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Investigations into concerns about BS EN 12874: 2001 flame arresters

Performance requirements, test methods and limits for use

Prepared by **University of Wales, Aberystwyth**
for the Health and Safety Executive 2004

RESEARCH REPORT 281

HSE
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Investigations into concerns about BS EN 12874: 2001 flame arresters

Performance requirements, test methods and limits for use

G. L. Oakley M.Sc. (Wales)
Dr. G. O. Thomas PhD, M.IChem.E, M.IoP
University of Wales
Old College, King Street
Aberystwyth
Wales
SY23 2AX

Concerns have been raised by both industry and testing organisations that a flame arrester tested in to BS EN 12874:2001 may satisfy the requirements of the test process yet allow flame transmission under all operational conditions.

Herein this report there is a comprehensive discussion of the current status of knowledge regarding flame acceleration within pipelines which forms an introduction to a review of BS EN 12874; the practical problems involved in the testing of flame arresters; and a more detailed consideration of some concerns that have arisen from actual testing and specifying of deflagration and detonation arresters.

Specific consideration is given to the so called creep flame phenomena in which an arrester which will prevent the transmission of flame from high speed deflagrations and detonations will on occasion fail to quench a “slow” flame, determining the most appropriate value of maximum experimental safe gap [MESG] to use for a multi-component mixture, and which value of MESG is most reliable for those fuels where the values measured experimentally are dependent on the apparatus used to obtain the MESG.

Other areas of the standard where some difficulties have been identified include the use of a 50 pipe diameter run up for deflagration arresters across all pipe diameter ranges – it is possible for a deflagration to detonation transition to occur within 50 • D with larger pipe sizes – and problems encountered with the deflagration test specified for detonation arresters. This latter is linked to weak flame acceleration in small pipes at low temperatures.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

HSE BOOKS

First published 2004

ISBN 0 7176 2913 9

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EXECUTIVE SUMMARY

Why should the European standard EN 12874 be subject to the scrutiny of this report? This essentially arises because of the requirement of flame arrester manufacturers to comply with the ATEX directive and, while it is generally assumed that to satisfy the directive it is sufficient to test for compliance with EN 12874, some UK flame arrester manufacturers pose the question as to their position should an arrester fail in service after it has been certified as compliant with EN 12874.

There exist some concerns from members of the flame arrester "community" that EN 12874 is not always sufficiently rigorous, this report considers these areas of concern and attempts to provide an unbiased review of available data.

1 INTRODUCTION

This section will first explain the genesis of the report and explain the key rationale that determined the content: a need to define clearly the basic phenomena that are associated with the term detonation. This is followed by a brief review of the content of EN12874. Results are then presented from tests conducted using protocols, where the observed outcome calls the validity of the protocol into question. The report concludes with a summary and a discussion of the steps by which the standard might be updated. Note that it is not the intention to present an alternative set of procedures to replace EN12874, but to identify any key generic areas of potential weakness requiring further detailed discussion by appropriate bodies, and hence facilitate their resolution.

Since its general adoption by the appropriate bodies in member states several aspects of the new European testing standard for explosion arresters (EN12874) have given cause for concern to a number of different individuals representing manufacturers, and those closely associated with testing, to review and revise some aspects the standard. In some quarters the level of concern was such that EN12874 shouild be reviewed and possibly revised. Manufacturers are unclear as to their legal liability if the device tested successfully in accordance with the standard fails in operation. This is compounded by the experience of those testing the devices, who have in some instances identified procedures where the device performs adequately when tested according to the standard but fails when the test conditions are slightly different. If one looks closely at both of the above concerns it seems possible to summarise both as arising from the following deficiencies:

a) There is a lack of widely distributed understanding of the nature and essential characteristics of process pipeline explosions.

b) The above is compounded by the lack on information to show unequivocally that the test conditions specified in the standard truly reproduce the events and pressures that arise during actual process pipeline explosions.

c) A further complicating and worrying factor is the approach adopted in the standard for the selection of an arrester to use with different gases and vapours. This is particularly so where the process pipeline contains a complex mix of gases and/or vapours where information upon the combustion properties of the combination is limited.

All of these issues are covered by the following questions.

a) Do the existing published values of maximum experimental safe gap (MESG) provide a sufficient measure of the relative severity/explosion hazard of chemicals and mixtures that might arise in chemical process plant?

b) Are the test conditions specified within the published standard truly representative and sufficiently robust to truly test the effectiveness of different devices when required to protect against actual process pipeline explosions?

2 FLAME ACCELERATION AND DETONATION PHENOMENA: DEFINITION OF TERMS

2.1 DEFLAGRATION

A combustion wave propagating through a gas at a speed lower than the local sound speed. The actual observed velocity is the sum of the velocities of the flame and the unburnt mix ahead of the flame. The laminar flame velocity is a fundamental property of the gas mixture. In practise flame acceleration phenomena in pipelines are usually characterised by a turbulent combustion front.

2.2 SHOCK WAVE

A shock wave is an abrupt gas dynamic discontinuity across which properties such as gas pressure, density, temperature and local flow velocities change discontinuously. Shock waves are always associated with a condition that a gas dynamic feature of the system under study move at a velocity faster than the local speed of sound.

2.3 STABLE OR CJ DETONATION

A self sustaining shock wave which will travel with a characteristic velocity and in which the reaction zone is coupled to the shock front. These are well defined and can also be characterised in terms of detonation cell size. The physical characteristics of a stable detonation are closely linked to the initial gas conditions of composition, pressure and temperature and can be accurately predicted using the Chapman Jouget (CJ) or Zeldovich, von Neumann, Doring (ZND) model.

Typical values of pressure ratio $P_{det} / P_{initial}$ in a stoichiometric hydrocarbon air mixture are 18, while the detonation wave velocity is around $1800ms^{-1}$.

2.4 OVERDRIVEN DETONATION

A region in which the detonation is travelling in excess of the CJ detonation velocity with due regard for the pressure, temperature and gas composition of the system. This is a short lived event and decays to a stable detonation.

2.5 DEFLAGRATION TO DETONATION TRANSITION

The region in which a deflagration becomes a detonation is very complex and not well understood. The term is used to describe that region where the complex combination of a shock wave and trailing flame exists prior to the formation of an overdriven detonation. The detonation wave arises within the unburnt gas between the flame and the leading shock front.

2.6 SPINNING DETONATION

Can occur when the detonation cell size is comparable with the dimensions of the tube which the detonation is propagating. Nettleton[1]

[1] *M.A. Nettleton, Gaseous Detonations- their nature, effects ands control, Chapman and Hall, (1987)*

2.7 GALLOPING DETONATION

An interesting form of detonation can be observed in some cases, usually near to the limits of propagation of a detonation in a pipe. Here the wave velocity is not constant at the CJ value, but fluctuates dramatically between approximately 1.5 and 0.5 M_{cj} where M_{cj} is the Chapman Jouget detonation Mach number. This behaviour is a constant of the following sequence of events: a transition to detonation leading to a overdriven detonation which decays to a steady detonation which subsequently fails whereupon the sequence is repeated.

3 REVIEW OF CURRENT KNOWLEDGE OF FLAME ACCELERATION AND TRANSITION TO DETONATION

3.1 INTRODUCTION

Given the significant over pressures that can be generated when a reactive mixture detonates it is fortunate that accidental detonations are extremely rare occurrences. In truth, it is still a question of debate as to whether a truly self-sustaining detonation has occurred in any actual unconfined accident scenario. The most likely candidate is the 1970 incident involving propane at Port Hudson[2]. The primary reason for this is the lack of mechanism to give sufficient flame acceleration in unconfined geometries.

Notwithstanding the ability to form a self-sustaining detonation, significant damage can still arise during the pre-cursor stages of transition to detonation. The process of transition to detonation is thus still of great concern in certain circumstances due to the degree of flame acceleration that can occur in long pipelines or regions of plant containing complex obstructions. There is also concern in process pipelines as flame acceleration can be promoted by turbulence generated by wall boundary layers.

To achieve an understanding of the transition to detonation process it is useful to first appreciate the nature of a self-sustaining detonation and of the factors that control its propagation characteristics. It is then possible to make some estimation as to the likelihood of detonation or incipient transition and of the overpressures that might arise.

3.2 BASIC SHOCK AND DETONATION THEORY

3.2.1 Shock Waves

A shock wave is an abrupt gas dynamic discontinuity across which properties such as gas pressure, density, temperature and local flow velocities change discontinuously. Shock waves are always associated with a condition that an element in the system under study travels faster that the local speed of sound.

The speed of sound is the speed at which a small pressure perturbation moves in a fluid (such as the pressure waves that carry human speech through the air). If the air moves faster that this speed or an object moves at a similarly high velocity (such as Concorde) elements of the flow are now termed super sonic and a shock wave will be formed. The distant sound heard from Concorde is the weak remnant of the shock wave formed when it travels supersonically. The ratio of the velocity to the local speed of sound is called the Mach number.

A shock discontinuity can be represented schematically as follows:

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[2] *D.S. Burgess and M.G. Zabetakis, 'Detonation of a flammable cloud following a propane pipeline break', US Bureau of Mines Report of Investigations 7752*

	Shock Front	
Velocity	U2	U1
Pressure	P2	P1
Temperature	T2	T1

Basic physical laws require that some properties are conserved.

Mass $\rho u_1 = \rho u_2$

Momentum $P_1 + \rho u_1^2 = P_2 + \rho u_2^2$

Energy $H_1 + \frac{1}{2} u_1^2 = H_2 + \frac{1}{2} u_2^2$

where ρ is the density, u particle velocity, P pressure, H enthalpy, and subscripts 1 and 2 refer to conditions before and after the shock. Using these laws it is then possible to relate the changes across the shock wave and derive exact expressions for their magnitude. Examples of the values computed from these expressions are given in the following table for shock wave discontinuities of increasing velocity in air, sound speed 332 ms^{-1}

Shock velocity ms^{-1}	Mach number M	Pressure ratio P2/P1	Temperature ratio T2/T1
365	1.1	1.3	1.1
665	2.0	4.5	1.6
996	3.0	10.5	2.4
1329	4.0	18.9	3.3

3.2.2 One-dimensional detonation theory

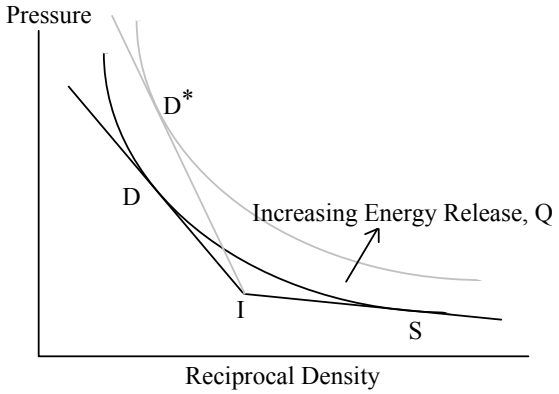
Chapman-Jouguet detonation

One dimensional detonation theory was developed independently by Chapman (1899) and Jouguet (1905) and was based on the preceding shock theory, with the inclusion of an addition energy term, q, corresponding to the energy released by chemical reaction. In this theory, the C-J theory, the chemical reaction is assumed to occur infinitely fast. Further manipulation of these equations leads to the following expression,

$$q_{cj} = \frac{(M_{cj}^2 - 1)^2 a_1^2}{2(\gamma_b - 1)M_{cj}^2(\gamma_b + 1)}$$

which relates the resulting wave Mach number (M_{cj}), the corresponding energy release q_{cj}, the sound speed in the initial reactants (a_1), and the ratios of specific heats of the product gases γ_b.

