Energy Research Institute

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Explosion venting data: A single maximum over-pressure is not sufficient

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Venting Terms and Venting Standards

- Vent Area, **A_v**, non-dimesionalised as
  - **Vent coefficient $K_v = V^{2/3}/A_v$ (V is the vessel volume) -** BS EN 14994 (2007)

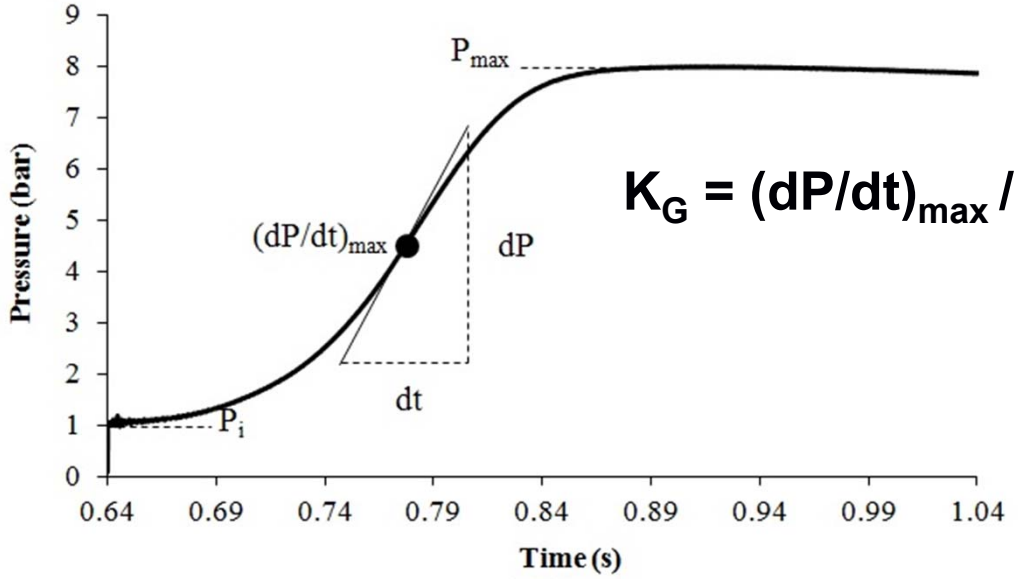
    - Also $K_A = A_x/A_v$ (A_x is the cross-sectional area of the vessel in the plane of the vent) – British Gas Research and successors

    - And A_v/A_s (A_s is the internal surface area of the vessel) – NFPA 68 (2013)

      - A_x and A_s can be related to $V^{2/3}$ therefore the different definitions are similar

Mixture reactivity

- Deflagration index, K_G



$$K_G = (dP/dt)_{max} / V^{1/3}$$

- Laminar burning Velocity, S_u

It can be shown that the two parameters are directly related.

Venting Standards

- standards and guidance focus on providing the correct vent area
  - as function of the mixture reactivity, vessel volume and shape, and some vent properties e.g. for compact vessels
- BS EN 14994 (2007)

$$\frac{1}{K_v} = \left[\frac{0.1265 log_{10} {K_G}^{-0.0567}}{{P_{red}}^{0.5817}} + \frac{0.175(P_{stat} - 0.1)}{{P_{red}}^{0.5717}} \right]$$

- NFPA 68 (2013)

7.2 Venting by Means of Low Inertia Vent Closures.

7.2.1 When $P_{red} \leq 0.5$ bar, the minimum required vent area, A_{v0}, shall be determined by Equation 7.2.1a and Equation 7.2.1b:

$$A_{v0} = \frac{A_s C}{\sqrt{P_{red}}} \qquad \textbf{(7.2.1a)}$$

$$C = \frac{S_u \rho_u \lambda}{2 G_u C_d} \left[\left(\frac{P_{max} + 1}{P_0 + 1} \right)^{1/\gamma b} - 1 \right] (P_0 + 1)^{1/2} \qquad \textbf{(7.2.1b)}$$

Issues with the Standards

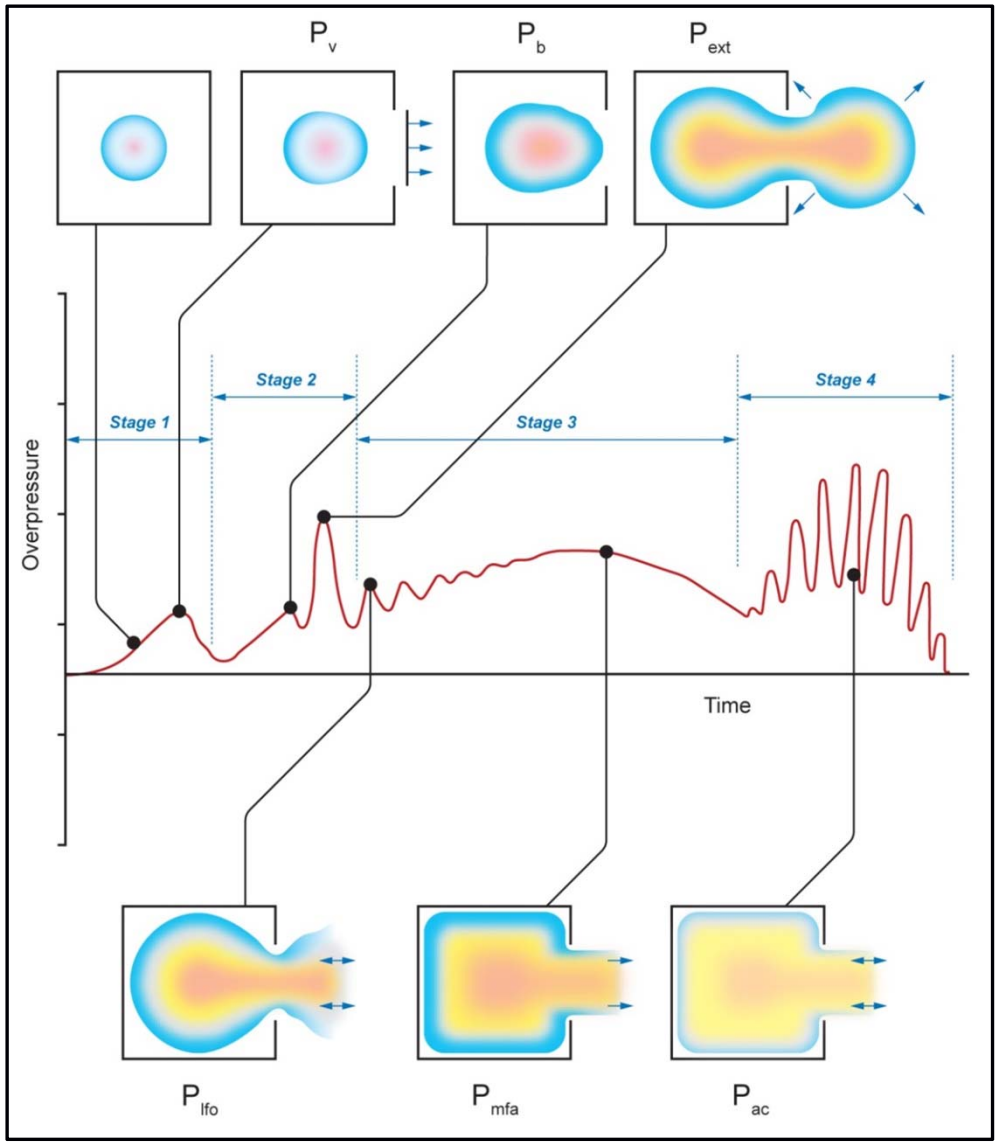
- For a given vent area they give a maximum overpressure – effectively based on correlations of experimental data.
- No insight /understanding of mechanism of pressure generation
- Effect of positioning, number and shape of vents not included
- Effect of ignition location not included

