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PROPANE-AIR EXPLOSIONS IN A PARTIALLY FILLED INTERCONNECTED VESSEL

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Interconnected compartments are common in a wide range of situations including two adjacent rooms with a linking corridor, two linked reactor vessels, and two adjoining tanks with connecting pipework.

Connected chambers with potential flammable gas leaks, have a potential for accidental release.

In many cases this release will occur in only one of the connected volumes, as it is unlikely that two simultaneous leaks will occur in two connected volumes at the same time.

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It is this situation of a leak in one compartment connected to another, with no flammable gas, that is investigated in the present work.

The extreme example is investigated whereby if the leak had mixed with the volume in both vessels then no ignition could occur as the amount of flammable gas studied was insufficient to form a flammable mixture.

To achieve this a volume ratio of 4/1 was used for the air/stoichiometric mixture ratio yielding an overall equivalence ratio of 0.25.

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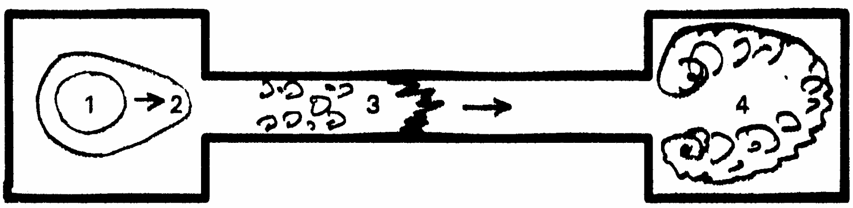
Summary of previous work of Phylaktou and Andrews on connected vessel explosions with flammable mixture in both volumes and a volume ratio of 1/1.

Two 0.5m diameter vessels 0.5m long were connected by a 76mm diameter pipe 1.5m long.

Essentially the configuration was a vented explosion with a vent pipe with a vent pipe discharge into a connected volume of the same size as the initial explosion volume. The vent coefficient of the vent pipe was 46.9.

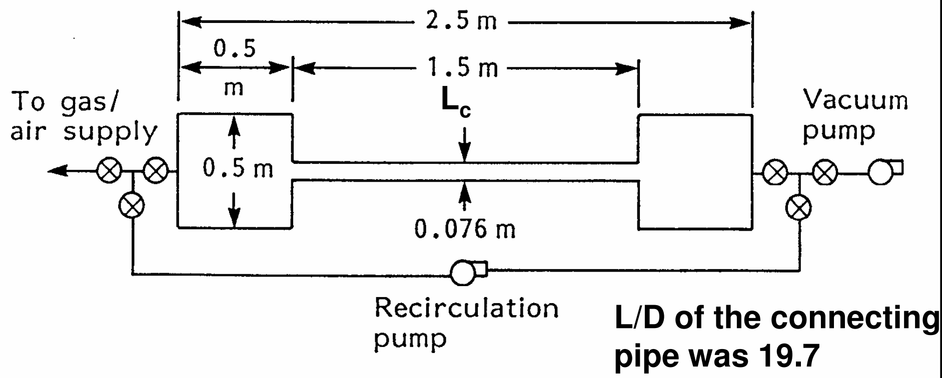
The vessels consisted of a closed volume and these results have been used to calibrate at least two explosion CFD models.

Summary of mechanism



1. **ignition and spherical expansion, outflow initiation**
2. **flame elongation towards exit (ΔP between vessels)**
3. **turbulent flame acceleration in pipe**
4. **jet-ignition of highly turbulent (precompressed) mixture**

