GEXCON

Fysikaliska risker vid vätgashantering

presentarad av Jonny Danielsson

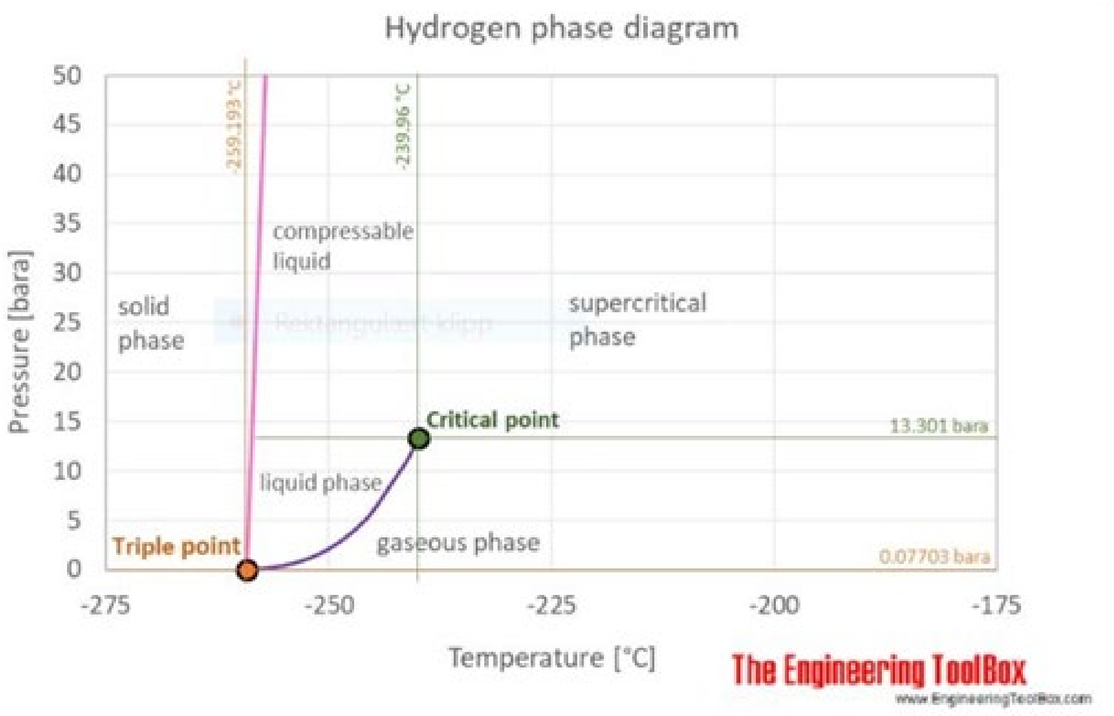
Gasdagarna 27 maj 2021, 10.20-11.20 Parallella sessioner
Vätgasinmatning i naturgasnät

Fysikaliska Egenskaper Vätgas H2

Brown, Gray, Blue and Green

Atomic number	1
Molecular Weight	2,01594 g/mol
Relative density (air =1)	0,069
Density gas NTP	0,085 kg/m3
Density Liquid	70,78 kg/m3
Boiling point	-253°C or 20 K
Energy density	120-142 MJ/kg
Ignition Temperature hot surface in air	580 °C
Minimum Ignition energy	0,011 – 0,017 mJ
LEL (Lower Explosion Limit)	4,0%vol
UEL (Higer Explosion Limit)	75%vol
Stoichometric concentration in air	29.5%vol
Expansion ratio liquid/ambient	845