In a C-J detonation, the reactants at an initial pressure, temperature and density are transformed instantaneously to products at a final pressure, temperature and density in a manner consistent with the conservation equations given above. In this way an equation can be derived that relate the initial and final states.



For detonations, a curve can be drawn that links all possible final states. This is called the Rankine-Hugoniot curve. The steady state solution is the point D, where a line drawn from the initial state, I, is a tangent to the Rankine-Hugoniot curve.

The absolute values of the final states also depend on the magnitude of the energy release and varying the energy release gives a different steady state solution, at D* for example.

The C-J theory gives a remarkably accurate prediction of detonation velocities based only on a knowledge of the initial conditions despite the actual multi dimensional complexity of a real detonation (see later section). Unfortunately neither the CJ or any other theory will allow us to predict whether a detonation will occur for a given set of initial conditions.

3.2.3 Overdriven detonation

Under certain circumstances, it is possible for the detonation wave to move faster than the unique steady-state velocity given by C-J theory. This usually occurs because another event causes the detonation products to move faster than the velocity they would have in a C-J wave. As a result, the pressure associated with the detonation front can be significantly higher. An overdriven detonation can correspond to the point D* on the preceding Rankine Hugoniot curve, equivalent to a more energetic mixture.

The extent of pressure increases that can occur can be seen on the following table for an ethylene-air detonation

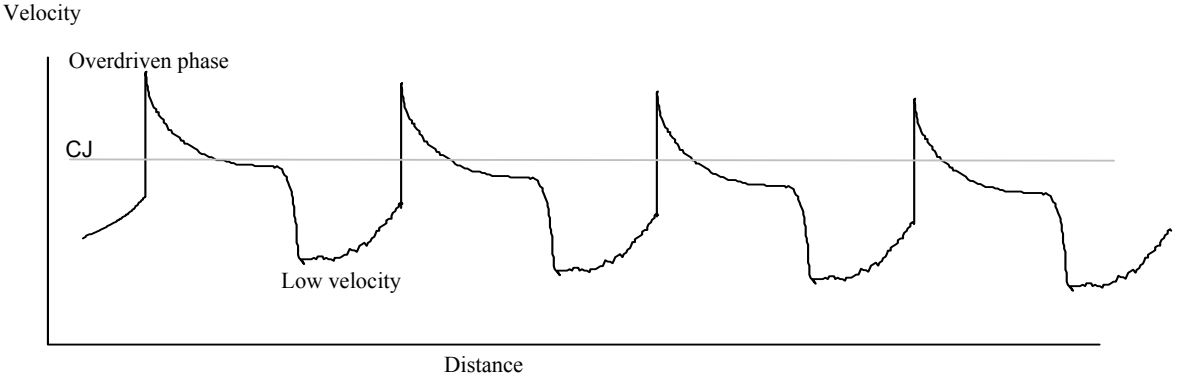
(M/Mcj)	1.0	1.05	1.1	1.2	1.4	1.6
Detonation pressure (Bar)	18.7	26.7	31.8	41.3	61.4	83.9

3.2.4 Galloping detonation

An interesting form of detonation can be observed in some cases, usually near to the limits of propagation of a detonation in a pipe. Here the wave velocity is not constant at the CJ value, but fluctuates dramatically between approximately 1.5 and 0.5 M_{cj} where M_{cj} is the Chapman Jouget detonation Mach number. This behaviour is a constant of the following sequence of

events: a transition to detonation leading to a overdriven detonation which decays to a steady detonation which subsequently fails whereupon the sequence is repeated.

These transitions between these states can occur with remarkable consistency over a large number of cycles. Such an event can lead to severe damage at each of the locations where transition to the overdriven phase occurs.

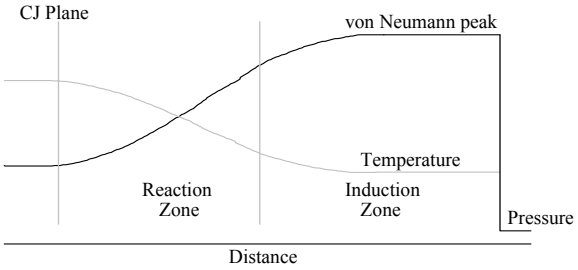


3.3 DETONATION STRUCTURE

3.3.1 Z.N.D. model of detonation

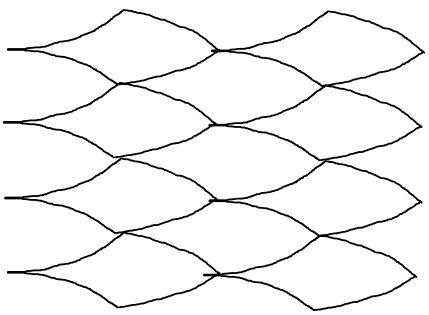
In reality, the chemical reactions occurring in a detonation do not occur infinitely fast. Zeldovitch,(1940) , von Neumann (1942) and Doring (1943) independently proposed a slightly more detailed description.

In their one-dimensional model, an initial shock discontinuity still existed but energy release from chemical reaction occurred after a finite delay. The conditions corresponding to the C-J detonation values would now be observed some distance from the leading shock front and this equilibrium point is called the C-J plane. The variation of pressure, density and temperature across the detonation wave is now as follows:



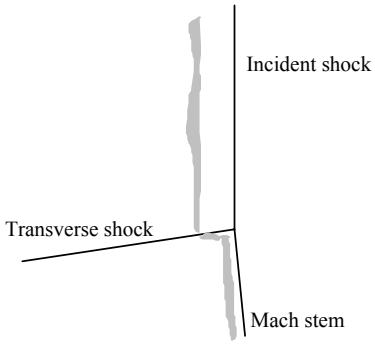
The region between the shock front and the start of energy release is called the von Neumann spike. The gas pressure etc. in this region are given by the non-reactive shock relationships. In this region the initial reactants dissociate with a finite induction period before energy release starts. The induction delay is determined by the rates of certain chemical reactions. This delay and the gas velocity determine the width of the von Neumann spike.

3.3.2 Multi-dimensional structure

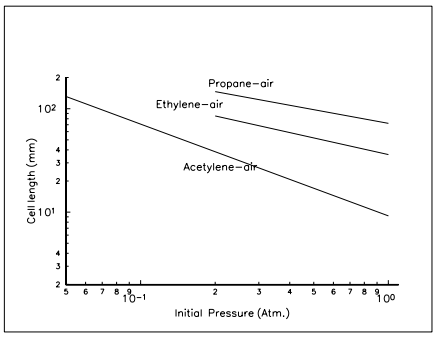


Experiments have shown that, despite the success of one-dimensional models, detonations actual exhibit a complex three-dimensional structure. This can be observed

optically and also by the pattern it leaves on a lightly sooted surface. The latter means of measurement has led to the concept of a detonation cell, corresponding to the spacing between the loci of triple points between collision events. It is thus a form of time integrated picture of the wave structure.

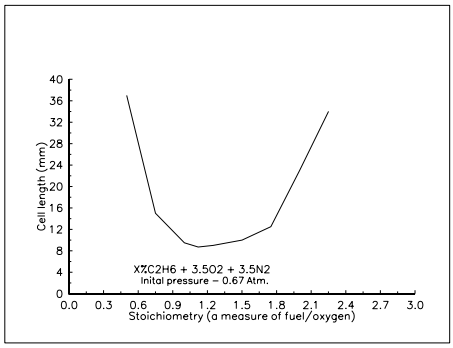


The multi-dimensional structure arises because the detonation front is not a truly planar shock followed by a secondary reaction zone but is actually composed of a number of transverse shocks propagating back and forth across the detonation front. The patterns left on a sooted surface are the loci of the points where shocks meet the leading detonation front. The reaction is now initiated by these shocks, which are of differing strengths with differing pressures and temperatures. The induction distances are thus different for each. Also, a detailed study shows that each of these shocks is decaying. They are reinforced when two transverse waves collide, at which point an explosive release of energy occurs. A detonation front is therefore composed of shocks that are continually decaying. Continued propagation is only possible by transverse wave collision with other transverse waves or solid walls or boundaries.



A strong relationship can be observed between the chemistry and cell size in gaseous detonations. The cell size is a convenient parameter determined from the average width to length of the roughly diamond pattern left on a sooted surface. The cell width is also a measure of the average spacing of the transverse waves across a detonation front and the average time between collisions. It is also possible to demonstrate a link between an average induction zone length and cell size.

Cell size varies with both initial pressure and temperature and with mixture composition. Theories for predicting cell sizes from only basic chemical and thermodynamic data have met with mixed success.

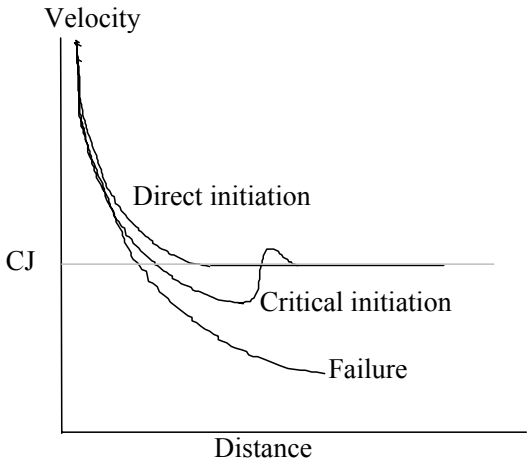


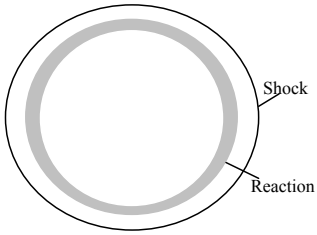
The cell size can also be related to the ease with which a detonation can be initiated.

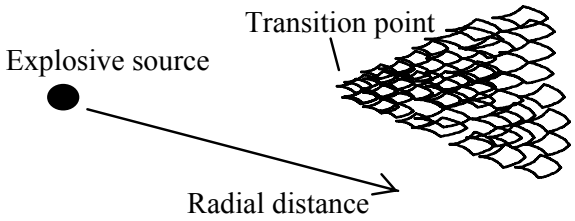
3.4 DETONATION INITIATION

3.4.1 Direct initiation

The vast majority of instances where detonations are initiated require some form of energetic source. If this is a localised point source then the initiation is often termed a direct initiation. An example would be the use of high explosive charges. In this case the source creates shock front that exceeds steady state detonation velocity. This initial blast wave thus initiates the chemical reaction and sustains it until the detonation structure gives rise to a self-sustaining detonation. As the source strength decreases, or the mixture becomes less reactive, a point is reached where the source only just manages to initiate the detonation. In this case clear separation of the leading shock front and reaction can be seen. This is usually followed by a localised explosion in the shocked gas which then leads to an initiation. The velocity minimum during critical initiation has been identified with a quasi-steady region with a clearly separated leading shock and following reaction zone.