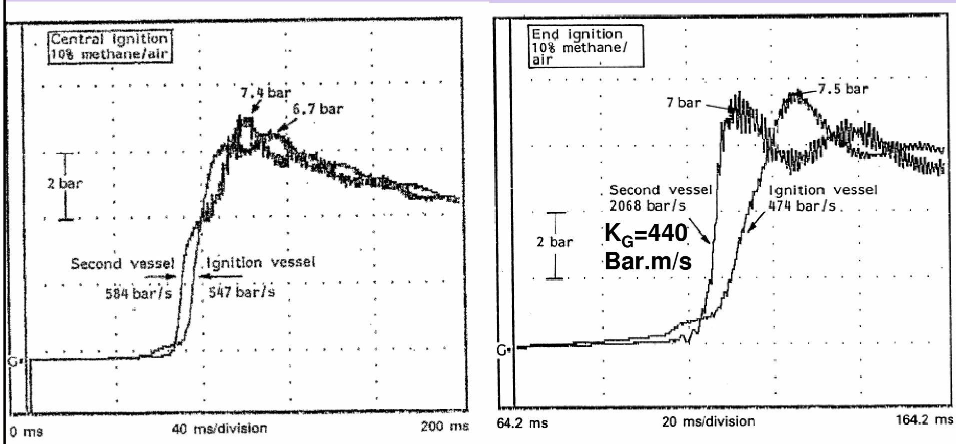
The mechanism (Leeds research)



L/D of the connecting pipe was 19.7

Central Ignition

End Ignition



End ignition gives a greater time for unburnt gases to flow through the connecting pipe and create more turbulence.

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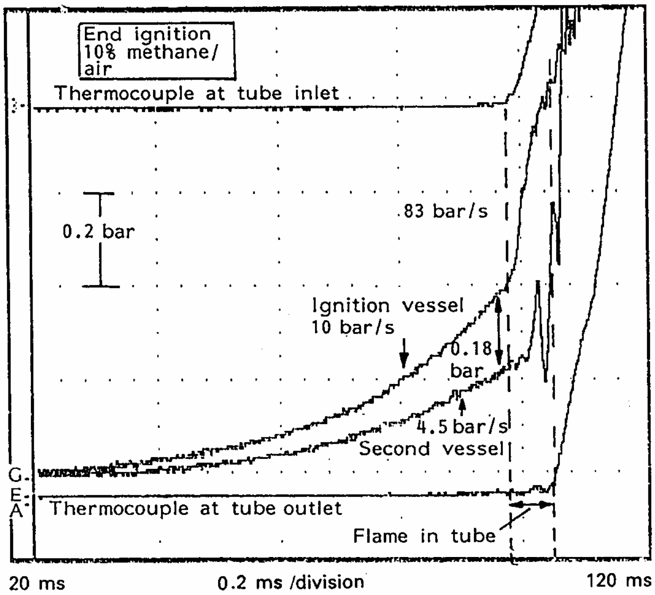

End Ignition. Note that prior to the flame entering the pipe the pressure in vessel 1 was higher than in 2. Thus a jet flow was created in the pipe. This created high turbulence in vessel 2 and as soon as the flame left the pipe there was a very rapid pressure rise in vessel 2 and flow reversed in the connecting pipe. This created turbulence combustion in vessel 1 and a high dp/dt.

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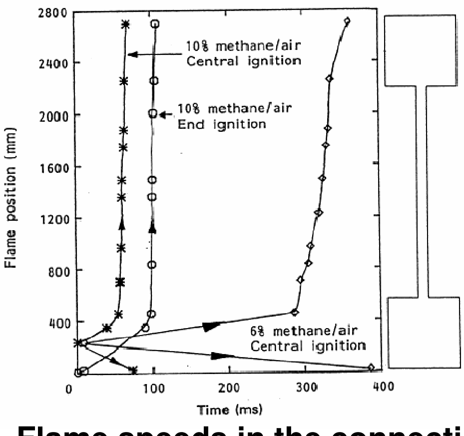
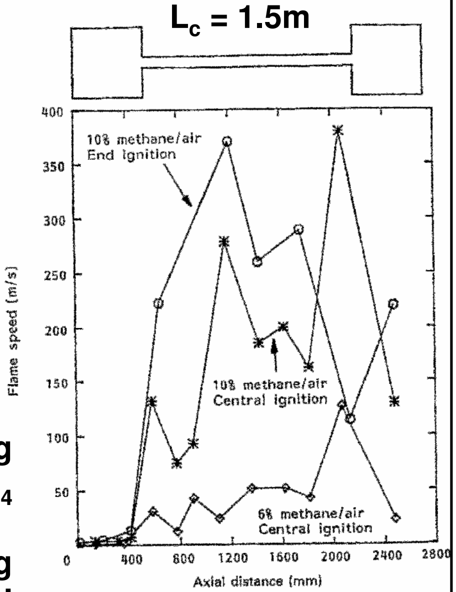


L_c = 1.5m



Flame speeds in the connecting Pipe were ~350 m/s for 10% CH_4 and 50 m/s for 6% CH_4.
Flame speeds in the connecting vessel were 220 m/s for 10% CH_4.