Explicitly or implicitly the above are taken to have no effect

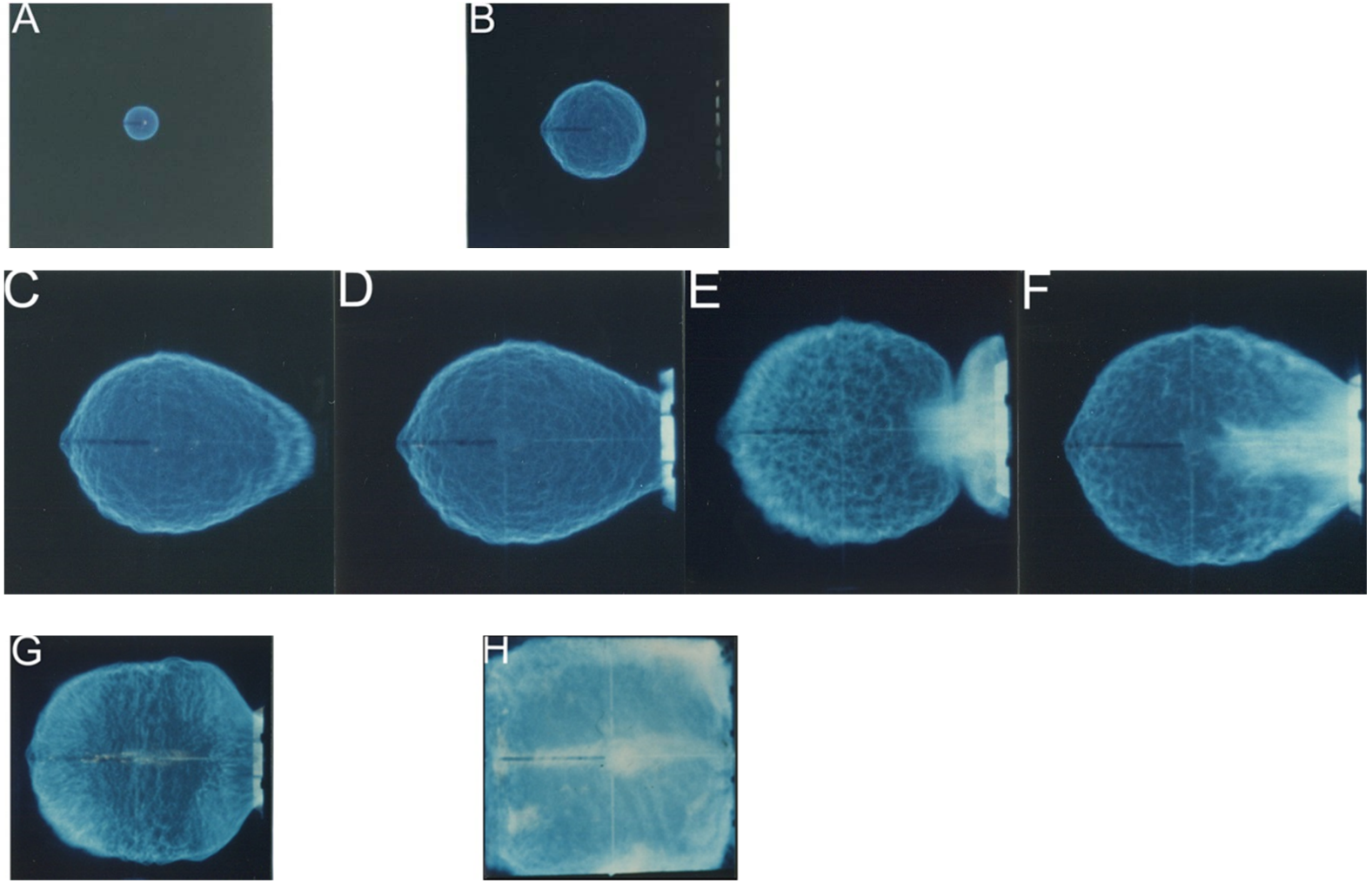
What is needed for model development

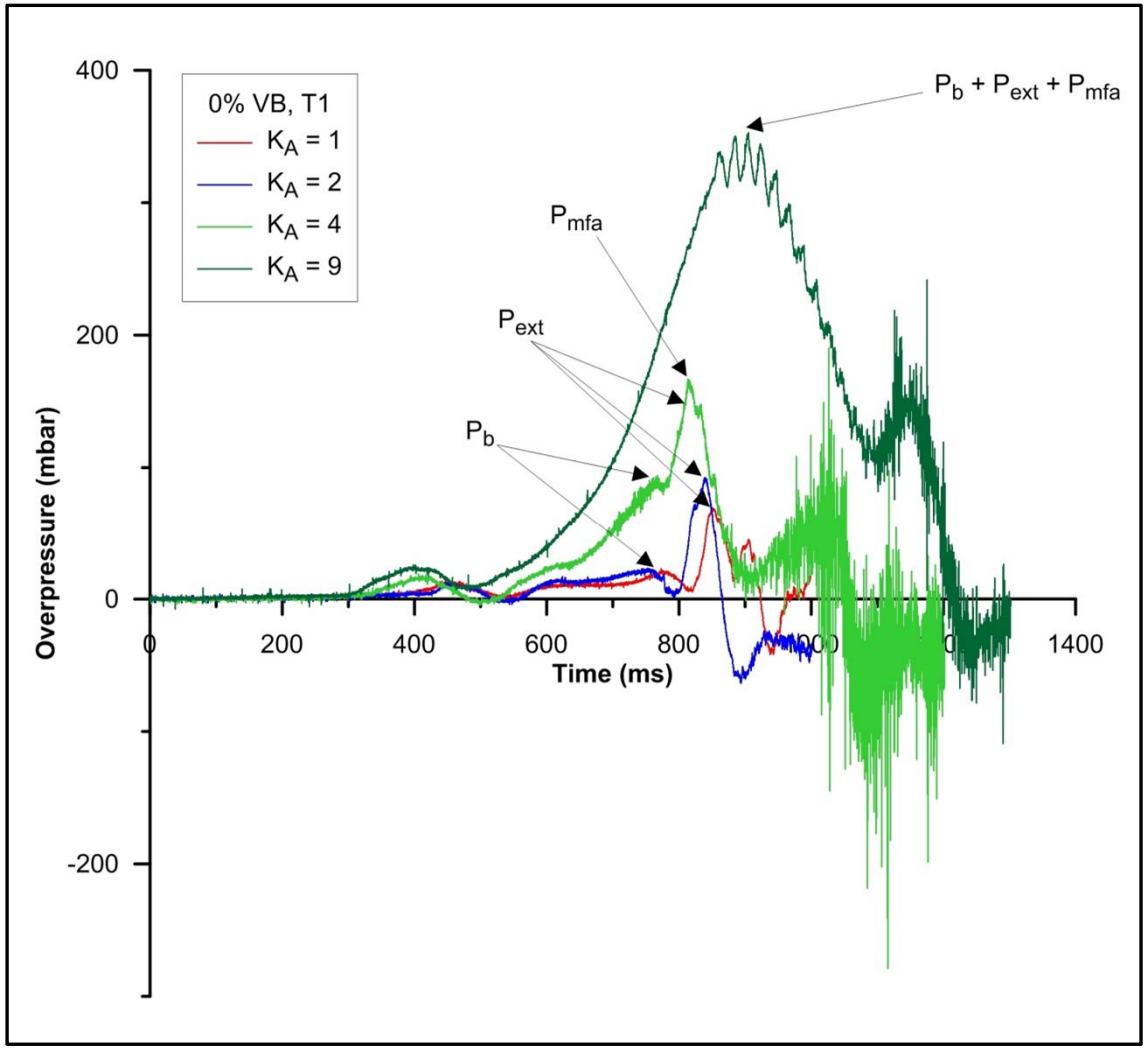
- For correct structural design the full pressure profile is needed
  - Experimental data sets of vented explosion overpressures can't be provided for every potential practical scenario and we need to develop reliable models.
- Ultimately for correct modelling and for validation of such models we need detailed quantitative data that
  - elucidate the mechanisms and processes involved, and
  - give dependencies on the important parameters.

