously react with themselves in an exothermic reaction without an oxidant.

Flame arresters can potentially be used to provide explosion protection for plants handling these substances but their testing and use for chemically unstable substances is outside the scope of the European Flame Arrester Standard EN 12874<sup>1</sup>. In order to develop flame arresters for use in these applications Protego carried out a wide range of detonation and deflagration tests across the complete concentration range with ethylene oxide/air and acetylene/air mixtures at their research centre.

This paper presents the results from these tests. For ethylene oxide the tests demonstrated that an increase in ethylene oxide concentration results in an increasing detonation pressure with the maximum reached at approximately 70% volume. Additionally it was found that ethylene oxide/air mixtures can detonate with low ignition energies. Detonation tests with acetylene/air mixtures indicated two peaks of detonation pressure across the entire range of acetylene concentration. Therefore tests across the entire range of concentration are necessary for the type approval and safe use of detonation arresters for these gases.

### INTRODUCTION

Ethylene oxide is used in a range of applications in the chemical and process industries. It has a Maximum Experimental Safe Gap (MESG) value of 0.59 mm. For instance it is widely used in plant for the sterilization of medical equipment. However it is well known that ethylene oxide is chemically unstable and can propagate decomposition flames in the absence of any oxidant. Explosions involving ethylene oxide are documented, most recently by the US Chemical Safety and Hazard Investigation Board.<sup>2</sup> This incident involved an explosion at an ethylene oxide sterilization facility operated by Sterigenics in Ontario, California, USA. A release of ethylene oxide was ignited by a catalytic oxidizer and traveled back through ducting to the sterilization chamber which contained a large volume of ethylene oxide. The resulting explosion injured four workers and caused significant damage to the plant.

With respect to ensuring safe handling of ethylene oxide Brittan (1990)<sup>3</sup> reports that deflagration flame arresters consisting of tube bundles of a specified length and diameter have been used for some years in process units. It is unclear whether these designs have been tested and subject to third party approval. Use of these devices is not common but there are believed to be some devices still in use at ethylene oxide production plants.

Acetylene is also used in the process industry and can decompose in a detonative manner. It has a MESG value of 0.37 mm. Gossel (2002)<sup>4</sup> reports that a number of different types of flame arresters such as hydraulic flame arresters, packed bed, sintered metal and metallic balls have proven

successful in stopping acetylene decomposition flames. Some of these types are small diameter units used for oxyacetylene welding equipment. Again it is unclear which of these designs have been subject to third party approval and if they are suitable for use in process applications.

With the implementation of the ATEX directives flame arresters are defined as Protective Systems and to be placed onto the market in Europe must be subject to a process of Type Approval by a Notified Body. Usually the Type Approval is carried out by third party testing to the European Flame Arrester standard EN 12874 using specified test gases chosen to meet the MESG limits of the Explosion Group classification. However EN12874 specifically excludes from its scope flame arresters for substances which tend to self decompose or are chemically unstable. Due to the special characteristics of these substances it was clear that selection of an appropriate device could not be made on the basis of MSEG alone.

In order to develop devices and gain Notified Body approval for detonation arresters suitable for use with ethylene oxide and acetylene Protego undertook a program of testing to understand more fully the nature of the combustion process for these substances.

### ETHYLENE OXIDE TESTS

Detonation tests using test apparatus generally in accordance with EN12874 (Diagram 1) were carried out with a range of ethylene oxide/air mixtures at ambient temperature and pressure conditions. The results shown are from tests in

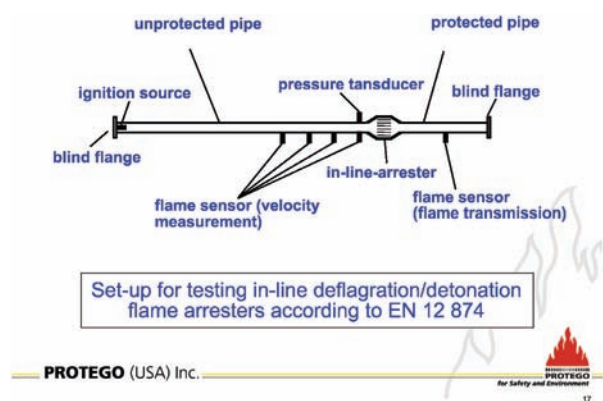


Diagram 1.

a 3' pipe but additional tests were also carried out with 4" and 8" pipes. Diagram 2 shows the measured flame velocity in the pipe section immediately before the detonation flame arrester for a range of run up distances to the arrester measured as a ratio of length to diameter. These tests were carried out with ethylene oxide/air concentrations of 9%, 70% and 90% by volume. The range of  $L_1/D$  ratios is such that stable detonations should be generated.