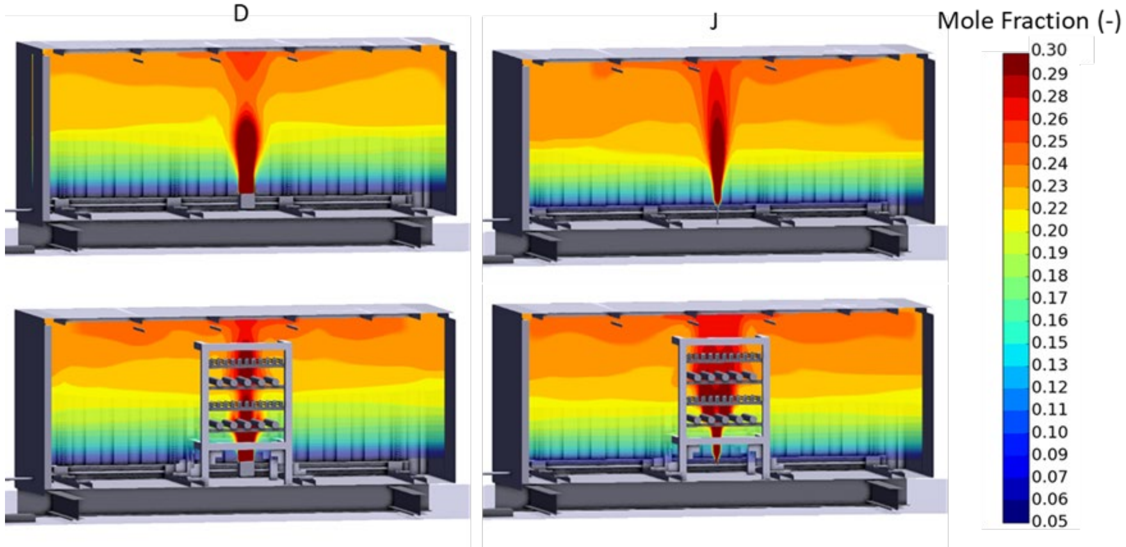
Phase Diagram

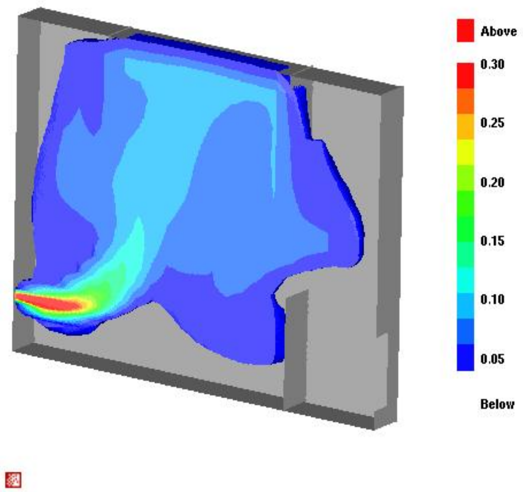


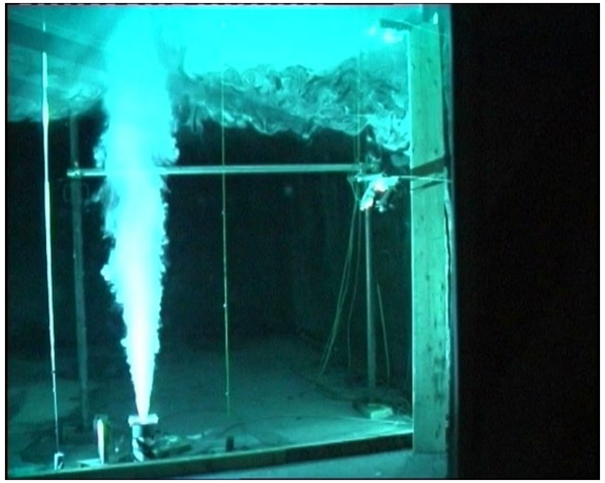
- The curve between the critical point and the triple point shows the hydrogen boiling point with changes in pressure.
- It also shows the saturation pressure with changes in temperature.
- At the <u>**critical point**</u> there is no change of state when pressure is increased or if heat is added.
- The <u>**triple point**</u> of a substance is the temperature and pressure at which the three phases (gas, liquid, and solid) of that substance coexist in thermodynamic equilibrium