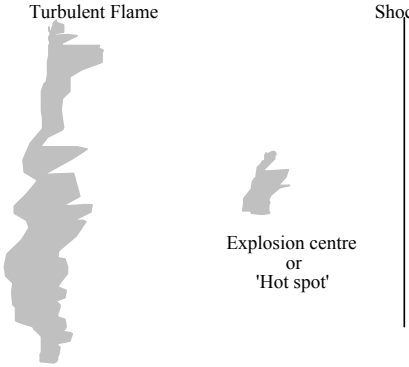


A common feature of these critical transitions is the relaxation of the cell size back to the size corresponding to the steady-state detonation. The initial fine structure corresponds to an overdriven phase and can be correlated with the increased pressures etc. at the transition point.

The controlled direct initiation of mixtures has been used as one method of characterising the relative detonability of mixtures. Mixtures can then be ranked in order of the weight of explosives need to initiate a spherical detonation in each mixture and hence give an indication of the relative hazard they present.

3.4.2 Transition to Detonation

The direct initiation of detonation by a point source is an unlikely occurrence in practice. More likely is the initiation of detonation involving an initial flame acceleration phase. Two main scenarios have been investigated to date. The acceleration of a flame in a long pipe and acceleration of a less confined mixture within a region containing obstacles.In both cases gas phase turbulence enhances



combustion to a point where a shock wave is formed ahead of the flame front.

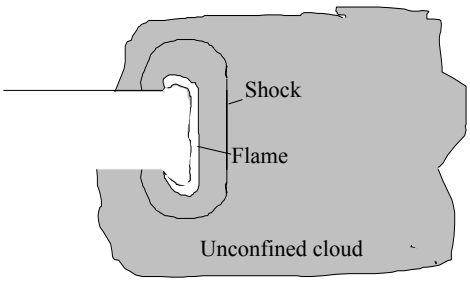
Once this stage is reached the final transition to detonation process is believed to occur by a similar mechanism whatever the initial mechanism that gives rise to the shock front.

Shock induced transition

In a detonation, the chemical reactions are initiated in different way to the corresponding reaction in a flame. Flame combustion is strongly dependent on heat diffusion ahead of the energy release zone. This process is of course much more complicated in a turbulent flame. In detonations however the reactions are initiated by the pressures and temperatures associated with the shock (cf the von Neumann peak and related induction zone). If a sufficiently strong shock front is formed ahead of an accelerating flame, these shock induced reactions (often called auto-ignition) can lead to the formation of a so called 'hot spot'. Further if the conditions of temperature etc. are correct this reaction centre can increase coherently leading to a rapid localised explosion in the shocked gas. This leads to a second shock wave that rapidly manifests itself as an overdriven detonation.

Jet initiation

A possible mechanism for initiating a completely unconfined cloud in an unobstructed region is when a detonation emerges into the external cloud. Provided the number of detonation cells across the pipe width is sufficient then the wave can propagate successfully into the external cloud.



Recently it has been demonstrated that a more serious hazard is presented if a accelerating flame and associated shock front emerges from the pipe. The actual transition mechanism is not clearly understood. The significance is that this mechanism allows mixtures to be detonated that could not be detonated if an established detonation emerged from the pipe.

A jet type mechanism has also been shown to lead to rapid transition, without an initial shock, if a highly reactive mixture such as fluorine is injected into the external cloud.

3.4.3 Limits of Propagation

Despite the success of the Chapman-Jouguet theory in predicting the parameters of an established detonation, such as velocity and pressure, the theory is unable to give any guidance as to whether that detonation can be initiated readily under any given circumstances. The cause of this lack in our understanding is the complex interaction between the chemistry and the gas dynamics, as characterised by the transverse wave structure.

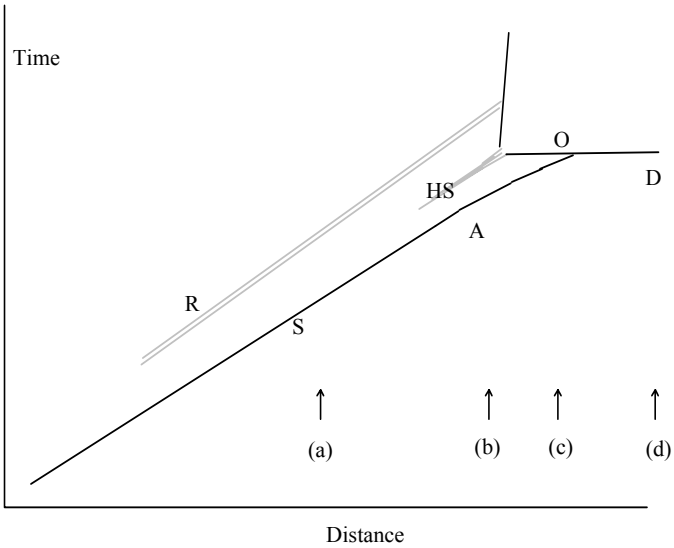
Initiation of a steady-state detonation requires that the self- sustaining multi-dimentional structure must develop. In a related way, if transverse structure can be eliminated, then the

detonation fails. Thus a detonation cannot propagate in a pipe whose internal diameter is close to the natural size of cellular structure in that mixture.

It has also been demonstrated that lining a tube wall with an acoustic absorber can weaken the transverse structure to the point where the detonation fails[3].

3.5 FLAME ACCELERATION AND TRANSITION TO DETONATION

The final stages of transition to detonation after an initial flame acceleration phase is shown in the following sketch. Four main regions may be identified.



a) Initial shock-flame complex. A leading shock (S) and turbulent flame (R) propagate together

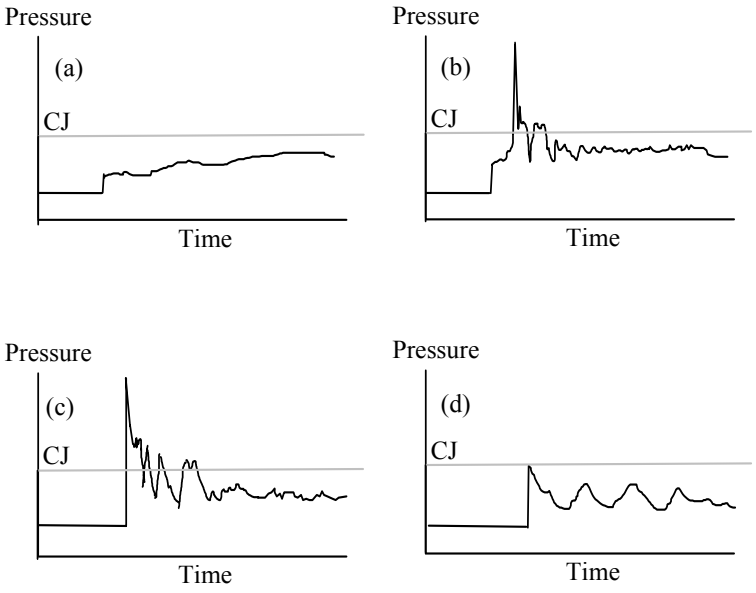
b) Hot spot (HS) formation. Energy release here may also lead to a slight acceleration of the leading shock (A)

c) Transition leading to an overdriven detonation O

d) Steady state detonation D

The above also corresponds to the final stages of the low velocity regime in a galloping detonation.

The nature of the pressure histories associated with the transition process are shown in the following sketches.



The particular point of concern is the extent of the transient over pressures that can be generated during the transition process.

Transient pressure several times the CJ value, corresponding to pressure 50 atmospheres or more could be generated with hydrocarbon air mixtures. They are however of relatively short duration.

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[3] *G. Dupre, O. Peraldi J.H.S. Lee and R. Knystautus, 'Propagation of detonation waves in an acoustic absorbing walled tube', Prog. Astronautics and Aeronautics, Vol. 114, pp. 248-263 (1988)*

4 DEVELOPMENT OF EXPLOSIONS IN PIPELINES

Explosion events in pipelines, initiated by low energy sources, first propagate as slow deflagrations where the flame velocity relative to the pipe is small (<< 300ms^{-1}). During this stage the gas flow displacements ahead of the exothermic flame or reaction front are relatively small, the pressure increase ahead of the flame is correspondingly low, less than one bar, and no shock wave is formed.

As the flame front velocity and rates of energy release increase, due to increased rates of turbulent burning resulting from the interaction of the flowing gas with the pipe walls, a shock wave is formed ahead of the flame front and the overall explosion process accelerates further. This acceleration is caused by the positive feedback between the combustion front and the gas flow ahead of the flame. The feedback arises via flow induced turbulence and subsequent increased turbulent mass burning rates. It is generally acknowledged, but not fully quantified, that further escalation of the explosion process can occur as the velocity of the shock-flame complex approaches *ca.* 1000 ms^{-1}. Localised explosions now develop, with significant transient overpressures in some cases. This is termed the deflagration to detonation transition or DDT phase. Following this transition the detonation wave moves faster than that predicted from simple steady state theory but is always decelerating and eventually reaches the steady or Chapman Jouguet state. For an explosion in a pipeline, each of these stages could potentially develop at a location where a detonation arrester is located. Once the stable detonation condition has been reached then there is no influence upon the flame and shock velocities by any feedback from in front of the detonation wave.

Steady state detonation are a special form of propagating supersonic combustion waves characterised by the constancy of their velocity, whose magnitude can be readily computed from basic thermodynamic data pertaining to the initial gas mixture. Detonations are potentially damaging as the pressures can increase to more than 18 times the ambient pressure. The process of transition from a deflagration to a detonation is still relatively poorly understood, but, as the transient pressures can reach in excess of 100 times the ambient pressure, the potential for very damaging localised overpressures is significant. During the period immediately following transition, and before the detonation wave relaxes to its steady state velocity and pressure, the wave is described as being overdriven. During this phase, both peak pressures and local wave propagation velocity are greater than the theoretical steady state values.