Physical Causes of venting overpressures



Peak pressure events	This work	Fakandu et al. [2011,2012] Kasmani et al. [2010b]	Cooper et al [1986] Central ignition	Harrison and Eyre [1987] End ignition	Cates and Samuels [1991]	Bauwens et al. [2010] Central ignition
Peak due to vent opening at pressure P_{stat}	P_{burst}	P_1	P_1			
Peak due unburned gas flow through the vent (onset of burnt gas venting)	P_{fv}	P_2		P_{emerg}	ΔP	
Peak due the external explosion	P_{ext}	P_3	P_2	P_{ext}	Dominant	P_1
Peak due to maximum flame area inside the vessel	P_{mfa}	P_4	P_3	P_{max}	Max. burning rate	P_3
Peak due to the reverse flow into the vented vessel	P_{rev}	P_5				
Peak due pressure oscillations.	P_{ac}	P_6	P_4			P_2


A
B
C
D
E
F
G
H

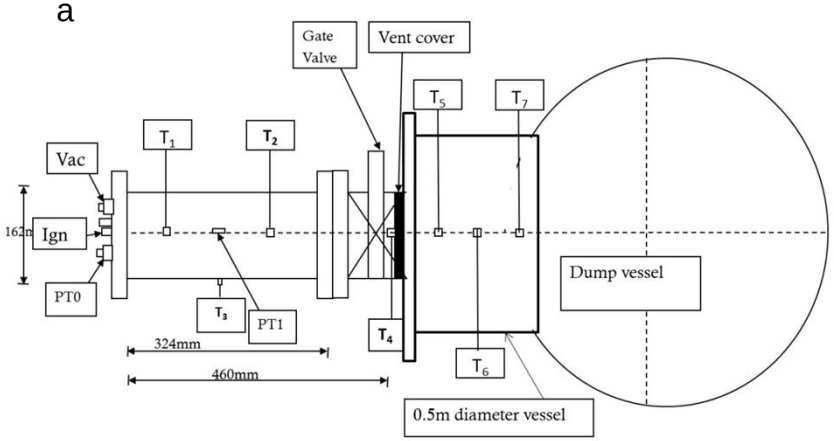


Not all pressure peaks are always present. Which one dominates depends on the test conditions

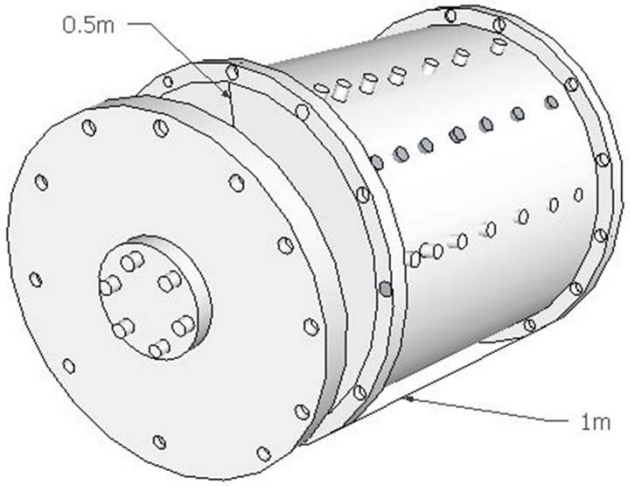
Test vessel 1 0.01 m^3

Test vessel 2 0.2 m^3

a



(a)



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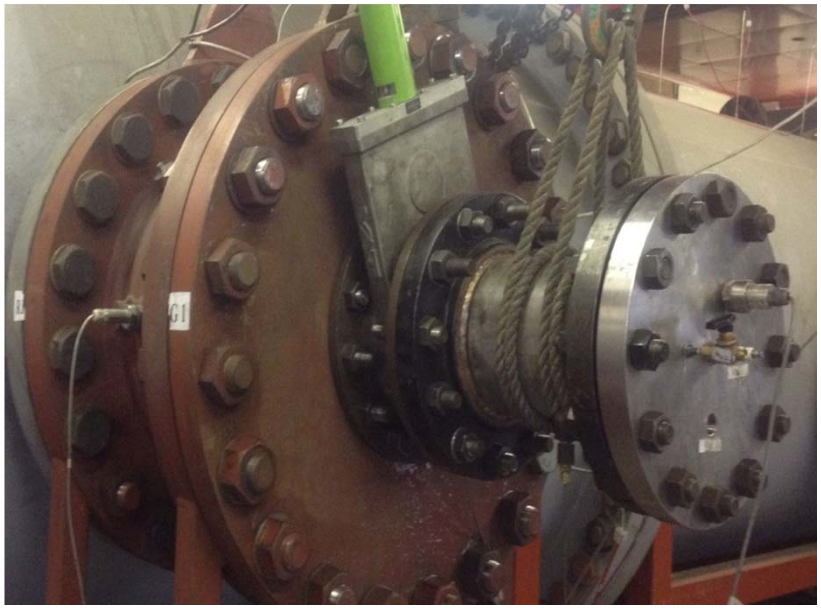
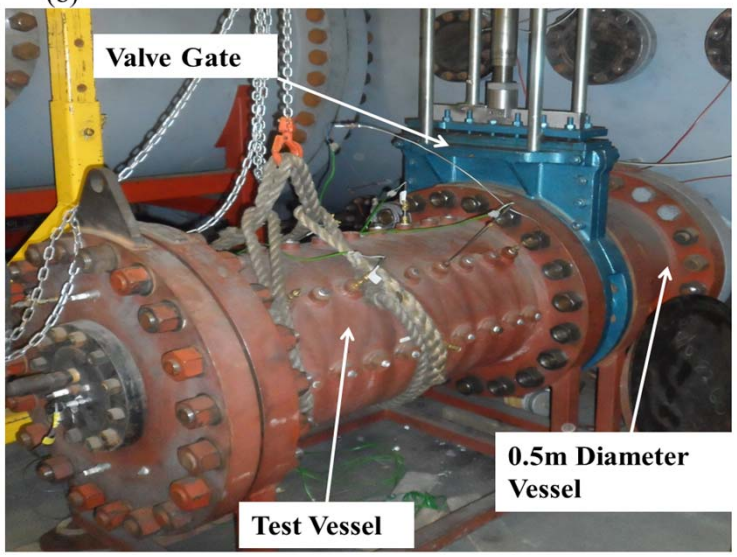


(b)



Experimental set-up for test vessels (a) Schematic diagram, (b) Photograph.