Hydrogen leaks

Hydrogen has a low density causing it to disperse upwards and generate flammable gas layers against the ceiling







Characteristics

Auto-ignition temperature (hot surfaces)

- The lowest temperature of a hot surface at which a mixture of fuel and air can ignite
  - Hydrogen 580 ^{o}C
  - Methane 537 ^{o}C
  - Propane 493 ^{o}C
  - Acetone 535 ^{o}C
  - Ethanol 363 ^{o}C
  - Petrol ca 250 ^{o}C
  - Diesel ca 220 ^{o}C

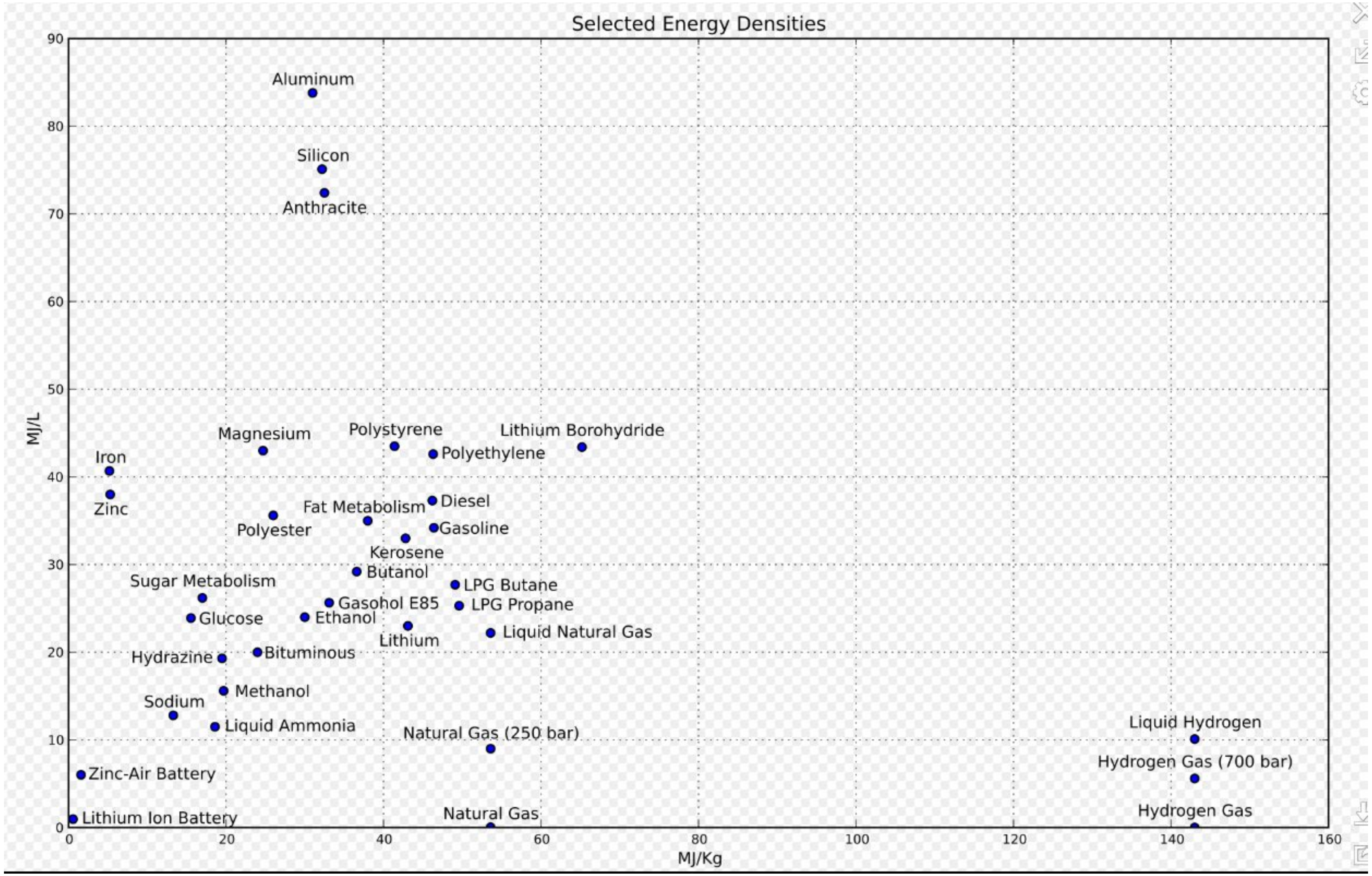
Minimum ignition energy (electric spark)