With a 90% concentration flame velocity was rather low. At  $L_1/D = 185$  the velocity was 200 m/s falling to 15 m/s at  $L_1/D = 265$ . However at 70% concentration the measured flame velocity was 1800 m/s across the same range of  $L_1/D$  indicating a stable detonation. At 9%

concentration the measured flame velocity was again above 1800 m/s.

Further tests were carried out to measure the maximum detonation pressure  $P_{max}$  across the full range of concentrations. The time average value of the detonation pressure in the time interval of 200  $\mu$ s after the arrival of the detonation shock wave  $P_{md}$  was also measured as this is required to validate detonation tests in EN12874. Diagram 3 shows the results. At the stoichiometric concentration (9%) the detonation pressure  $P_{max}$  is of the order of 120 bar and rises to a peak of 140 bar at 70% concentration before falling away significantly at 90% concentration. The  $P_{md}$  values are of the order of 20 bar between 9% and 70% concentration which are higher than values experienced in testing with the usual test gas mixtures in EN12874.

**ACETYLENE TESTS**

Detonation tests were again conducted using test apparatus generally in accordance with EN12874 and were carried out with a range of acetylene/air mixtures at ambient temperature and pressure conditions. Tests were conducted with a range of six mixtures from 6% acetylene in air up to 60% acetylene in air. Flame speeds were measured across a range of  $L_1/D$  between 70 and 240 and the results are given in Diagram 4. Flame speeds consistent with detonation were recorded for mixtures from 6% to 30%. For a mixture of 60% acetylene in air the flame speed was consistent with deflagration.

**Detonation Tests: Ethylene oxide**

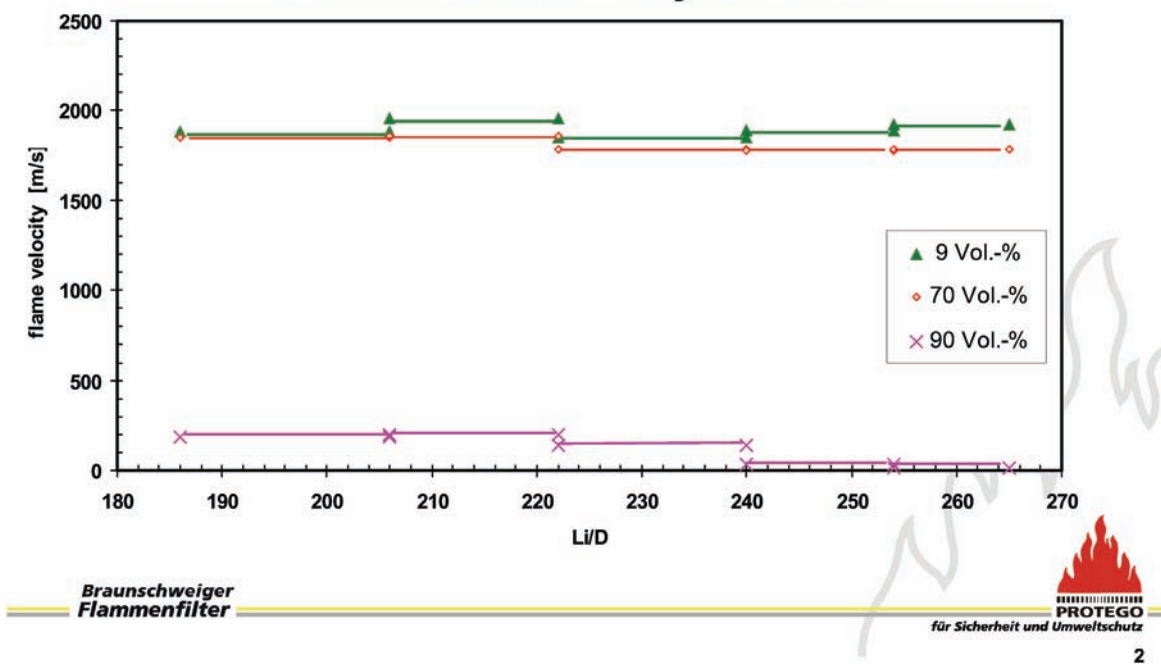


Diagram 2.