Gas mixtures and vent designs

- Different gas mixtures:

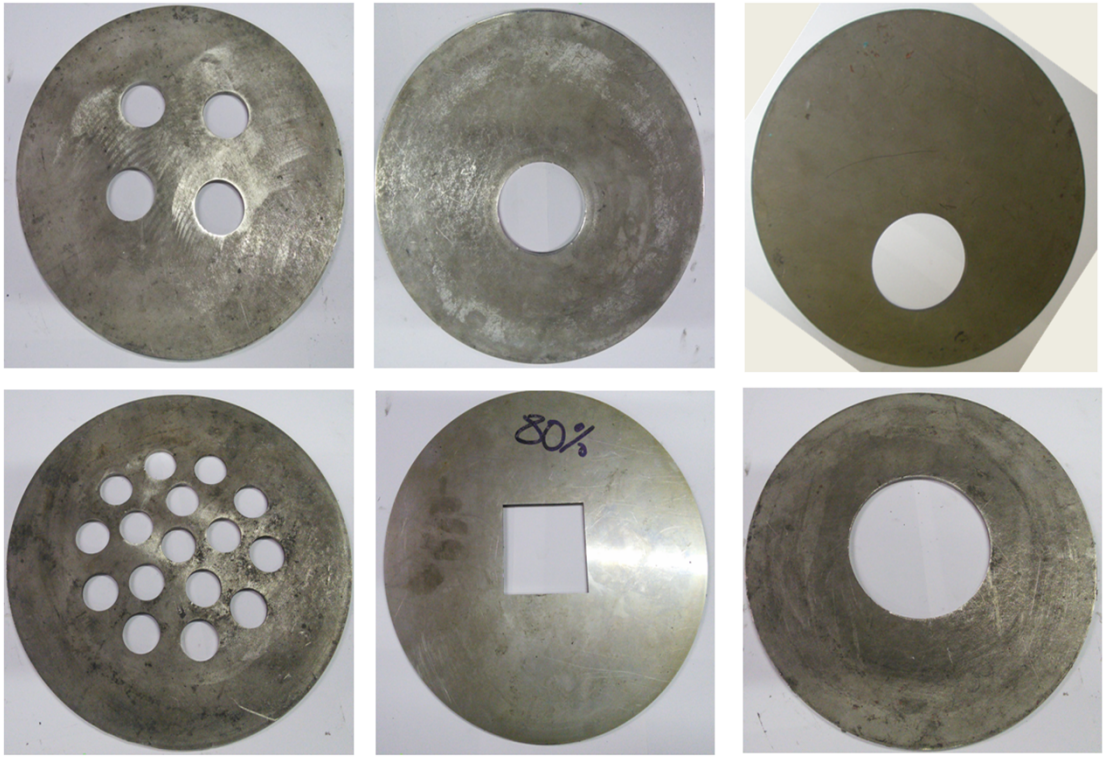
Methane-air(10%),
Propane-air (4%, 4.5%),
Ethylene-air (6.5%, 7.5%)
Hydrogen-air (30%, 40%).

A range of K_v was investigated.

- 16 Joule spark ignition.
- Central and end ignition compared

- Repeatability

Each test conducted at least three times with each individual result plotted in the graphs.

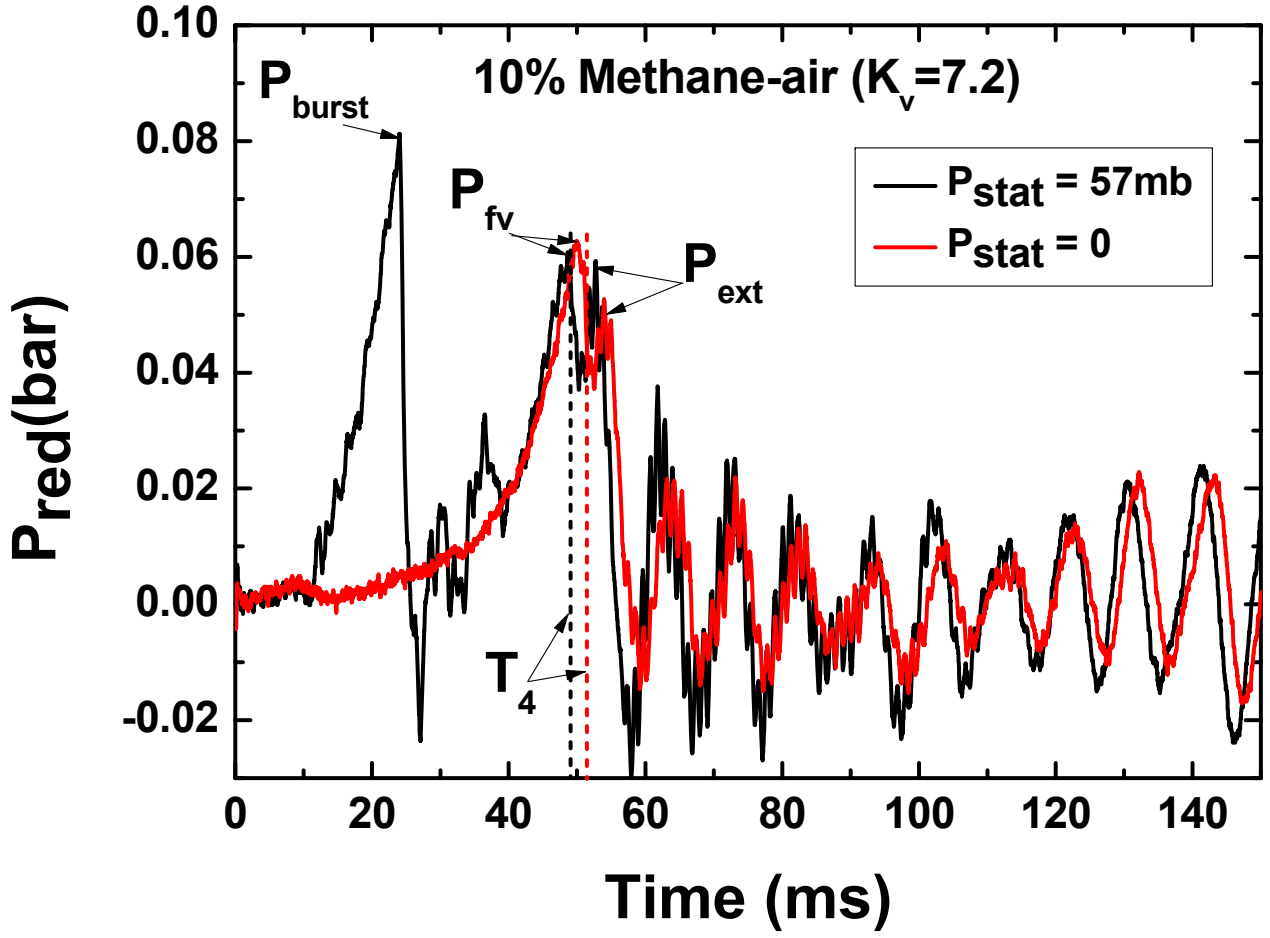


Vent orifice Grid-Plates

Influence of the number of vents, the shape of vent and the position of the vent were investigated, as these are stated in the US and EU standards as having no effect.

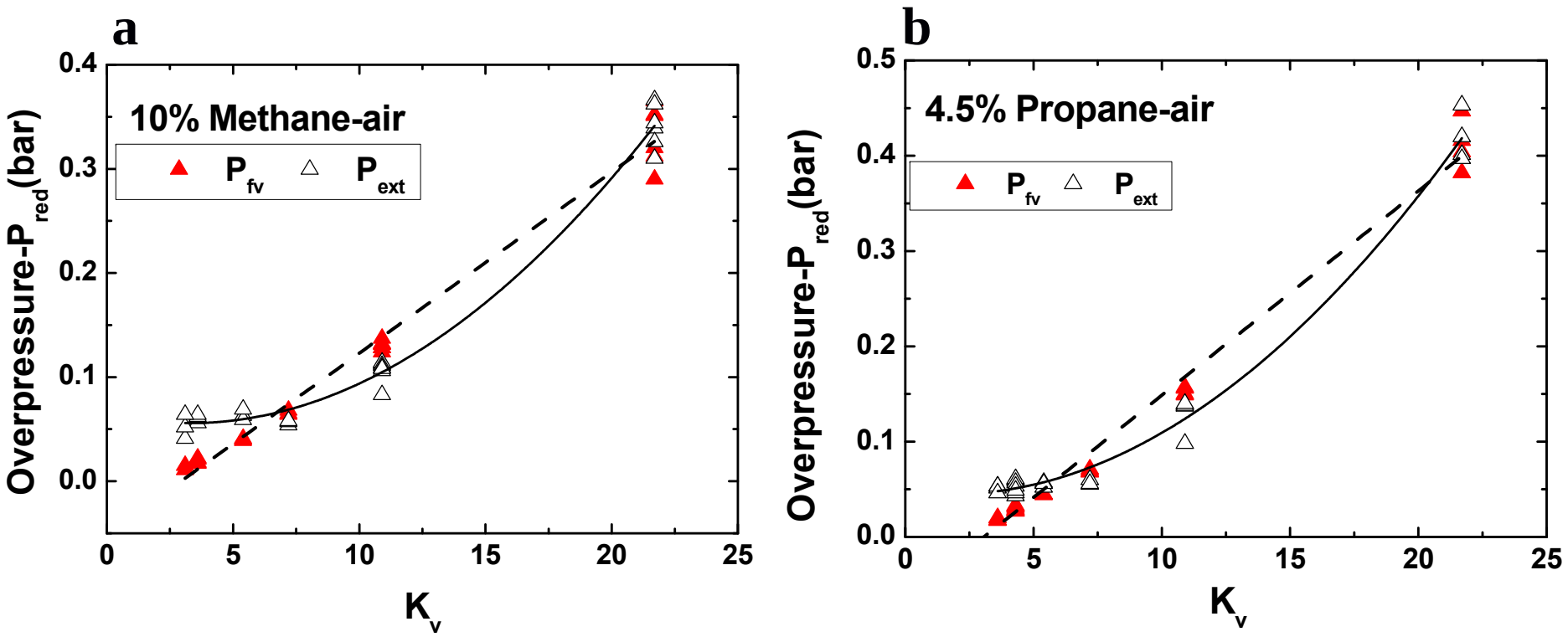
The results show a significant effect for all.