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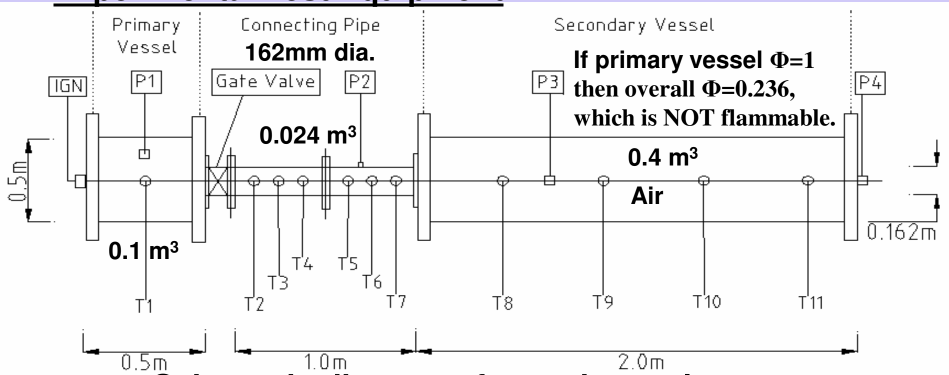
Experimental Test Equipment



Schematic diagram of experimental setup
(P = Pressure transducer, T = Thermocouple).

The connecting duct represented a vent duct for the explosion in the primary vessel, with the secondary vessel a capture vessel for the vented gases. Hence, this work has applications to safe vent design for toxic substances. The connecting duct area was equivalent to an explosion vent coefficient, K_v (=$V^{2/3}/A_v$) of 10.3.

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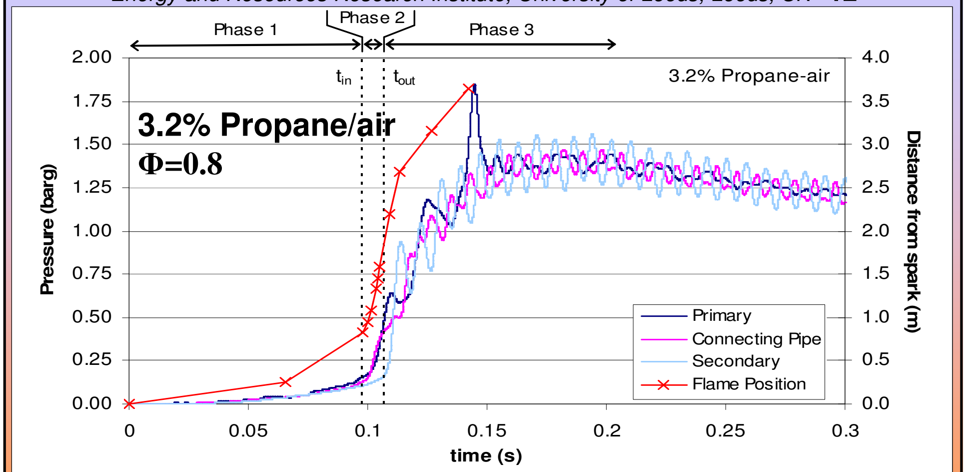

Typical smoothed pressure records for 3.2% (Φ = 0.80) homogeneous propane-air mixture present within the primary vessel only. The adiabatic pressure rise for this explosion was 1.5 bar and the peak pressure of 1.8 bar in the primary vessel indicates pressure piling had occurred.