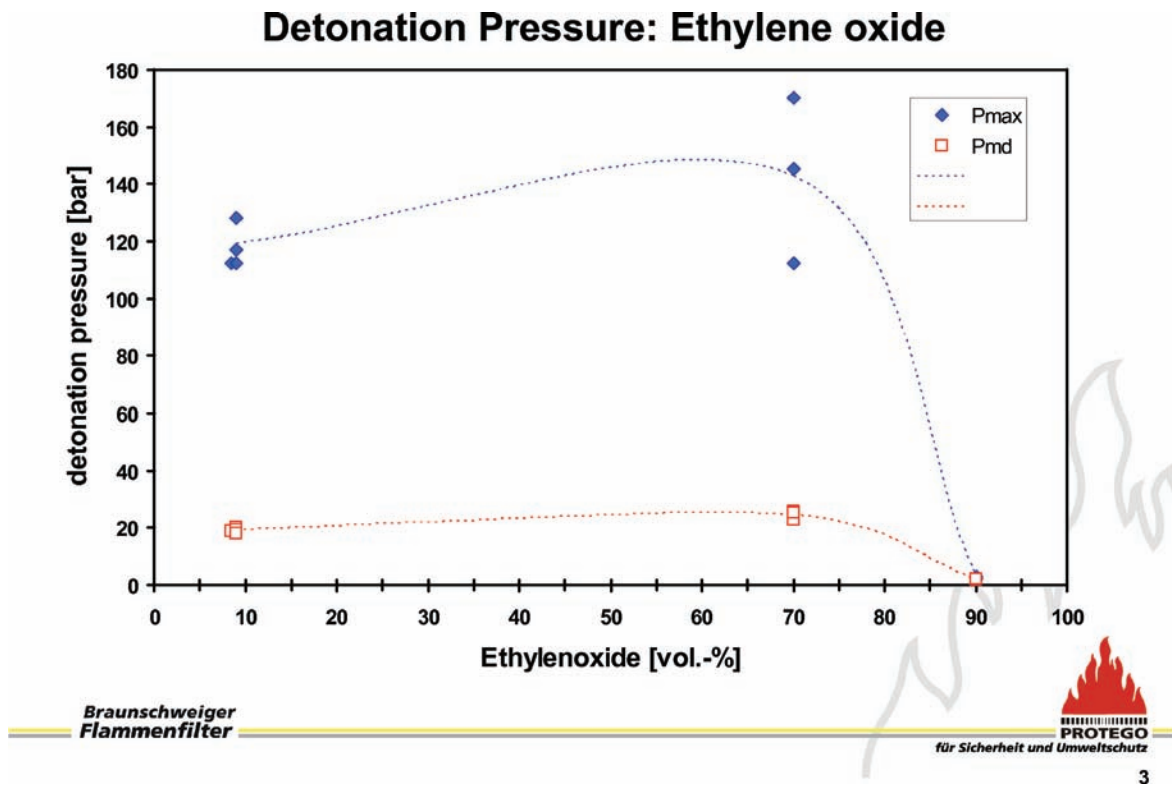


Diagram 3.