Vent Static Burst Pressure effects



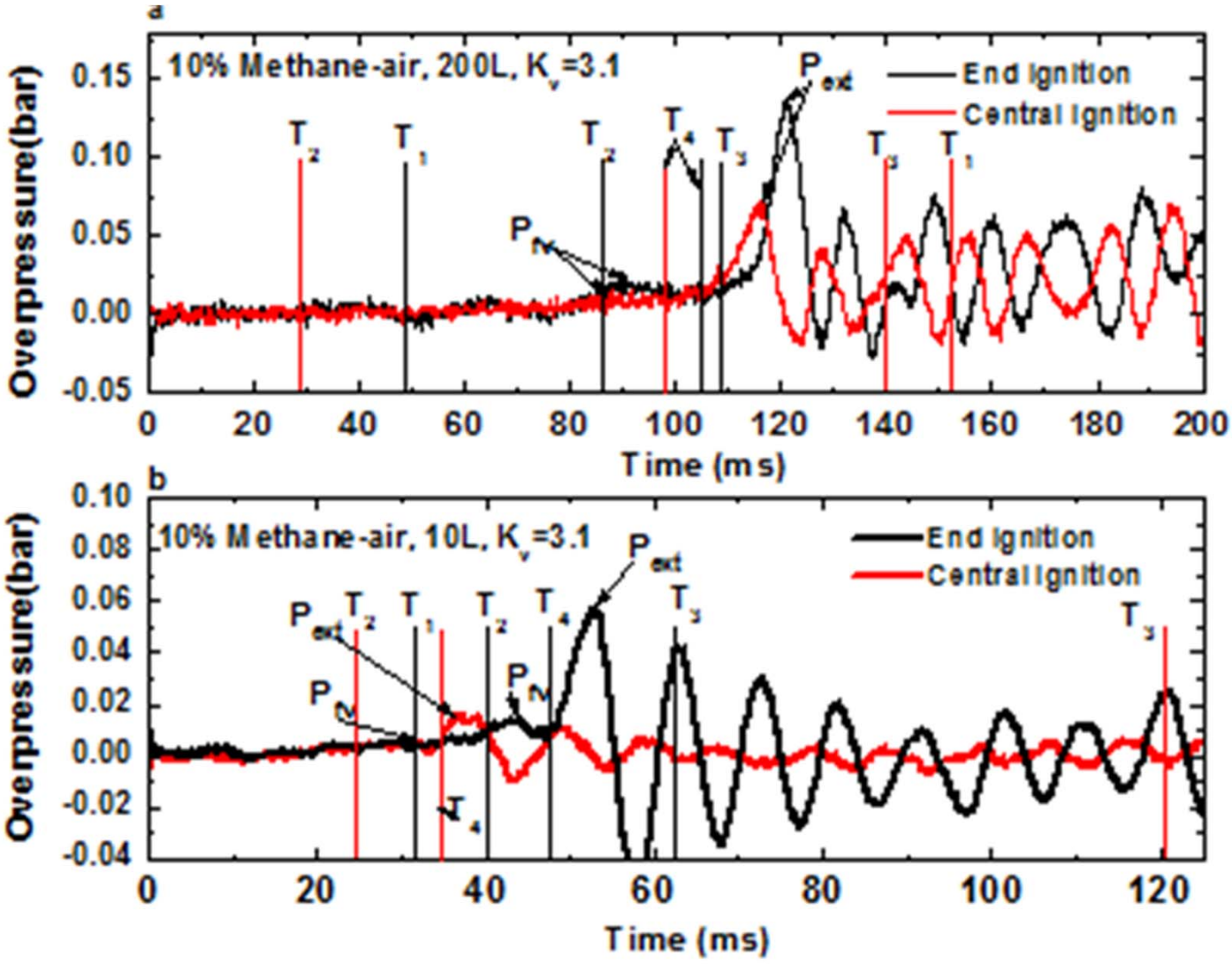
Comparison of the pressure time records for 10% methane-air for K_v = 7.2 for free venting and for P_{stat} = 57mb