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***Phase 1*: Initial slow development**
Average flame speed 8.5 m/s . The pressure in the primary vessel was always greater than in the connecting pipe and the secondary vessel

***Phase 2*: Fast flame propagation through the connecting pipe. It took 7.5 ms to travel through the connecting pipe at an average speed of 100 m/s.**

Just prior to the flame emerging from the duct the pressure difference between the primary and secondary vessel was at least 0.3 bar and this would indicate an unburned gas velocity exiting the duct ahead of the flame of about 180 m/s, using a 1.5 dynamic head pressure loss in the duct. These high jet velocities produce a very turbulent jet in the secondary vessel.

***Phase 3*: Fast burning of the flammable mixture displaced into the secondary vessel from the flame expansion in the primary vessel. K_G of 550 bar m/s in the secondary vessel.**

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The peak pressure in the secondary vessel was then higher than in the primary vessel by 0.3 bar and this caused a flow reversal into the primary vessel and a fall in the pressure in the secondary vessel. The primary vessel pressure then rose to 0.65 bar, due to fast combustion by the reverse jet that created turbulence in a previously laminar situation in the primary vessel. This pressure reversal initiated a pressure oscillation wave in the secondary vessel with a time period of 0.01s. These pressure oscillations in the secondary vessel had a frequency corresponding to Helmholtz bulk oscillations.

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The initial flow reversal into the primary vessel resulted in a sudden increase in the combustion rate of the unburned mixture trapped in the primary vessel, together with a decrease in the pressure in the secondary vessel due to the flow into the primary vessel.

However, the unburned gas was predominantly in the primary vessel and the pressure here continued to rise and generate flow into the secondary vessel. Eventually the venting flow caused the primary vessel pressure to be reduced, this second peak pressure in the primary vessel was 1.2 bar.

This second venting flow expansion into the secondary vessel caused the primary pressure to fall, <u>until there was a sudden increase in the primary pressure to 1.8 bar</u>. It is considered that this was caused by the sudden <u>autoignition of the remaining unburned gas mixture in the corner regions of the primary vessel.</u>

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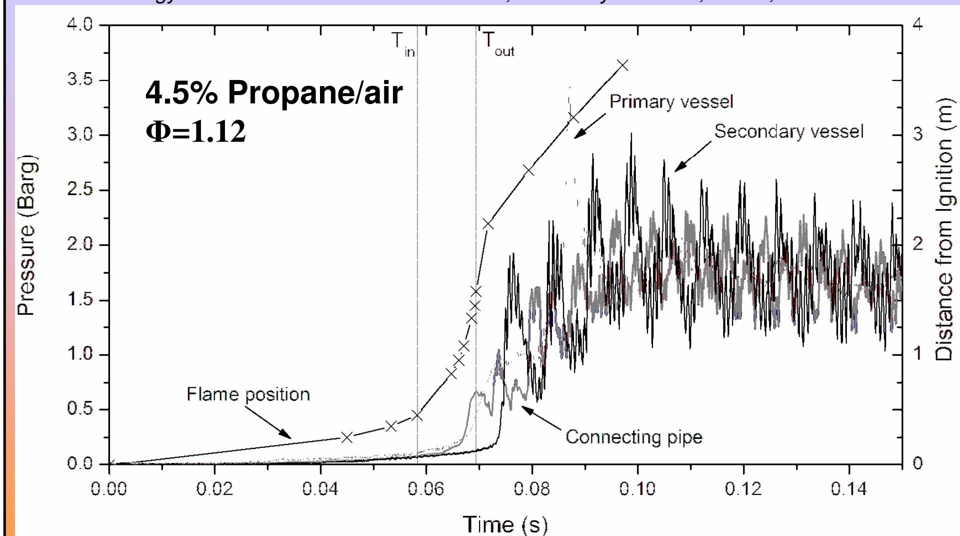

Unsmoothed Pressure-Time history in the primary vessel, connecting pipe and secondary vessel, with axial flame position for 4.5% propane-air.