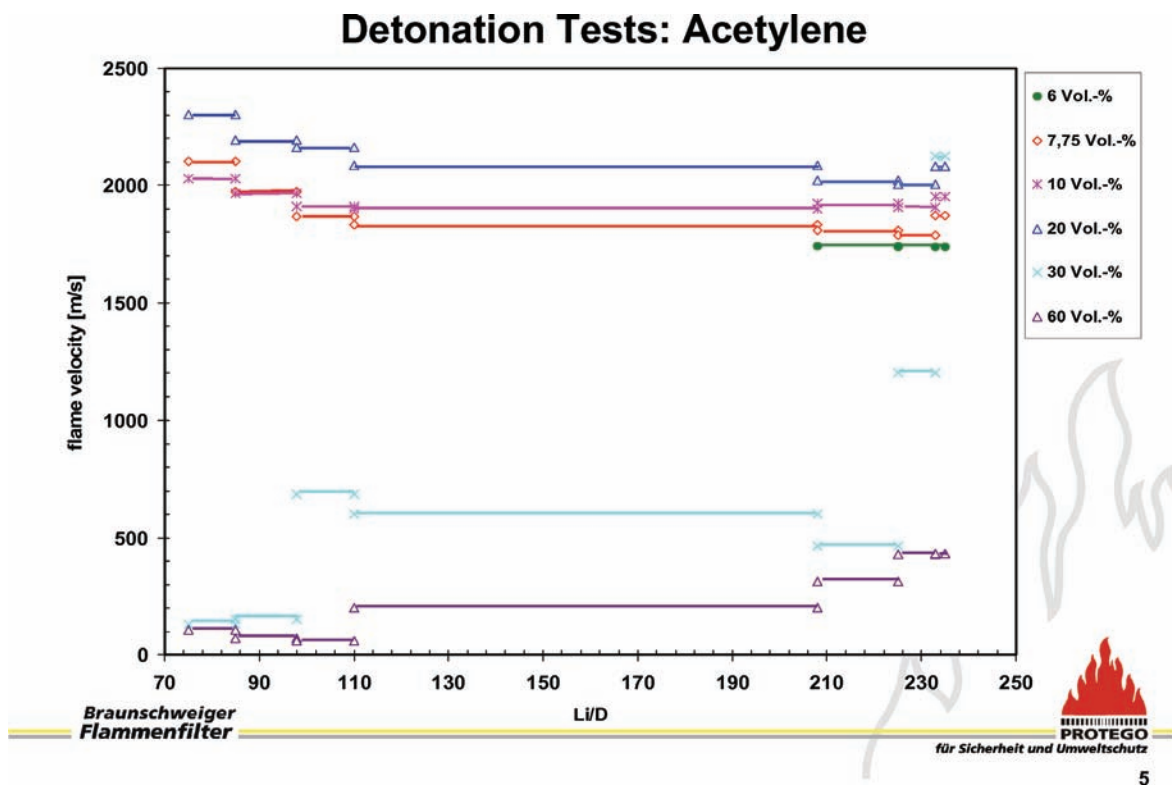


Diagram 4.

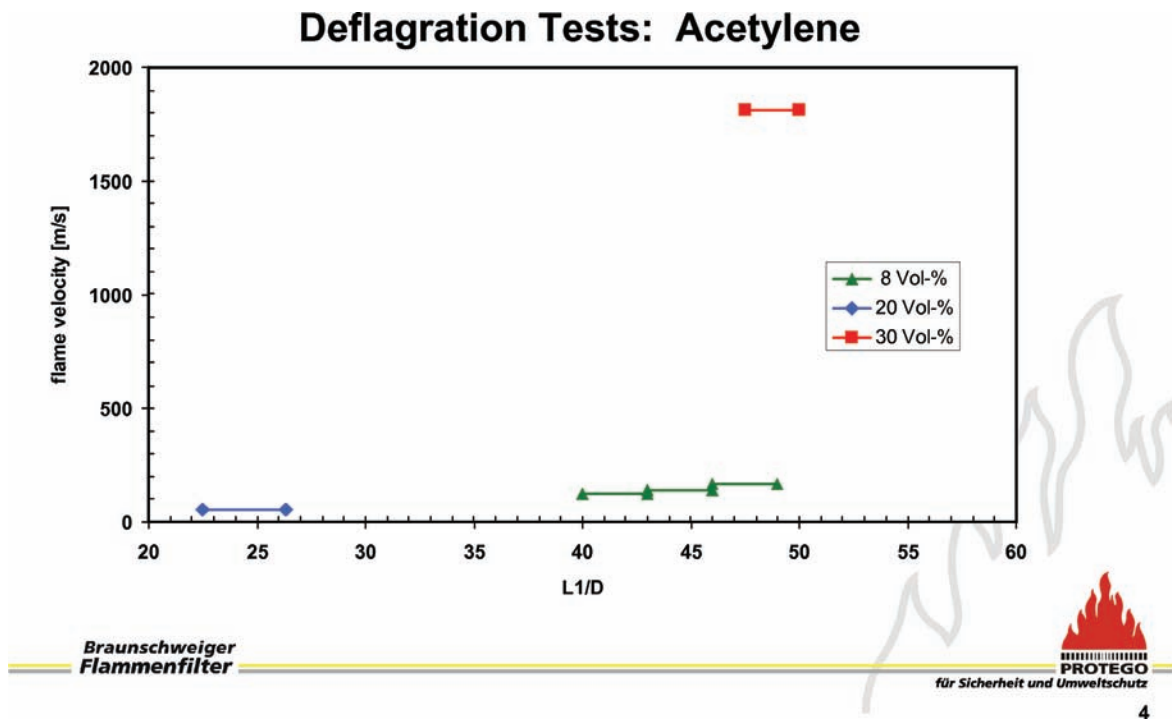


Diagram 5.