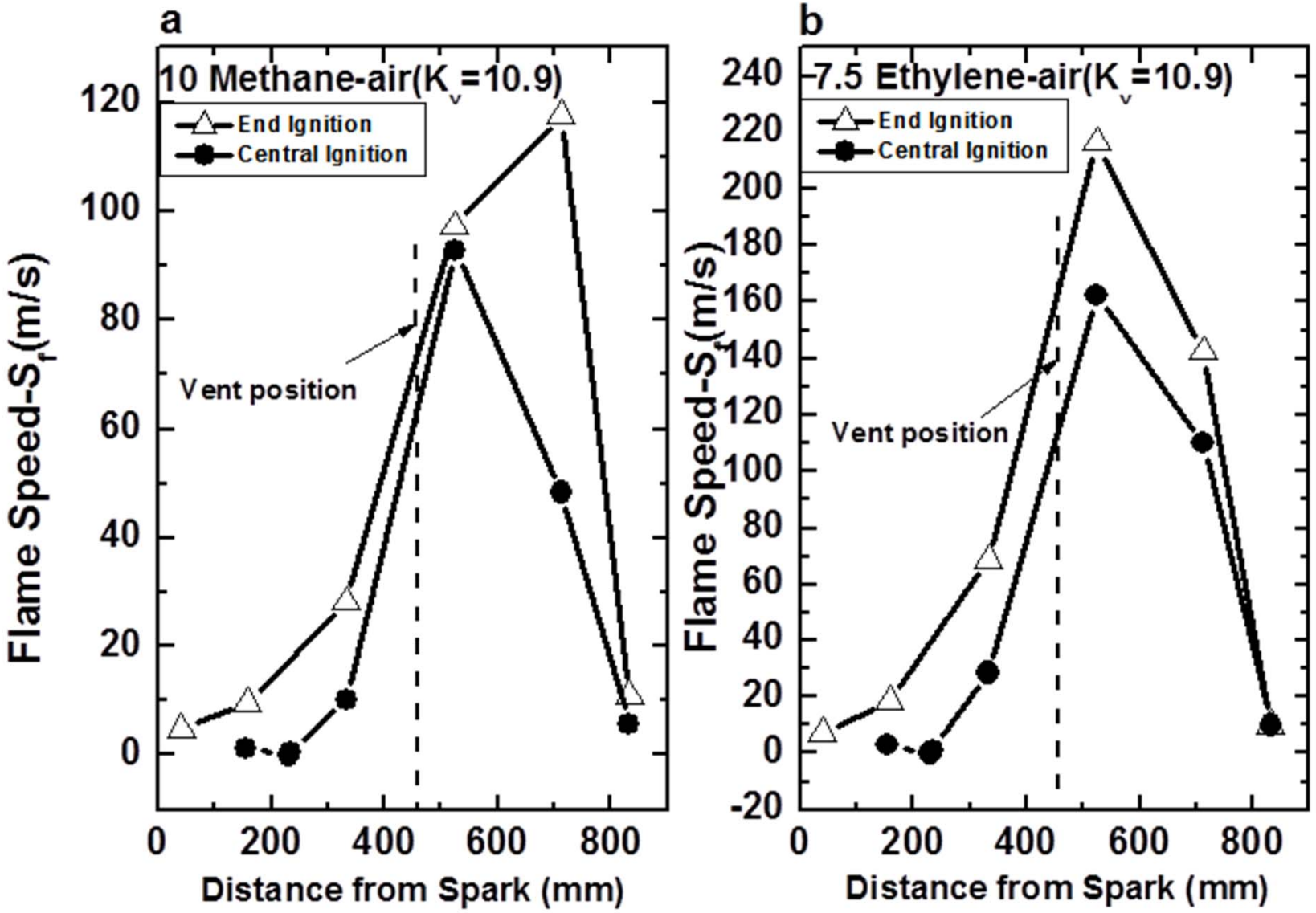
Effect of vent area



Overpressure against K_v with end ignition for (a)10% methane-air(b) 4.5% Propane-air

End Vs Central ignition




a
10 Methane-air(K$_v$=10.9)
End Ignition
Central Ignition
Vent position
Flame Speed-S$_r$(m/s)
Distance from Spark (mm)
b
7.5 Ethylene-air(K$_v$=10.9)
End Ignition
Central Ignition
Vent position
Flame Speed-S$_r$(m/s)
Distance from Spark (mm)

Effect on vent area distribution

EN 14994-2007:

6.2 Positioning and shape of explosion vents

Explosion vents shall be positioned so that the effectiveness of the venting process is not impeded. If the enclosure is small and relatively symmetrical, one large vent is as effective as several small vents of equal combined area. For large enclosures, the location of multiple vents to achieve uniform coverage of the enclosure surface to the greatest extent practicable is necessary. One shall also assure that nearby plant and personnel will not be at risk from flames, blast and flying debris. Recoil forces shall be taken into account when considering the location and distribution of the vent.

NFPA 68, 2013:

A.6.4 The P_{red} developed in a vented enclosure decreases as the available vent area increases. If the enclosure is small and relatively symmetrical, one large vent can be as effective as several small vents of equal combined area. For large enclosures, the location of multiple vents to achieve uniform coverage of the enclosure surface to the greatest extent practicable is recommended. Rectangular vents are as effective as square or circular vents of equal area.

Effect on vent area distribution

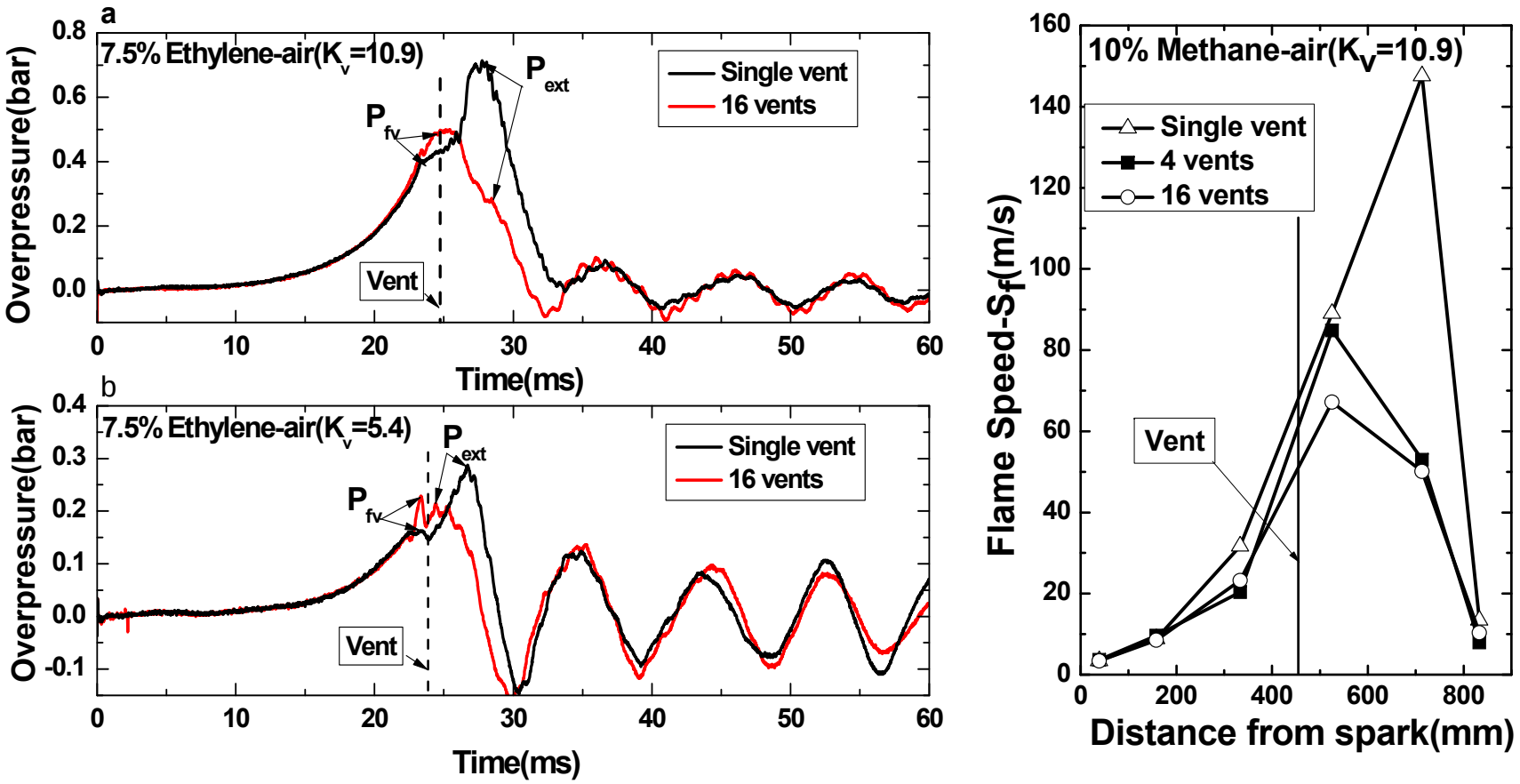


Fig. 13 Pressure-time records of single and multiple vents for 10% Methane-air and 7.5% ethylene-air (Kv=10.9 and 5.4)

What influences the external explosion

In all tests except for one (methane, small vent area, 4 hole) the external explosion was the highest pressure peak.