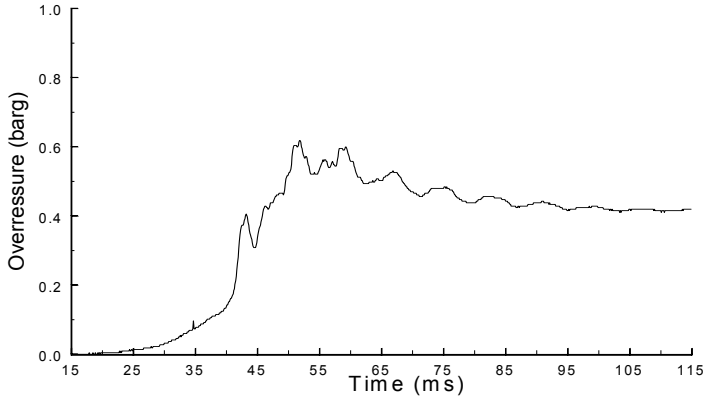
The various phases during an accelerating explosion event in a pipeline explosion initiated by a low energy ignition source may therefore be categorised in general terms as follows:

1. Slow deflagration (Sdef)
2. Fast deflagration (Fdef)
3. Overdriven or transition to detonation (Odet)
4. Steady CJ detonation (CJdet)

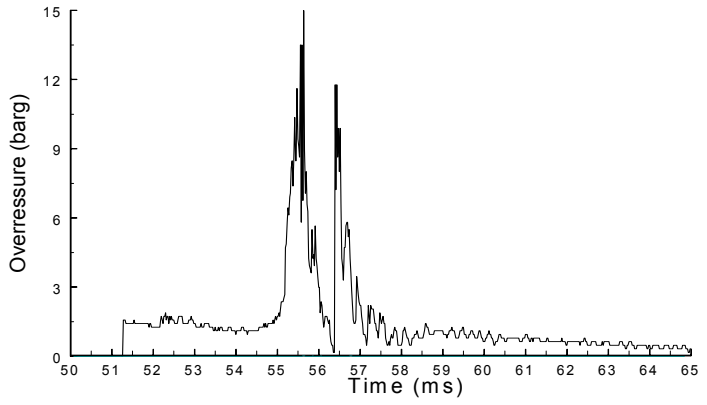
Examples of experimental pressure histories corresponding to each of these phases are shown in Figures 4.1 (a)-(d), obtained during flame acceleration tests, some of which were performed with an explosion arrester device in position. Explosion development in pipelines is known to

be a stochastic process and the pressure evolution is seldom repeated in multiple tests. However, Figure 4.1 does serve to illustrate the general forms of the pressures developed and their respective magnitudes.

Figure 4.1(a) shows a slow deflagration which exhibits a gradual pressure rise with a maximum over pressure below 1 bar. Figure 4.1(b) is a pressure record from a fast deflagration test where a pre-cursor shock has formed. The flame front arrival at the pressure gauge is coincident with the second pressure rise at *ca.* 55.5 ms. The third pressure change, at some 56.5 ms, is due to the entry of the flame into a flame arrester housing, where a localised explosion sends a pressure wave back towards the ignition point. The pressure gauge in this test was located some 100 mm before the arrester flange. Figure 4.1(c) shows the pressure histories typical of an overdriven detonation immediately following a transition to detonation event. The peak pressures are several times greater than the pressures observed for a steady detonation wave, shown in Figure 4.1(d).



a)



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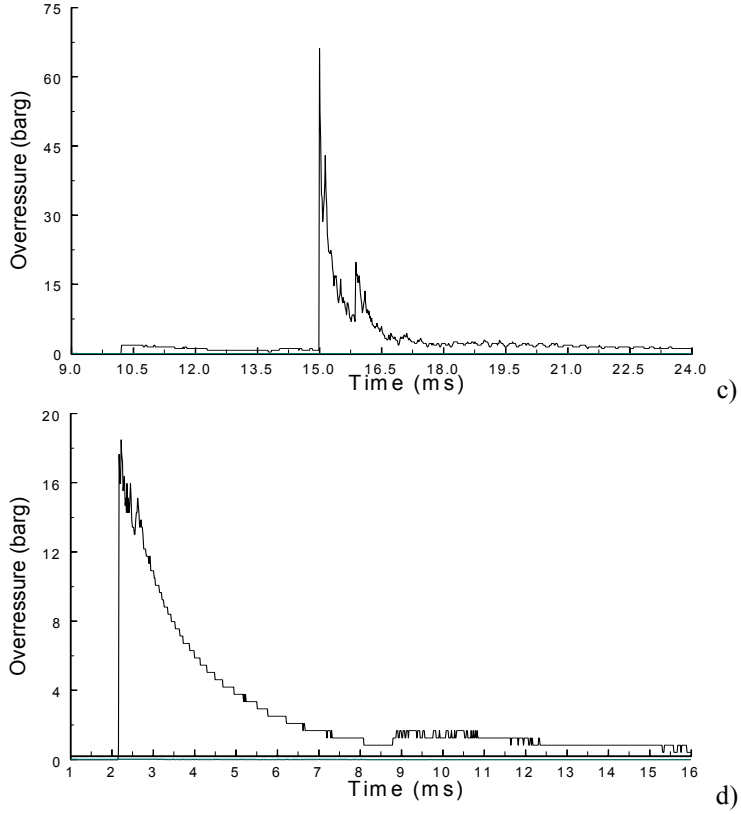

Figure 4.1. Typical pressure histories showing a) slow deflagration, b) fast deflagration, c) overdriven detonation and d) steady detonation

In a pipeline system then the acoustic wave running in front of the flame front will influence the development of the flame. It is unclear to what extent this phenomena extends, but there is some evidence from tests in an open ended 150mm diameter tube[4] that the rarefaction wave associated with the early stages of the flame development and travelling back from the open tube end can interact with the later propagating shock wave which has developed ahead of the flame front and catalyse the ddt event.

Thus it follows that the addition of a flow obstruction, for example a flame arrester, will influence the development of a detonation within a pipeline.

[4] *PipEx project report GO Thomas, NS Lamoureux, GL Oakley; Flame Acceleration and DDT in pipes; UWA/PipEx/fr15099*

5 KEY ELEMENTS OF EN12874 — ISSUES ARISING

In this section we identify some key features of EN12874 together with a précis of the associated weaknesses or limitations. A more detailed discussion of the main issues in which UWA have particular expertise follows in the next section, together with supporting evidence.

5.1 END OF LINE DEFLAGRATION – SECTION 6.3.2.1 OF EN12874

A test designed to ascertain that an arrester designed to prevent a pipeline system from an external explosion will function as designed. There are no significant issues with this test.

5.2 IN LINE DEFLAGRATION TEST – SECTION 6.3.2.2

The aim of this test is to provide a comprehensive test for deflagration arresters. The actual test is based on a fixed run up length — limited to a maximum of 50 pipe diameters — and the arrester is certified for use where the potential ignition source is any length up to the tested length. This approach has several drawbacks. Firstly there is the assumption that a flame arrester that prevents flame transmission of a "high" speed deflagration will also stop a "low" speed flame. While this is generally the case we will later present some evidence that this is not universally true. A second consequence of this approach is that an arrester may comply with the requirements if tested in one test pipe and yet fail if tested in another. There are several reasons for this, generally related to variations in flame acceleration between setups. Known causes of differences in flame acceleration rates include:

i) The surface roughness of the tube walls
ii) Inner diameter differences between pipes – in practice only likely to be an issue in small diameter systems.
iii) Joints between pipework (alignment, gasket protrusion and flange setback).
iv) Temperature of the test tube.
v) Ignition source.

A further concern is the arbitrary 50d runup, is this universally applicable because it has been demonstrated that in some larger diameter pipes ddt can occur within 50 pipe diameters

5.3 IN LINE STABLE AND OVERDRIVEN DETONATION – SECTIONS 6.3.3.2 AND 6.3.3.3

Parameters are set out in look up tables to determine whether an explosion is a detonation (stable or unstable). The derivation of these values appears to be arbitrary and in some instances it can be extremely difficult, if not impossible, to meet the set values. This is particularly so with IIB1 gases as there was no adjustment made to compensate for the lower energy release – GASEQ[5] gives the CJ detonation pressure for stoichiometric ethylene air mixes as 17·5 bar; this falls to 15·3 at IIB1 concentrations.

In addition, for unstable detonation tests with the instrumentation arrangement as described section 6.3.3.3 of the standard, it can be impossible to determine unequivocally whether the transition was in the incident or reflected wave.

It is important to understand the extremely transient nature of an overdriven detonation. This leads directly to many of the practical test difficulties. There are several reasons for this:-

[5]Gaseq chemical equilibrium programme; http://www.c.morley.ukgateway.net/

i. the individual arrester will affect the development of the overdriven detonation
ii. the location of the transition region will vary along the length of the tube both depending on the arrester fitted, the ignition source and variations in the initial test conditions, for example temperature, pressure and concentration

5.4 ENDURANCE AND SHORT TERM BURN TESTS

In our experience the manufacturers are not requesting that their arresters are tested for either short term or endurance burning.

It is possible that the manufacturers recognise the difficulty in meeting the 2 hours endurance burn test; and that the short term burn test of 1 minute, with its associated control systems, is inappropriate for their requirements. Should a pragmatic approach to this issue be adopted with a third burn test option possibly in line with the 30 minute burn test described in BS 7244:1990?

5.5 MESG

In EN 12874 MESG is used as a characteristic for ordering fuels for explosion severity. This measure is widely used and is generally considered a robust tool in ordering of potential flame transmission in for example flame proof enclosures. However there is little publicly available test value data for many mixtures of gases. This paucity of information on MESG mixture values is of concern to arrester manufacturers and end users alike and leads to some confusion as to the most appropriate arrester to use Some assistance is provided by Le Chateliers rule which gives a theoretical method of deriving the MESG of a mixture from the more readily available data for pure components. However there is published evidence, for example Mashuga and Crowl[6], that this rule is not always reliable.

A detailed discussion of the use of MESG to select flame arresters is presented by Britton[7]. In this paper the suitability of MESG for selecting flame arresters is questioned, with examples given where current practice in the choice of MESG value and application of Le Chateliers rule could lead to the inappropriate selection of flame arrester. In particular it is shown why including inerts in Le Chateliers rule is inappropriate and should be avoided.

Also in this paper Britton considers why with certain fuels, have widely different published MESG values dependant upon which apparatus – Westerberg or European – is used to determine the MESG value. The Westerberg apparatus gives either similar or lower, sometimes considerably MESG values - for example diethyl ether which has a MESG of 0.86mm measured in the European apparatus compared to 0.30mm measured in the Westerberg apparatus. In the instances where the Westerberg MESG value is lower this normally corresponds to fuels which have a low auto-ignition temperature. Differences in the measured MESG value are linked to the size of the receptor chamber in the MESG apparatus. Furthermore Britton examines why values of MESG obtained from the European apparatus are appropriate for electrical enclosures whilst values from the Westerberg apparatus appear to be preferable for specifying flame arresters. This is linked to the auto-ignition temperature and the compression of gas on the protected side of the flame arrester.

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[6] *Mashuga,C.V and Crowl, D.A., 2000, Derivation of Le Chateliers mixing rule for flammable limits, Process Safety Progress, Vol 19, No2, 112-117*

[7] *L G Britton, 2000, Using Maximum Experimental Safe Gap to Select Flame Arresters, Process Safety Progress, Vol.19, No.3, 140-145*

This concern regarding MESG values and applicability asks us to consider if mixtures with similar MESG values will always posses similar detonation properties and more importantly will is it possible for run up to ddt distances to be significantly altered?

5.6 GAS GROUPINGS

Only fuel air mixtures are covered by the standard, these are considered in 4 main categories: in ascending order of reactivity; IIA, IIB3, IIB and IIC, plus the little used IIB1 and IIB2.