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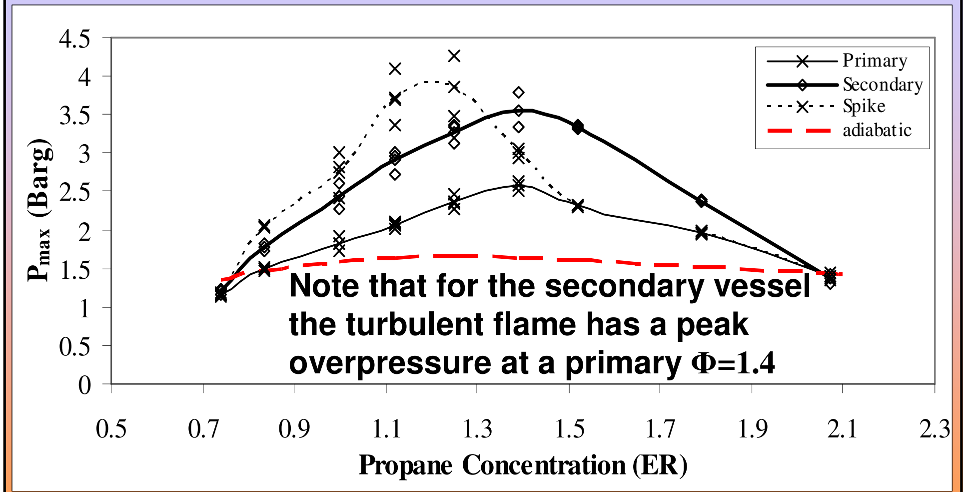

Maximum pressures recorded in the primary and secondary vessels with respect to equivalence ratio. Calculated system adiabatic pressure shown.

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The pressure in the primary vessel was only greater than that in the secondary vessel when the auto ignition pressure spike was included.

The pressure spike was present for concentrations between 3.2% and 5.5% (Φ = 0.80 and 1.4) inclusive and this was only greater than the peak pressure in the secondary vessel for primary vessel mixtures leaner than Φ=1.3.

For all concentrations, ignoring the pressure spike in the primary vessel, the highest maximum pressure was recorded in the secondary vessel.

For rich mixtures in the primary vessel the secondary vessel pressure was much greater than any pressure in the primary vessel. This was because the initial rich premixed flame had a slow rate of flame propagation and a low peak pressure, but once this rich mixture vented into the air of the secondary vessel, some of this air mixed in and the mixture burnt locally closer to stoichiometric

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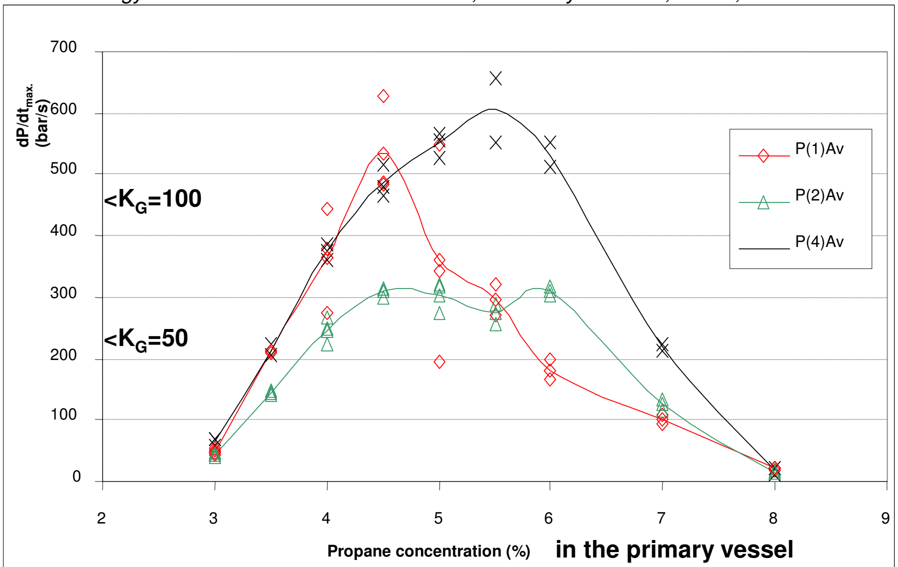

Maximum recorded rate of pressure rise in the primary vessel (P1), connecting pipe (P2) and secondary vessel (P4).