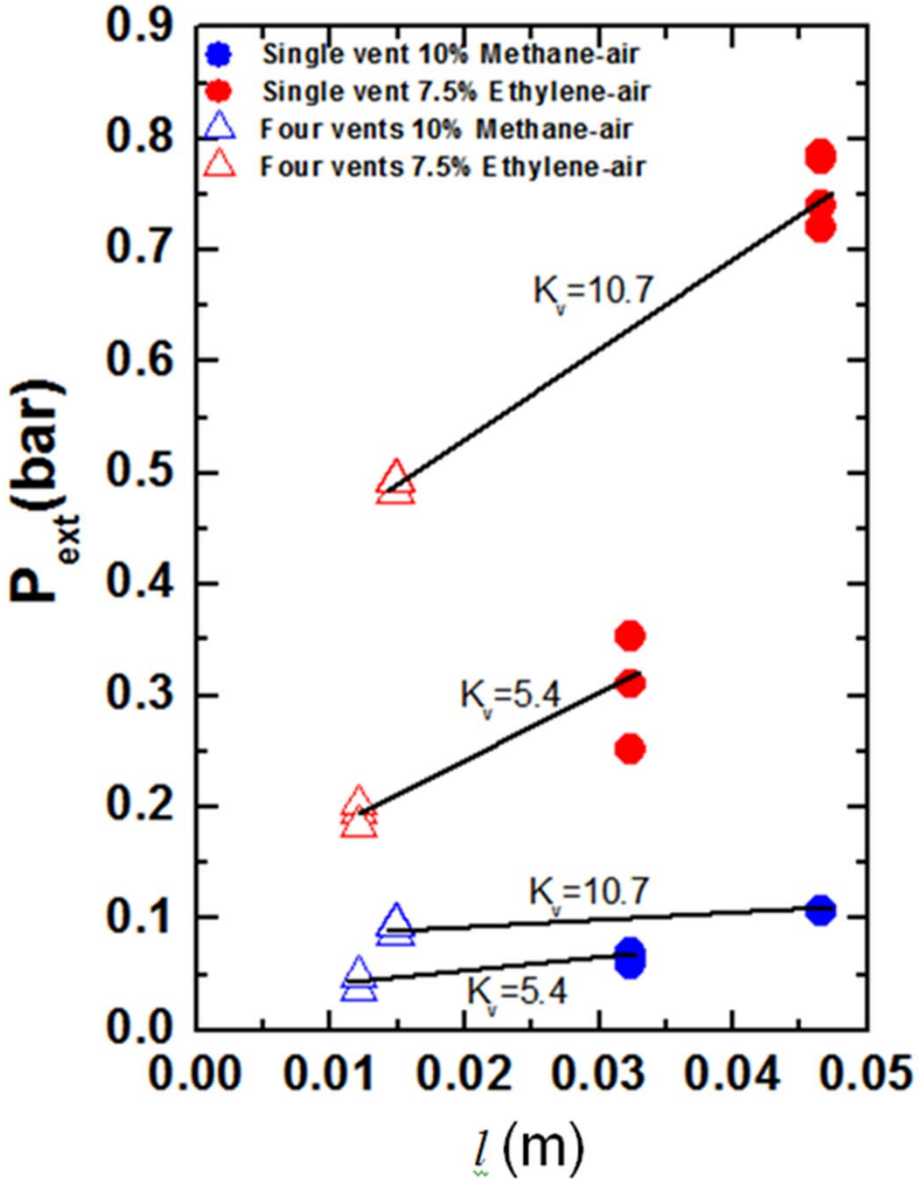
The external explosion is a turbulent combustion fire-ball, dependent on the turbulent burning velocity, often expressed in terms of the turbulent Reynolds number

$$\mathrm{R}_l = {}^{\mathrm{u}'l}/_{v}$$

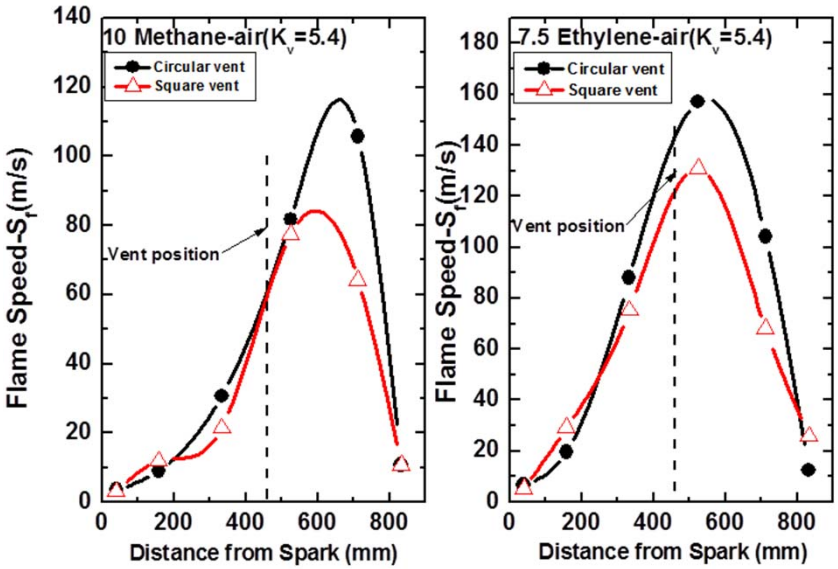
u' depends on flow through the vent and the pressure loss coefficient (upstream flame speed and BR).

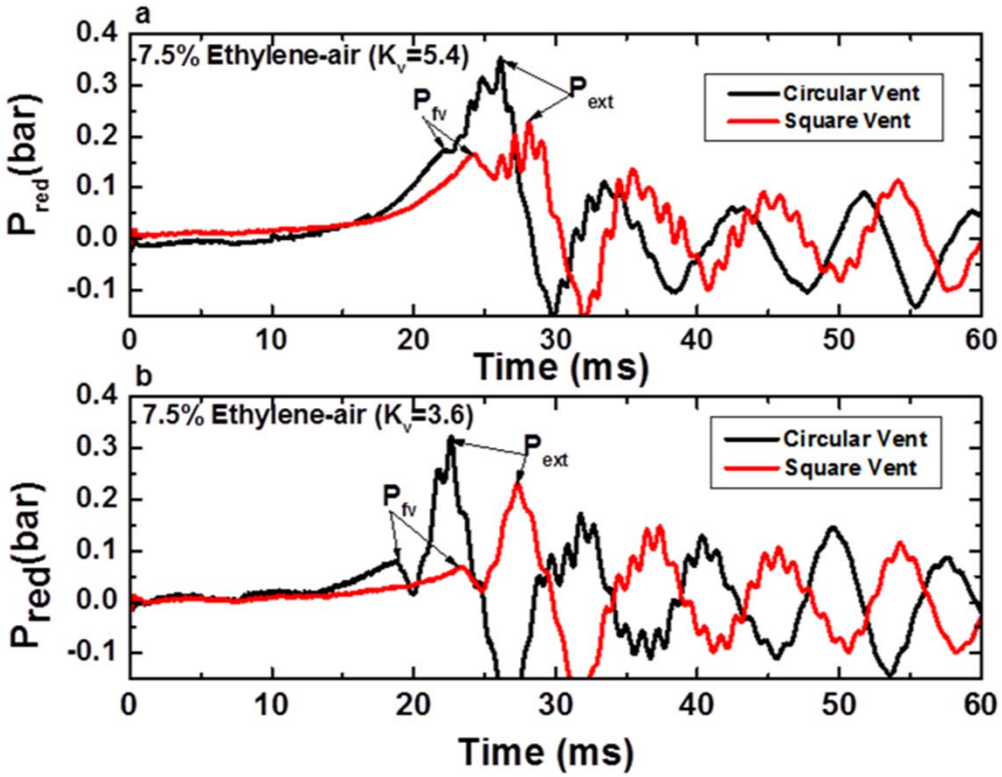
l is of the order of the width of the solid material between the holes (vents)