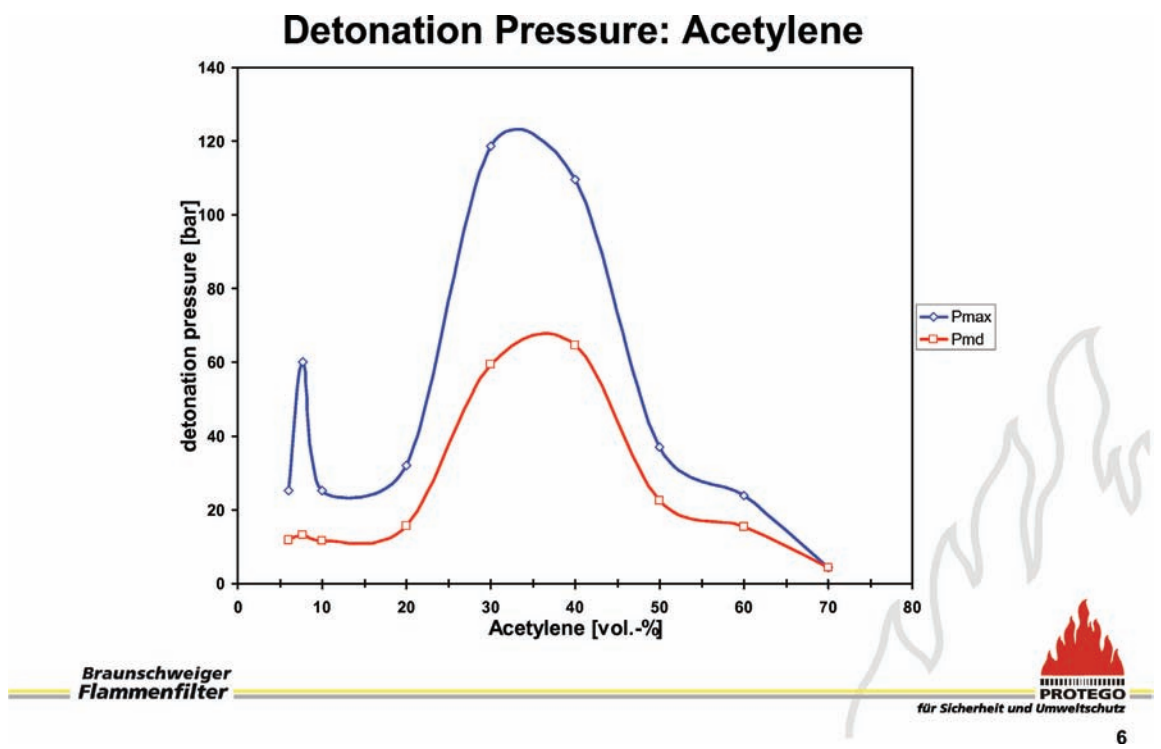


Diagram 6.

With lower  $L_I/D$  ratios (Diagram 5) deflagration was observed with concentrations of 8% and 20% but as the concentration was increased to 30% detonation was observed at a  $L_I/D$  ratio of 48.

Measuring the maximum detonation pressure  $P_{max}$  across the same range of mixtures gave some interesting results which are shown in Diagram 6. The graph shows two peaks in  $P_{max}$ , the first of 60 bar with a stoichiometric concentration of 7.75% acetylene in air. The maximum detonation pressure then reduces with increasing concentration before increasing again to a maximum of 120 bar at 30%. Following this peak the maximum detonation pressure then declines with increasing pressure. The  $P_{md}$  values follow the same profile but peak at very high levels giving an indication of the severity of the detonation that the detonation arrester has to withstand.

### CONCLUSIONS

Ethylene oxide and acetylene are highly flammable gases, which are often used in chemical and process industry. These chemical compounds tend to fast exothermic decomposition. The oxidation and decomposition are competing processes. Up to a stoichiometric gas mixture the combustion process dominates and the gases react like flammable stable hydrocarbons. The maximum experimental safe gap MESG is reached at stoichiometric mixture. With

increasing fuel concentration the reaction is controlled by decomposition. A second minimum of the gap size curve and the maximum detonation pressure can be observed at rich fuel/air mixtures. At very high fuel concentrations the detonation pressure and flame front velocity become smaller.

The test results show that explosions and detonations of stoichiometric mixtures of ethylene oxide/air and acetylene/air do not represent the worse case scenario. They present a special challenge to the flame arrester and EN 12874 is correct to exclude them from its scope. Therefore it is absolutely necessary that Protective Systems for ethylene oxide and acetylene shall be tested over the whole concentration range with the different loads at different gas concentrations. Only devices tested in this way can safely be used to provide protection for plant and processes handling these substances.

### REFERENCES

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