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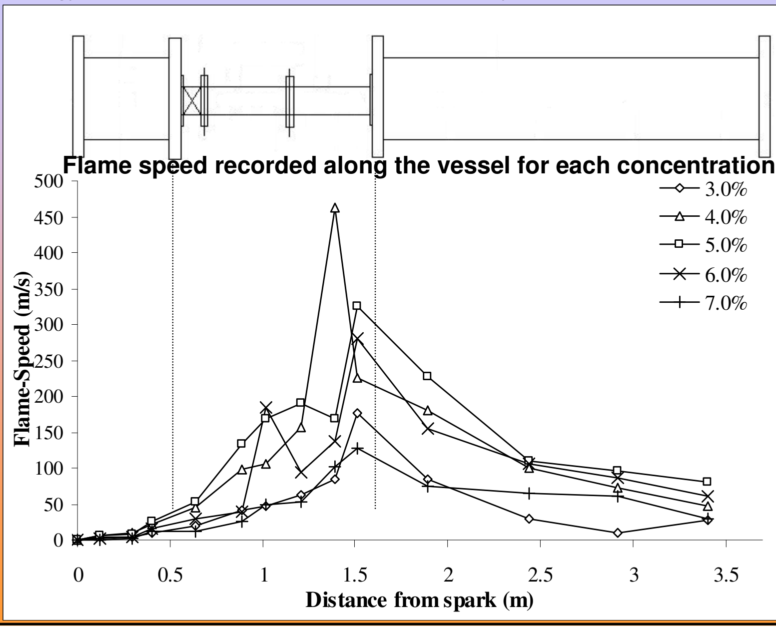

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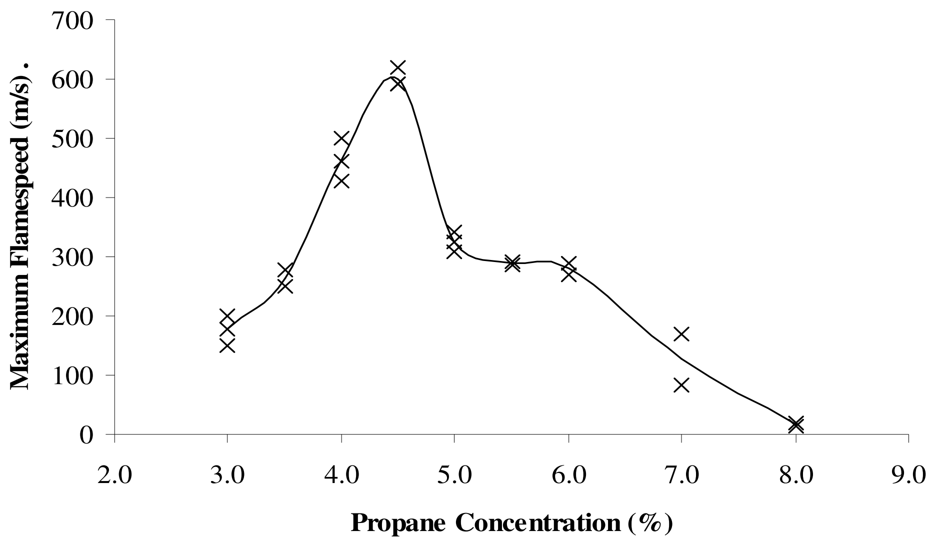

Maximum flame speed in the connecting duct as a function of propane concentration in the primary vessel.

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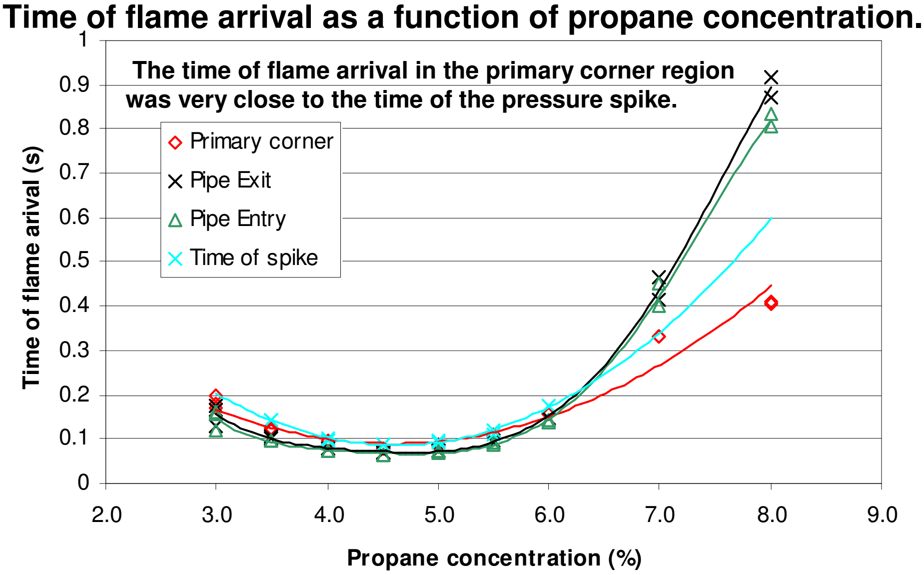
Time of flame arrival as a function of propane concentration.