External Pressure Vs length scale

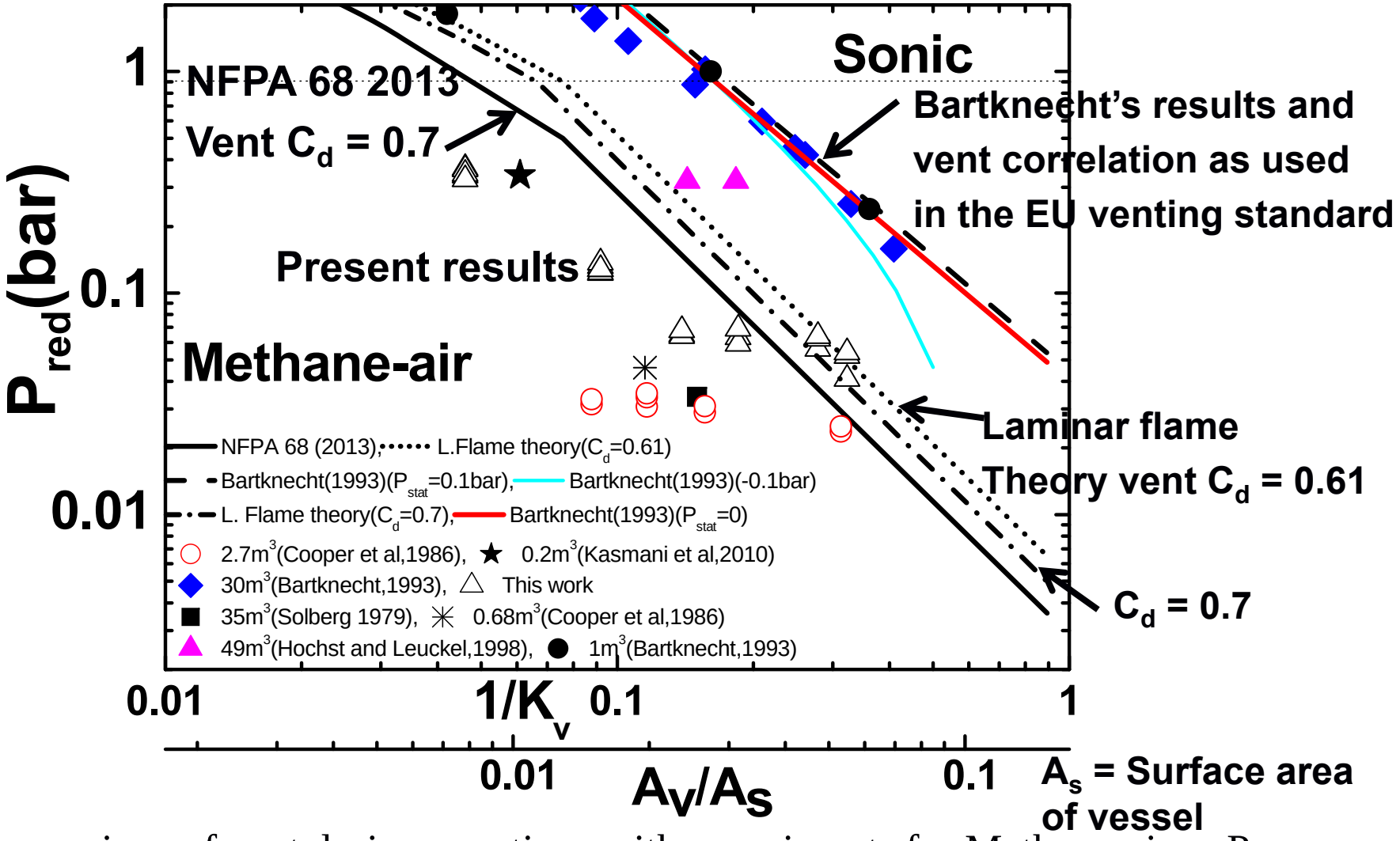


Vessel Shape : **Square vs Circular Vents**



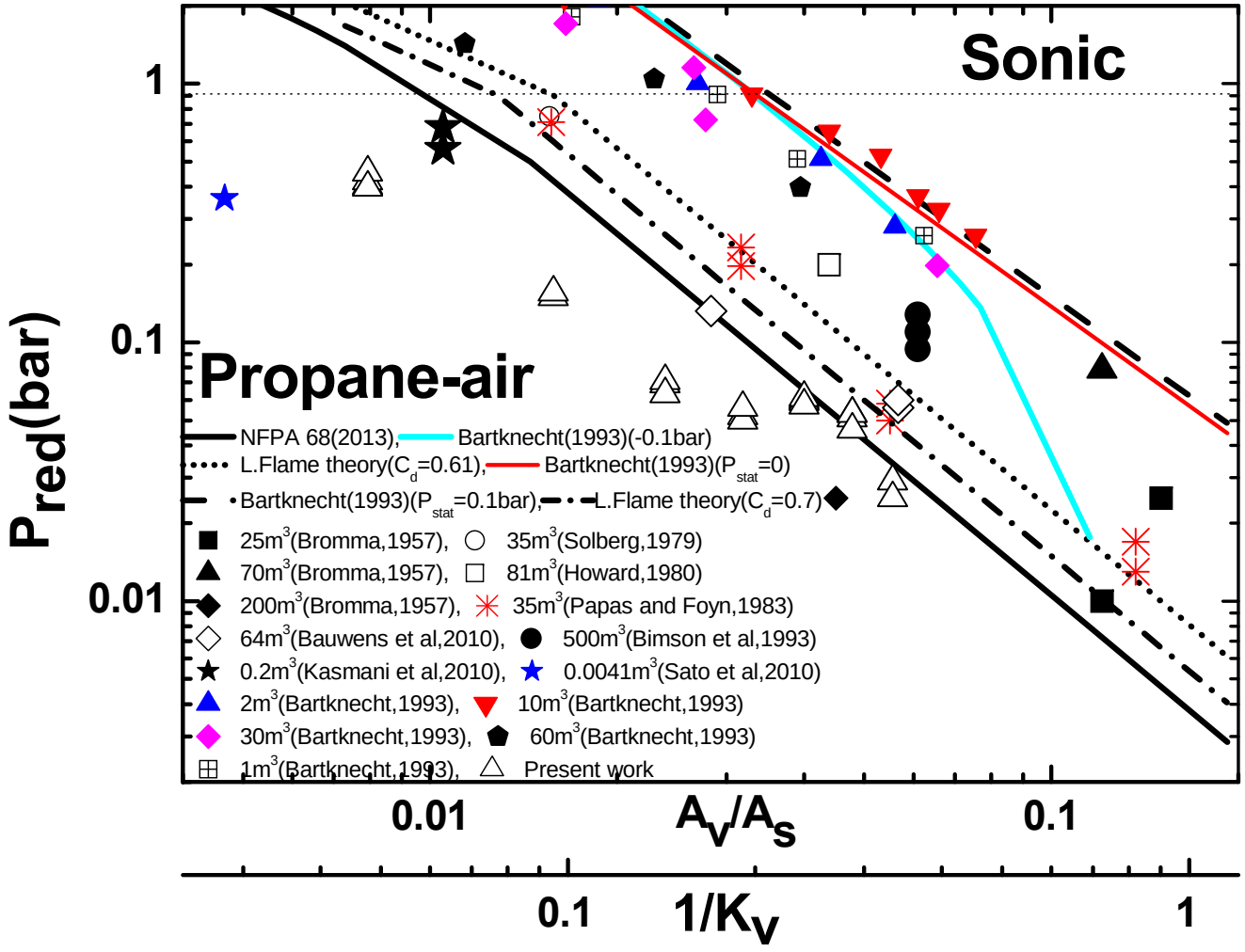


Overall results – Methane



Comparison of vent design equations with experiments for Methane-air as P_{red} v. $1/K_v = A_v/V^{2/3}$

Overall results – Propane



Comparison of vent design equations with experiments for propane-air as P_{red} v. $1/K_v = A_v/V^{2/3}$

Conclusions

- **Present results from small vessel tests comparable to results from very large scale tests.**
- **Able to identify and study the various mechanisms of pressure generation**
- **For low K_v <~7 the external explosion dominates P_{max} and for K_v > ~7 the flow through the vent dominates P_{max}.**
- **Vent number, shape, position and ignition position are all important but not recognised as such in the standards.**
- **Bartknecht's results (on which the european standards are based) are higher than anybody else's.**
  - **Possibly because of the coanda effect on the discharge jet when the vessel is flush with the ground. Similar effects observed in some of our tests..**