5.7 IGNITION SOURCE

Within EN12874 little consideration is given to the ignition source. The guidance provided varies with the test section, for example with in line deflagration it is specified with a spark in the centre of the end flange and with end of line tests the options of using a chemical igniter or electric fuseheads are given. At a general level it is known that the ignition energy can affect the initial development of an flame, many people will be aware of the difficulty in starting an engine with a weak spark, often combined with misfiring once running.

5.8 MECHANICAL PROPERTIES

These include specifying mechanical damage and static pressure strength plus acceptable material specification.

5.9 GAS FLOW

Essentially included to ensure that following an undetected explosion then any damage to an arrester will not cause an overpressure within the process plant.

5.10 MARKINGS

An essential part of any standard is traceability. This is covered.

5.11 LIMITS FOR USE

In this section it is stated that an arrester when tested at atmospheric conditions is acceptable for use at an operational pressure of $1{\cdot}1 \times P_o$. Development testing of flame arresters at Aberystwyth has shown that a 0·1 bar increase in pressure is sufficient to cause an arrester to no longer prevent flame transmission. It is strongly felt that an arrester should *never* be used at greater than the pressure at which it was tested at.

6 CONCERNS ASSOCIATED WITH THE TESTS AS SPECIFIED WITHIN EN12874

At UWA there are several concerns which have arisen as a result of practical testing to EN12874. These are discussed with some examples to illustrate. Unfortunately many of the observations are as a by product of specific tests for arrester manufacturers and not a result of a specific research programme. Thus the observations are in fact just this, observations of what has occurred in specific individual tests and are not generally backed by a robust and unequivocal experimental test programme.

6.1 DEFLAGRATION ARRESTER TESTS

In the deflagration tests as defined in EN12874 the tests are completed in a fixed length tube up to a maximum length of 50 times the pipe diameter. In larger size pipes testing at Aberystwyth has shown that deflagration to detonation transition [ddt] can occur within 50 pipe diameters. This data was obtained from tests in a 300 mm pipe with a group IIB3 gas at an initial test pressure of 1·6 bar, figure 6.1. Testing completed subsequently has shown that in a 400 mm pipe ddt will occur at 1·25 bar initial pressure. At least one other test house has tested a 300mm arrester without seeing ddt; it is likely that the construction of the arrester being tested affects the flame acceleration.

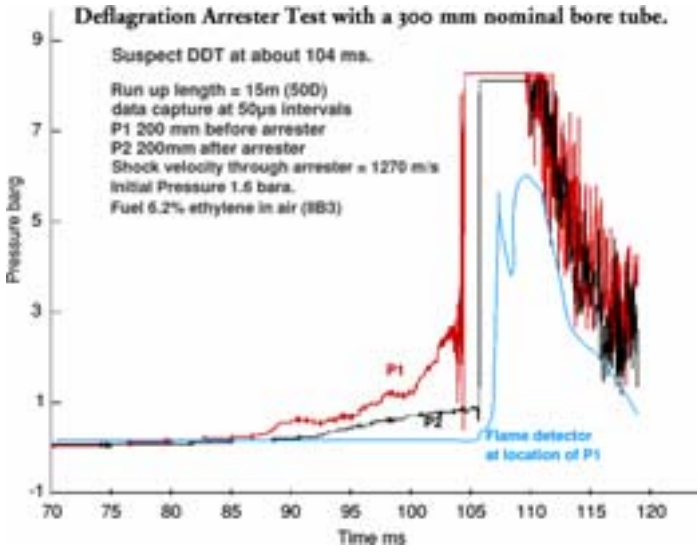

Figure 6.1 Transition to detonation within 50 pipe diameters in a 300 mm nominal bore pipe. Initial pressure 1·6 bar, temp 10°C. The data capture system was set for deflagrations and hence it is impossible to establish exactly what is occurring in the transition region

Under the flame conditions described above, that is approaching or at ddt, the arrester under test may still prevent flame transmission to the protected side; the question we pose is whether this was intended when EN 12874 was drafted and if this is a valid test for a deflagration arrester.

We believe that it is not always a valid test, and have some evidence to back up this claim. This evidence was obtained from some development testing on a prototype overdriven detonation arrester and as such the tests were more wide ranging than would be typical of EN 12874 trials.

In tests in a 150 mm nominal bore tube the arrester prevented flame transmissions with stable and overdriven detonations together with shock-flame / ddt conditions at an initial test pressure of 1·65 bar yet flame transmission occurred at an initial test pressure of 1·33 bar when the incident flame speed was in the region of 65 to 100 ms^{-1}.

The results from the testing of a 300mm crimped ribbon detonation arrester are more emphatic. In 16 tests with a 3m (10d) runup the arrester under test failed in 10 out of 16 tests. With a 9m runup (30d) flame transmission through the arrester occurred in 2 out of 20 tests. The 18 tests where the arrester quenched the flame were all with accelerators fitted to the start of the pipeline; twelve of these tests were with an initial test pressure of over 1·65 bara. The two tests without accelerators and 15 out of the 16 tests at 3m run up were at an initial test pressure below 1·28 bara. Details are from UWA internal report[8].

With a different 300mm nominal bore crimped ribbon detonation arrester[9] the results were different. In this instance stable and overdriven detonations with initial test pressure in the 1·5 to 1·6 bar range were quenched while slow and fast deflagrations in the initial test pressure 1·35 to 1·4 bar range were usually, but not always quenched. There was no obvious pattern to the pass – fail mix.

More data comes from some tests on a 50 mm nominal bore arrester where the arrester under test prevented flame transmission with a series of six "fast flame" tests in which flame speeds were between 470 and 830 ms^{-1} with an initial test pressure of 1·65 bar, yet in 4 out of 8 tests flame transmission through the arrester occurred with flame speeds of between 20 and 70 ms^{-1} at an initial pressure of 1·45 bar.

6.1.1 Summary and Relevance to EN12874

It is possible to test an arrester at 50d run up and generate an "unstable" detonation. Some designs of arrester will quench an unstable detonation yet fail with a slower flame. Thus there remains the possibility that an arrester could prevent flame transmission when tested to the 50d criteria of section 6.3.2.2 of EN12874 and yet still transmit flame in a shorter pipe under what would generally be assumed less demanding conditions.

6.2 DIFFICULTIES WITH TESTING FOR DEFLAGRATIONS AS DEFINED FOR DETONATION ARRESTERS

In the previous section we discussed the potential limitations of the deflagration arrester tests defined in section 6.3.2.2. We now move on to consider some issues which arise with the deflagration tests as defined for stable and overdriven detonation arresters. Here the deflagration characteristics are defined within the standard by reference to the overpressure developed *when the flame arrives at a position 200 mm before the arrester.* The definition used is $2 \times p_i \leq p_e \leq 0{\cdot}8 \times p_{md}$ where p_{md} is obtained from table 6 of EN 12874. The practical difficulty with this is that, the flame is generally accelerating strongly and it can be difficult to arrange run

[8] *UWA internal report CG12inInt*

[9] *UWA internal report UWA/USCG/WV/12"-300*

up lengths to comply with this requirement. Figure 6.2, taken from results in a 200 mm tube, illustrates this point. In this test the criteria was met and the flame speed averaged over the preceding 600 mm was 1250 ms^{-1}. However a small change is all that is needed for the test to miss on this requirement.

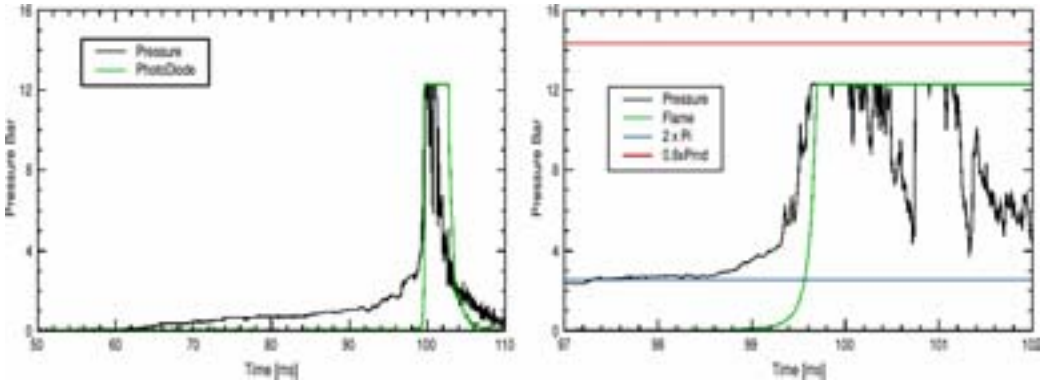

Figure 6.2 The rapid flame acceleration occurring when flame arrives during deflagration test on an overdriven detonation flame arrester

6.2.1 Suggestion

To relax the standard such that the pressure associated with the deflagration is no longer required to be $2 \times p_i \leq p_e \leq 0{\cdot}8 \times p_{md}$ at 200 mm before the arrester when the flame arrives and to replace this with the requirement that the pressure developed by the flame front to be in the range $2 \times p_i \leq p_e \leq 0{\cdot}8 \times p_{md}$ at 200 mm before the arrester.

6.3 INFLUENCE OF IGNITION SOURCE

We will now show some evidence as to why the ignition source may be important in deflagration tests.

Recent tests in equipment as covered by section 11 of EN12874 have shown that there is a difference in the development of the overpressure from combustion within the chamber where ignition was started which was dependant upon the ignition source used, figures 6.3.1 and 6.3.2

In these tests two ignition sources were used, firstly a spark source and secondly a testex fusehead. In the results discussed other factors, (such as mixture concentration, pressure and temperature) were considered and rejected as the cause of the differences in observed pressure profiles. One possible explanation is the *exact* location of the ignition; the fusehead was fitted into the equipment using the same access port as the spark, but practical design limitations meant that the fusehead was approximately 2 cm further into the chamber. However we do not believe this is the case because – reference figure 6.4.1 – one test was made with the fusehead deliberately positioned away from the ignition port location but close to the chamber wall. While the pressure history was altered compared with the other testex tests it was still very different to the history from the spark tests. It still remains possible that shrouding of the spark by the chamber is the reason for the difference but this explanation is believed to be less probable than the alternative of a difference in the ignition behaviour between spark and testex ignitors.

The graph in figure 6.3.1 does show that the main variation is in the initial phase; with the testex tests the time from the start of a pressure rise until “rapid” pressure rise is of the order of 5 to 10

milliseconds, with the spark ignition the time is 25 to 40 milliseconds. The later stage of the pressure rise is quite similar suggesting that once the initial phase is complete a different mechanism takes over.