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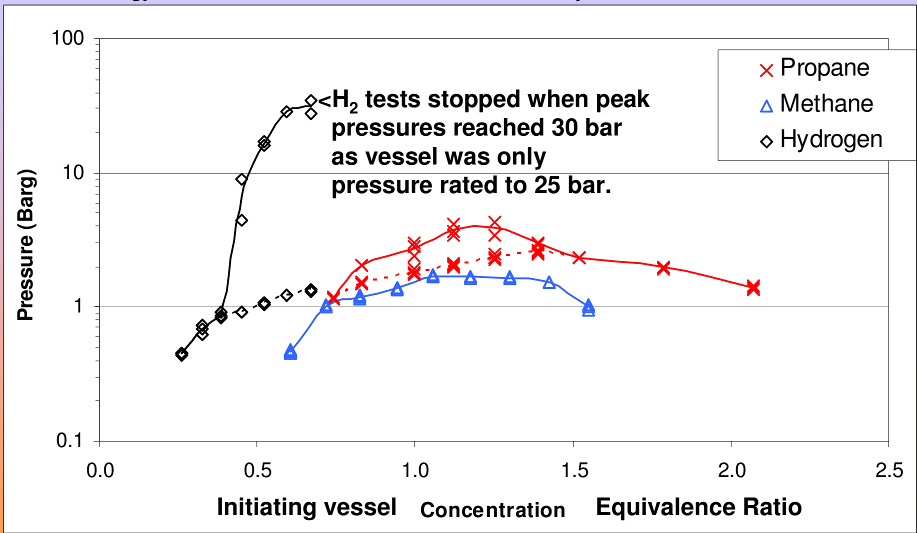

Comparison between the maximum pressures observed in the primary vessel for propane compared with methane and hydrogen.

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For hydrogen and propane two peak pressure have been plotted:

the peak pressure ‘spike’ and the underlying pressure from which the ‘spike’ has risen.

For hydrogen this was a very large difference and indicates a strong auto-ignition, detonation like, event. For propane the difference was smaller, but still significant and for methane there was no pressure spike. Methane does not auto-ignite easily.

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Conclusions I

Interconnected vessel explosions were studied with a 4/1 volume ratio and a premixed propane air mixture only in the smaller primary vessel. The 4/1 volume ratio ensured that the simulation of a leak in the primary vessel resulted in mixtures that were not flammable if the air in the secondary vessel mixed with the displaced unburnt gases from the first vessel.

The connected duct between the two vessels was equivalent to a vent on the primary vessel with a Kv of 10.3 and a connecting duct equivalent to a vent pipe with the same diameter as the vent.

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Conclusions II

Very severe explosions in the secondary vessel occurred due to the displaced unburned gases from the primary vessel and this indicated that the fast turbulence combustion of the displaced flammable gases occurred before the displaced gases could mix with the secondary vessel air.

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Conclusions III

There was evidence of reverse flow from the secondary vessel explosion back into the primary vessel and subsequent turbulence generation and fast flame development in the primary vessel.

Further expansion of this fast primary flame gases into the secondary vessel eventually resulted in a further reverse flow into the primary vessel followed by autoignition of the remaining unburned gases in the corner regions of the primary vessel, with a corresponding rapid pressure rise.

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Thank you

Questions?