- Acetone 1.15 mJ
- Methane 0.28 mJ
- Butane 0.26 mJ
- Ethylene 0.07 mJ
- Acetylene 0.017 mJ
- Hydrogen 0.011 - 0.017 mJ
- Carbon disulphide 0.009 - 0.015 mJ

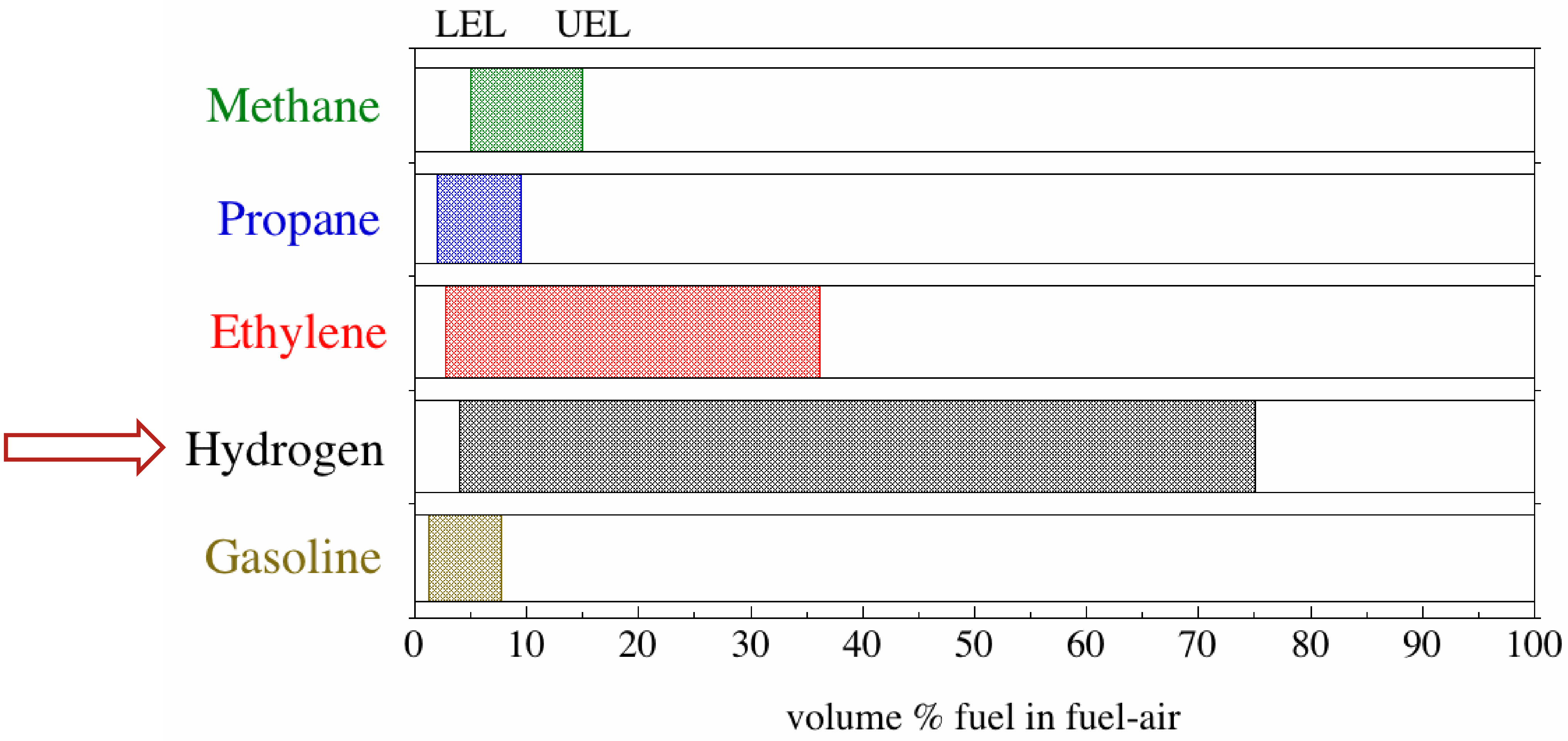
Ignition sources

- Electrostatics
- Frictional heat and sparks
- Spontaneous ignition