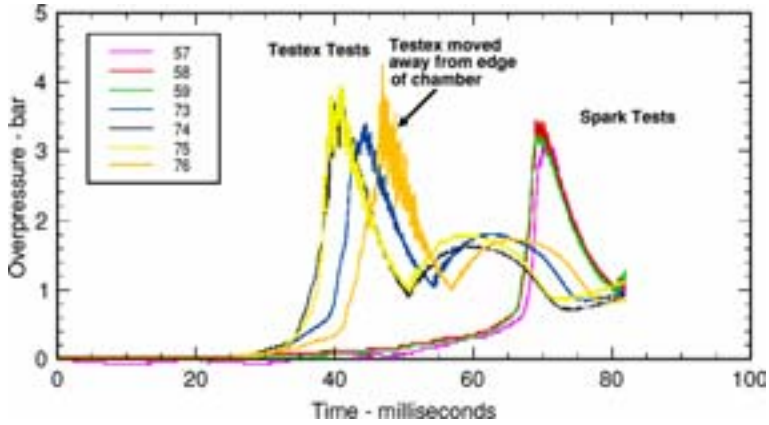

Figure 6.3.1 Comparison of pressure histories from different ignition sources – IIB3 mixture.

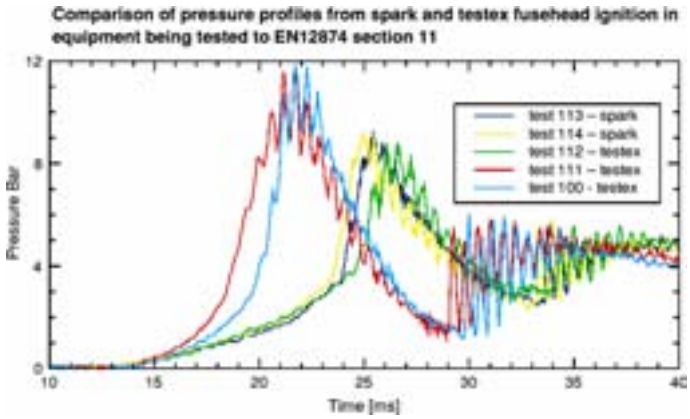

Figure 6.3.2 Comparison of ignitions in 43% hydrogen air mixtures with testex fuseheads and high energy spark

The influence of ignition source energy was also noted in a series of tests for overdriven detonations in a 200 mm tube, pressure histories shown in figure 6.3.3. In this case the necessary tube conditions for an overdriven detonation were established, and repeat tests commenced. After 3 tests the overdriven condition was no longer met. The cause of the failure to obtain further overdriven detonations was established. This was a weak spark which occurred because of moisture from the combustion process fouling the spark plug. In the test immediately after the spark plug was cleaned the result was once again an overdriven detonation. It is believed the detonation failed to develop when the weak spark condition existed because of slower growth of the initial flame kernel which reduces the initial flame acceleration.

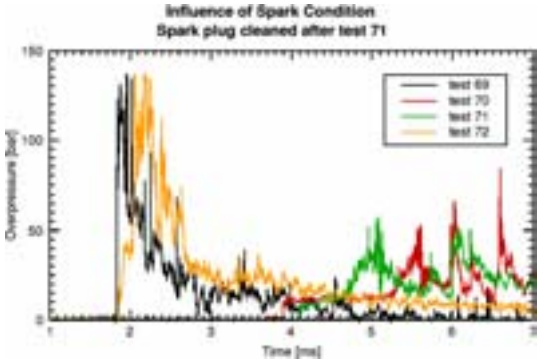

Figure 6.3.3 Influence of spark energy on flame acceleration

6.3.1 Why does this matter?

Let us consider the situation where a deflagration arrester is tested to EN12874 section 6.3.2.2 and furthermore let us assume that this arrester is of a design which will fail when the flame speed is in excess of a certain value. If this arrester is tested with a "weak" spark then the flame speed at the arrester will be low and thus the arrester could prevent the passage of flame. However in use the arrester could be placed within the test run up length yet fail because the ignition source was "strong" and hence a higher flame speed and / or higher combustion pressures were generated at the inlet of the arrester.

6.4 FLAME ACCELERATION MECHANISMS

The previous section shows an example of how ignition source can influence flame acceleration. Another flame acceleration variable is the tube condition. Previous work[10] at Aberystwyth with a 50 mm deflagration arrester tested to BS 7244[11] found a considerable increase of run up length to failure compared to the results from another test house. The increase in length was from about 7m to about 9m. Investigation at the time concluded that this difference was most likely explained by the tubes being used, the Aberystwyth tube was a new purpose made tube assembled with carefully fitted flanges sealed with 'o' rings, the other tube used was internally rusty and was assembled with gaskets, anecdotes say that these protruded slightly into the tube.

6.5 INFLUENCE OF TEMPERATURE GRADIENTS

Some recent experimental results have shown that a small temperature variation can have a large effect upon the flame acceleration within a tube.

This behaviour was identified with deflagration tests in a 40mm nominal bore tube and were part of testing of an overdriven detonation arrester. With an ambient temperature of 6 – 7°C it was impossible, in a smooth wall stainless steel tube, to generate the minimum pressure required in section 6.3.3.3 of EN12874 even when tube lengths were 150 × D. By applying heat using a 3kW hot air blower aimed at the tube close to (but not directly on) the ignition spark the flame acceleration was transformed in a manner dependant upon the temperature of the heated section. The flame acceleration obtained was very sensitive to the state of the heated section. If the peak

[10] Internal report , commercial in confidence

[11] Note that in BS7244 the deflagration test specifies that the arrester is tested with increasing pipe length until a failure occurs

temperature was circa 50 centigrade then the flame would accelerate close to detonation[12], while at 30 centigrade the pressure generated was below the value required by EN 12874 i.e. less than twice the initial pressure. Values of peak temp close to 42 centigrade were found to be optimum. The temperature gradient along the tube was not monitored throughout each test of the series, but a "typical" temperature is shown in Figure 6.5.1.

The temperature effect can be clearly seen by considering the overpressure at flame arrival, Figure 6.5.2. In the case of element 117 a series of 11 tests without heating gave an average pressure of 1·58 bar, with a peak of 2·77 and standard deviation of 0·45; whereas with a heated tube the mean of 7 tests was 7·82 bar, highest value 16·1 bar, standard deviation 5·63. Note that the pressure results plotted are at flame arrival, and the maximum pressures will generally be higher. The maximum pressure may be before or after the flame arrival – in an extreme example it is possible for a ddt event with a leading shock, for the flame arrival behind the transition shock to be back in the region identified as acceptable for certification.

A question mark remains to the influence of such an accelerating mechanism with a tube length of 50 pipe diameters, this requires further investigation.

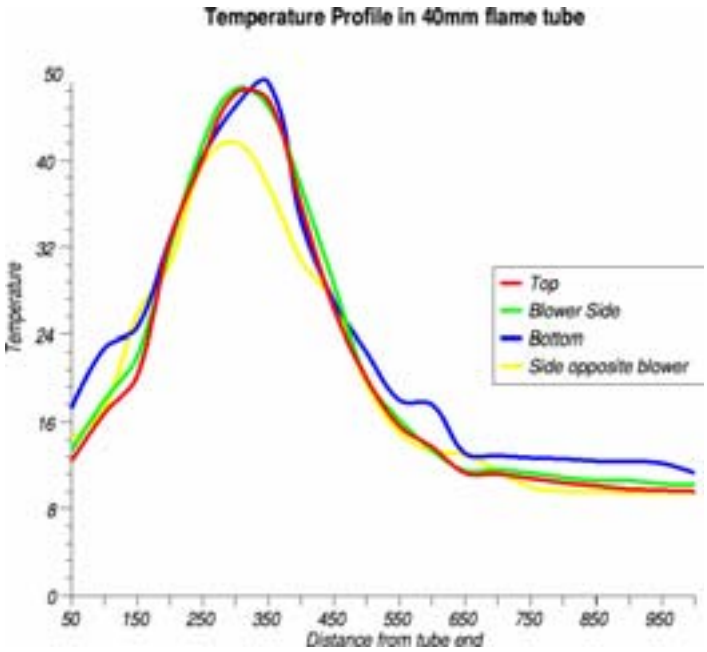

Figure 6.5.1 Typical temperature profile of heating deflagration tube

[12]Note: the instrumentation was set to detect deflagrations and thus the precise phase of ddt to stable detonation is uncertain

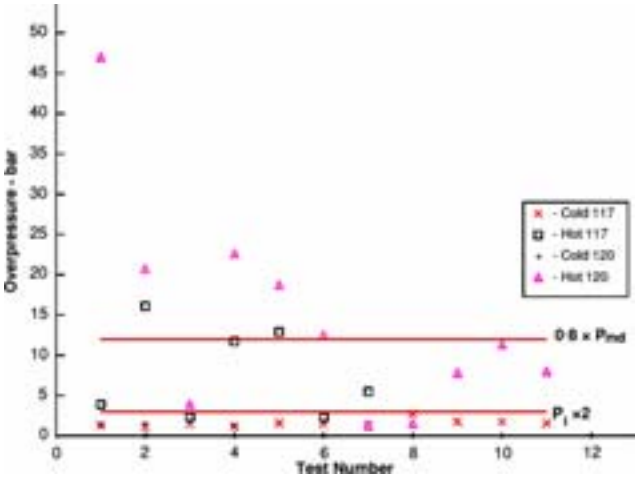

Figure 6.5.2 Temperature effects on the flame acceleration in a 40 mm tube. Initial cold temperature is 6 - 7 centigrade; the hot tests were with a short zone if the tube heated to between 30 and 50 centigrade

In this instance we are seeing a situation where the influence of the initial phase of flame acceleration is of critical importance; in many ways similar to the situation with different ignition sources.

6.6 OVERDRIVEN DETONATIONS

An overdriven detonation is by its very definition a transient phenomena. This transience leads to difficulties in testing flame arresters for protection against these events. Different flame arresters will, when tested in a given tube, lead to the ddt event to be located at different positions within the tube. This has been seen at UWA when an arrester has been fitted with alternative quenching elements and this has necessitated a change in the initial flame acceleration mechanism.

The results from the test shown in figure 6.6.1 give some reason for concern with respect to the overdriven test in EN 12874. These concerns revolve around the extreme transience of an overdriven detonation and whether the event “seen” by the arrester is the worst case. From the standard it is permissible to meet the 200µsec pressure criterion at between 150 and 250 mm before the arrester. Test results at UWA where pressure sensors have been located at 150, 200 and 250 mm before the arrester show that it is quite possible for this criteria to be met at one or two locations and not at the third. It is thus entirely feasible that the event within the arrester is somewhat less damaging than may occur in a real system where the ddt can occur within the arrester.

Potentially the most damaging, and difficult case to test for, is where the transition occurs at the arrester face.

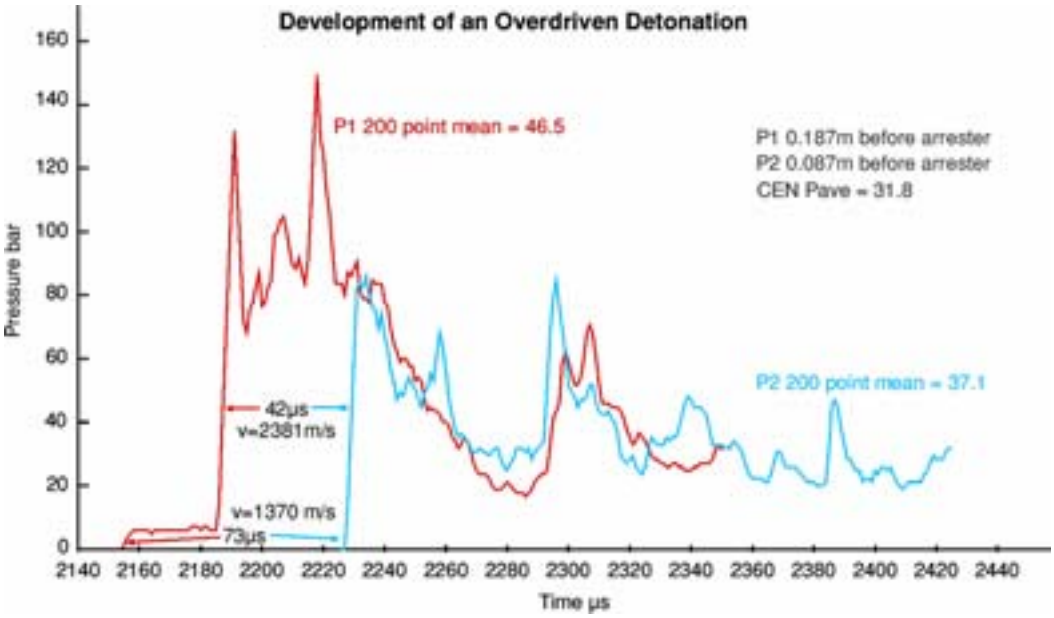

Figure 6.6.1 Pressure Histories of from two sensors located 100 mm apart. Tests from a 50mm nominal bore tube. The transient nature of an overdriven detonation is clearly shown

Figures 6.6.2 through 6.6.4 show results from various tests where either an overdriven detonation or ddt is occurring.

In figure 6.6.2 the development of an overdriven detonation in the reflected wave from the flame arrester is shown. This was in a 200mm nominal bore tube containing a 4.1% propane in air mixture. The damage to the arrester element was significantly more than to a similar element design used with a IIB3 gas mixture where a transition to detonation occurred in the incident wave. It is a characteristic that higher pressures occur when transition occurs in the reflected wave.

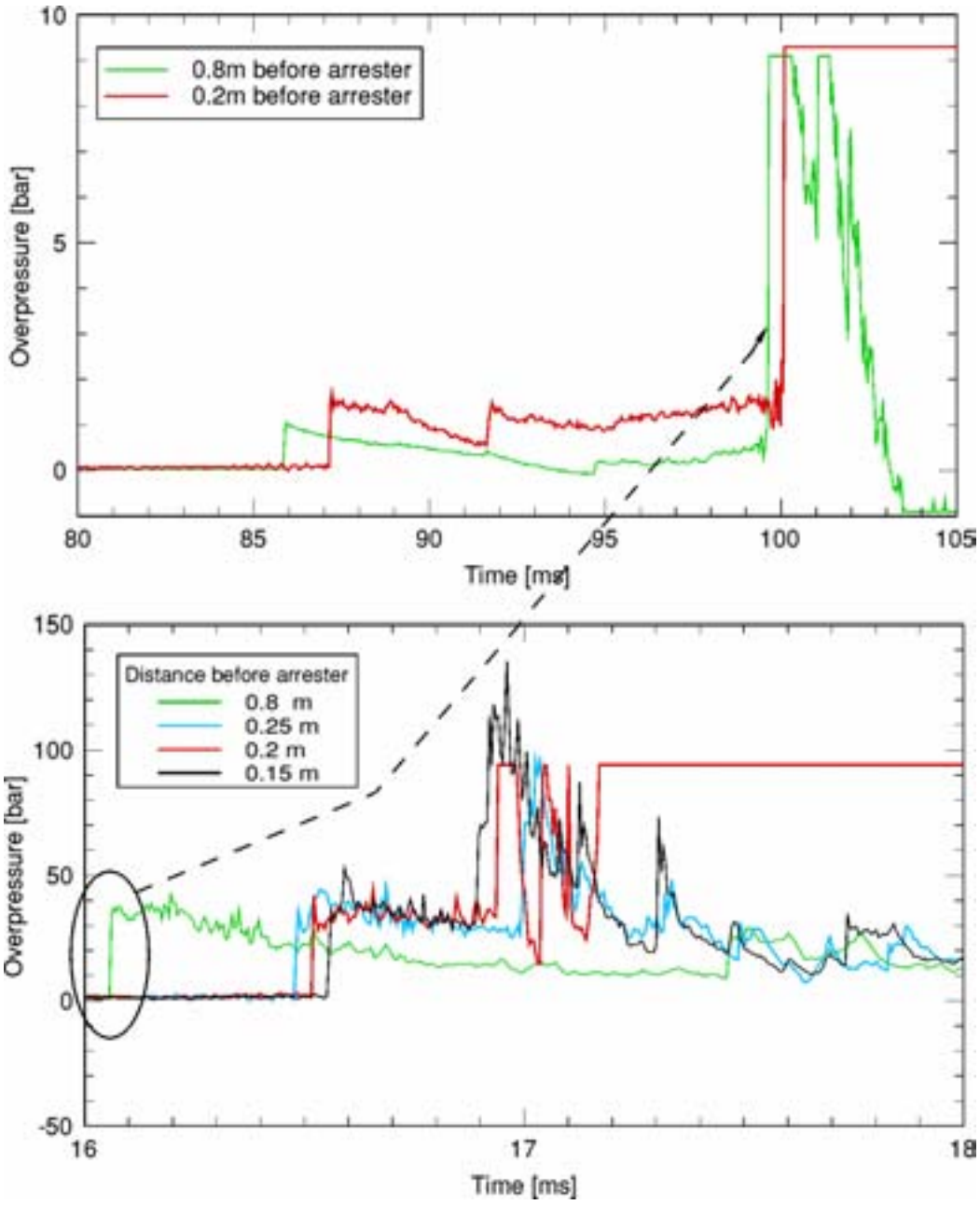

Figure 6.6.2 Pressure history in a 200 mm tube with IIA mixture. Note that the data capture in the lower graph is set to resolve the rapid transition event whilst the upper depicts an overview of the events leading up to the transition. Note that the initial lead shock of about 1 bar is not resolved in the lower graph. A full study of the data showed that in this test there was a ddt transition in the arrester housing and that with a single sensor it would have been impossible to establish the exact detonation development

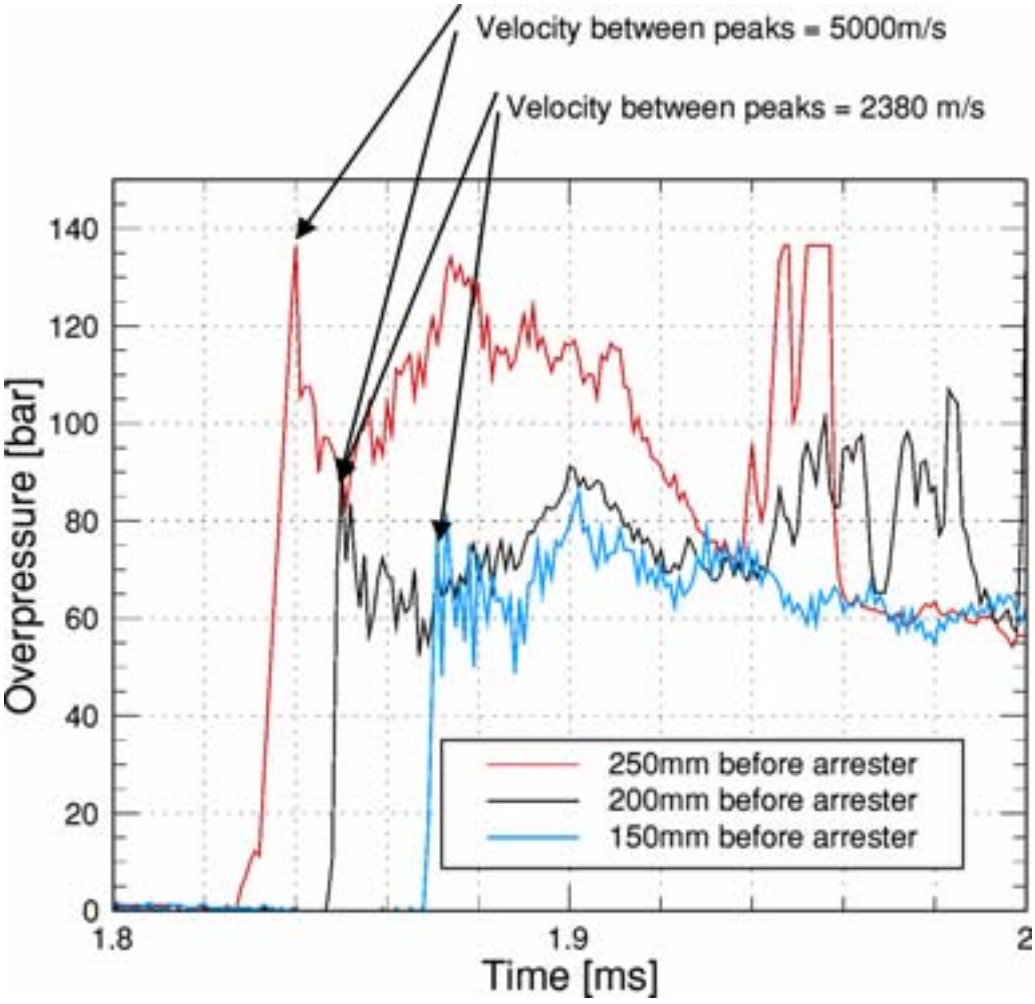

Figure 6.6.3 Pressure histories from test km8t69. Note that in this case the deflagration to detonation transition is captured, and is occurring in the incident wave

If we study the pressure waves shown in figure 6.3.3 where a transition happens in the incident wave we can clearly see that on the first pressure sensor we have captured the ddt transition, and that 50mm along the tube this is now a classic overdriven detonation.

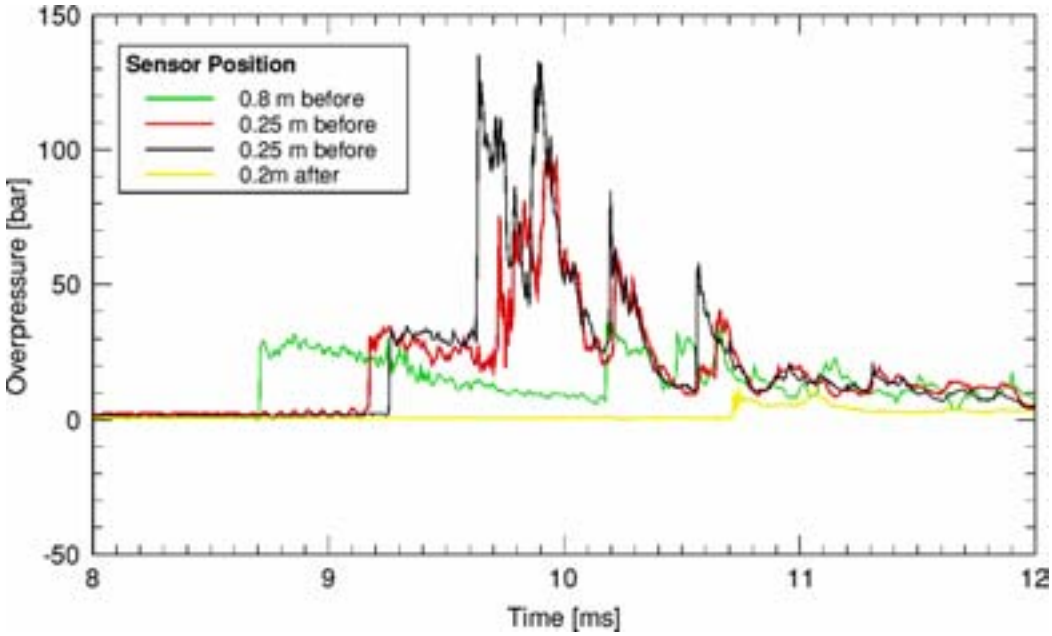

Fig 6.6.4 Transition to detonation in reflected wave

There remains to discuss the situation that arises when the pipeline down which a flame is propagating is smaller than the cell size of the mixture. In this circumstance the most likely event is a deflagration. However it is possible under certain conditions for the flame to burn slowly and a shock wave to form from any obstructions, e.g. a flame arrester, and eventually for the gas mixture within the pipeline to have been pre-processed sufficiently such that the cell size of the mix is smaller than the tube diameter and hence allow detonation to propagate. The probability of this occurring is low, but anyone specifying an arrester for use in a pipeline that is nominally too small to permit a detonation should consider the cell size of a mixture in a fault condition.

6.7 SPECIFICATION OF THE TUBES USED TO TEST ARRESTERS.

The tube used to test the arrester can influence the flame acceleration and thus in deflagration tests the flame speed and overpressure at the arrester entry. Influences include: the surface roughness of the test tube, the quality of the joints between tube sections and the actual bore (as against the nominal bore) of the tube used.

The isolation of the tube variables is a difficult problem and forms part of the larger issue of specifying a satisfactory deflagration test. Let us first consider a variable that with a minor change to EN12874 would be eliminated.

This is the actual tube bore. At present EN12874 does not specify the wall thickness to be employed for a test tube. While in larger size pipelines the wall thickness differences will make only a small percentage difference to the tube cross section, with small bore tubes there can be a large percent change. For example a 25 mm nominal bore tube made from ANSI dimensioned tubing could have a bore ranging from 1·52 cm to 3·0 cm. While these are the extreme limits and it improbable that would in practice use the thickest wall sizes, it is conceivable that a deflagration tube could be made from schedule 5 to schedule 80, that is bore sizes from 3cm to 2·43cm an area ratio of 1·53. This has implications for both the flame acceleration and total

energy release. This potential discrepancy could easily be resolved by including limits for the pipe specification used for the manufacture of the test pipelines.

Other differences in the test pipes between test houses which may result in variation of flame development within the system are harder to eradicate.

7 SUMMARY, DISCUSSION AND CONCLUSIONS

For a flame arrester manufacturer to sell a product within the European Union they must ensure that the product being sold complies with the requirements of the ATEX directive. It has been generally assumed that if a flame arrester complies with EN 12874 then the ATEX directive is also satisfied. Is this assumption valid? It is no longer clear that this is so, as implied by some of the evidence presented in this report. This does not mean that EN 12874 is a failure, indeed in providing formal testing guidelines throughout the European Union it must be regarded as a success – providing as it does a baseline from which all may be measured.

This does not however mean that EN 12874 cannot be improved upon, and it is by constant monitoring of new information that appears both as a result of routine standard testing and new fundamental understandings coupled with a willingness to tackle difficult issues that the test standard can be updated with the ultimate reward being greater process plant safety.

However not withstanding the above and in considering EN 12874 and its limitations, actual or perceived, it must be remembered that some of the phenomena that we are attempting to protect against are by their stochastic nature difficult to reproduce in a repeatable and controlled manner. This makes devising a universal, repeatable, test standard a difficult and time consuming undertaking. Perhaps these very difficulties make the task of striving to improve the existing standard even more important and to use these as an excuse for inaction must be avoided.

In any event any changes to the existing standard should not be implemented before a thorough technical assessment of the implication of the changes.

7.1 SUMMARY OF TECHNICAL CONCERNS

In considering technical concerns one factor appears to be of prime importance – this is a lack of understanding of the way pipeline explosions develop with the different mixtures and pipe geometries possible. Hence there is an inability to define precisely the nature of the potential explosion characteristics, (flame propagation rates and associated pressures, etc.) that could be developed during actual explosion event in the immediate proximity of an arrester device. Ignorance of the nature of real explosion events also makes it difficult to devise procedures that will automatically lead to repeatable and reproducible test conditions at different test establishments. Virtually all of the specific problems identified can be linked to this lack of understanding.

In an attempt to resolve the deficiencies it is proposed that a number of avenues be pursued.

First, a review of existing experimental data on flame acceleration in long pipes should be completed together with a detailed review of the relevant literature.

To supplement the preceding work, a further programme of experimental flame acceleration investigations should be completed, preferably combined with further numerical and theoretical studies.

7.1.1 Testing issues identified

These can be separated into two broad categories. Firstly are the existing procedures entirely satisfactory from a technical viewpoint – for instance flame acceleration variables with in-line

deflagration arresters, are unstable detonation arresters tested at the most severe part of the transition to detonation cycle and, perhaps the most serious problem, the validity of the MESG technique used for ranking explosion severity – and secondly reproducibility of testing between different experimental setups.

A brief summary of testing concerns:

i) Flame acceleration variations.
ii) Limitations of a single fixed run up in deflagration tests.
iii) Certain arrester designs may be better able to quench fast flames than slow flames.
iv) If the test devised will function as anticipated across the full range of pipe sizes within the standard.
v) Unstable detonation test is not always possible to meet in practice (IIB1gasses).
vi) Single flame detector is specified to establish arrester failure.
vii) Repeatability between testing.
viii) Limits of testing of detonation arresters with respect to the minimum size pipe that a detonation will propagate in.

7.1.2 Implications of technical concerns

What are the implications of variable flame acceleration for EN 12874, arrester manufacturers and end users? If we accept that the flame acceleration can vary significantly between systems then it becomes impossible with any degree of certainty to state that a deflagration arrester will always prevent flame transmission in a system where the arrester is at the same distance from an ignition source to that tested. A possible solution would be to always specify an overdriven detonation arrester; however this has does not address the concerns with respect to the overdriven detonation arrester tests and also there could be certain practical drawbacks in terms of installation into existing systems – for instance larger physical size and different normal flow properties.

Perhaps a better short term solution would be to introduce an additional safety margin into the test standard, for instance undertake the standards testing at a higher pressure than the arrester is certified for use.

A short term solution of the kind suggested above would give time to derive improved test procedures possible because of improved technical knowledge. The difficulties involved in formulating better practical tests can be appreciated by considering the in-line deflagration test, the many variables involved make deriving a better, universal, test a complex exercise.

7.2 PROPOSALS FOR FUTURE STUDY

Ideally for explosion protection within pipelines and process plant we would have a complete understanding of the way that the flame develops from the initial phase through to a detonation, in all geometries and fuel - oxidant mixtures. Unfortunately we do not live in an ideal world and currently we do not have this level of knowledge. While difficult to attain we should at least strive to achieve this goal.

i) To review the scaling of arrester testing with particular consideration to deflagration tests.
ii) To conduct a systematic experimental study of the variation of run up lengths on arrester failure with different design of arresters
iii) Review the effects of low and high temperature on flame acceleration

iv) Study the detonation behaviour of different mixtures which possess the same MESG.
v) Consider alternative deflagration tests to resolve the issues of variable flame acceleration, or impose a safety margin.
vi) Examine the influence of ignition source energy and location.
vii) Modify the deflagration test which form part of the detonation test procedures.

7.2.1 Phase 1 – review of existing experimental data

There is now a large amount of data which has been obtained by the various test houses throughout Europe. Thus if a programme of work where existing data from different test houses was pooled were to be instigated there is the possibility of valuable information being obtained. While such a study must be approached with an open mind one would anticipate looking for systematic inconsistencies between test houses and issues resulting from for example, the fixed values of pressure multiples for determining overdriven detonation status.

A fundamental requirement for the success of such a review would be a willingness for a sufficient number of test houses and arrester manufacturers to allow full access to the available data.

7.2.2 Phase 2 – collaborative experimental programme

A collaborative experimental study involving as many test houses and arrester manufacturers as possible.

It is envisaged that this would involve different test houses undertaking trials on flame arresters from different manufacturers. Each test house would complete a matrix of tests using as wide range of pipe diameters and the range of representative mixtures as possible. This would allow comparison of the same arrester between different test rigs all of which should comply with the existing standard. It would be hoped that similar results would be obtained by all test houses. If significant differences were found then detailed analysis of the test rig and procedure would be instigated as this could have important repercussions for real life applications.

It is envisaged that as much existing equipment as possible would be used as this would

i) enable comparisons with existing results
ii) keep the programme costs to a minimum

In addition some preliminary tests to study arrester behaviour for fuels with the same MESG but different compositions, for example ethane and n-hexane.

7.2.3 Phase 3 – fundamental study

A fundamental study of flame acceleration in pipes would expect to look at both theoretical and experimental aspects of flame acceleration and to apply the knowledge gained to improving flame arrester design and selection criteria. To do this would require a multifaceted approach with an initial programme determined in consultation between interested parties.

Topics for inclusion in such a research project would be how the presence of arrester affects the flame acceleration and development of an explosion within a pipeline; initial conditions - for example initial pressure and temperature, ignition source and location; and a study of the use of MESG for determining the selection of flame arresters. In addition a parallel work programme should be conducted to measure the MESG values of explosion test mixtures and allow these to

be correlated with the explosion development characteristics observed in pipe explosion tests. The MESG study would include a comparison of MESG measurement techniques

A further extension of the experimental testing would be to use the latest Norwegian version of the random choice computer model[13], which includes a deflagration model, to simulate the experimental tests and allow numerical predictions and experimental determinations of flame acceleration histories together with flow velocities and pressure profiles ahead of the flame to be compared

There are different ways to instigate a fundamental study. One which has numerous advantages is a carefully structured doctoral research programme preferably arranged to run alongside a collaborative experimental study as outlined in phase 2. A proposal for a doctoral research programme at UWA that will address many of the aspects of flame acceleration and transition to detonation is currently being prepared for submission by Dr. Geraint Thomas.

[13] *Bjerketvedt D., Vaagsaether K, Kristoffersen K., Mjaavatten A., Thomas G. and Bambrey R (2002) Simulation of Gas Explosions with a Matlab Version of the Random Choice Method (RCM). Journal of Physics IV France, 12, 247-251*

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RR 281

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ISBN 0-7176-2913-9

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