Comparison Energy density MJ/L and MJ/kg

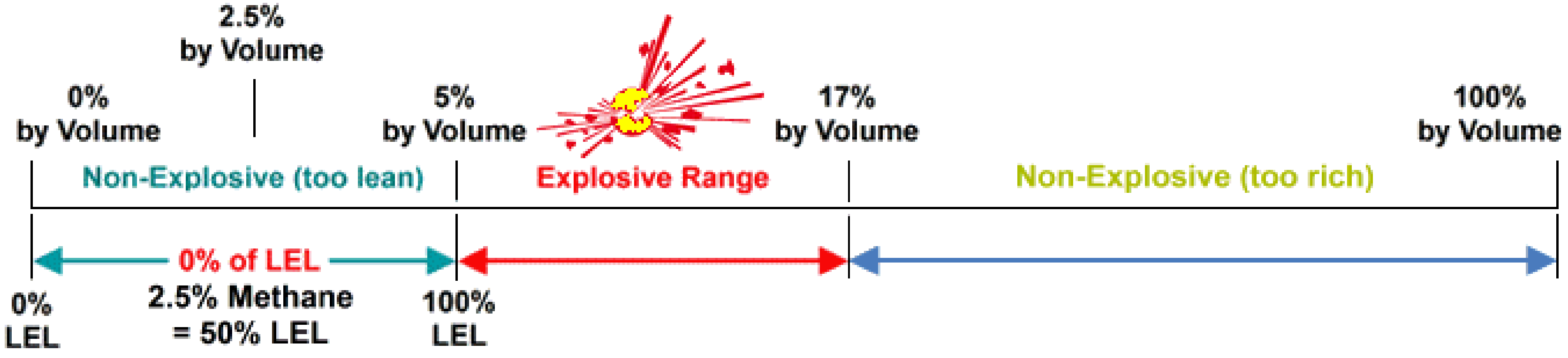


Explosive part of cloud



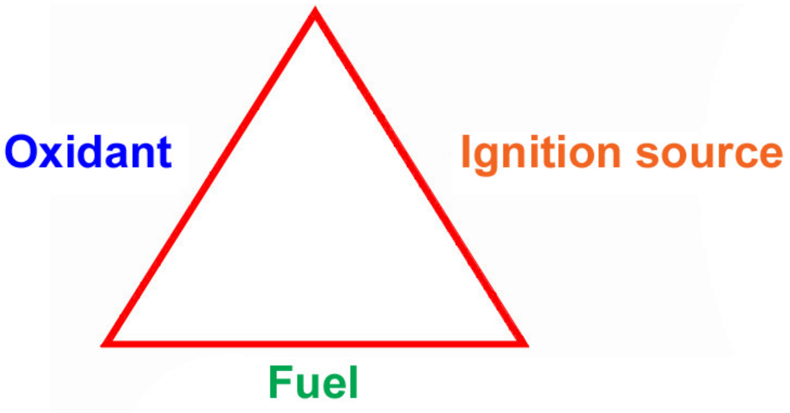
Explaining the LEL and UEL with CH4 as example

Methane - LEL: 5% by volume in Air / UEL: 17% by volume in Air

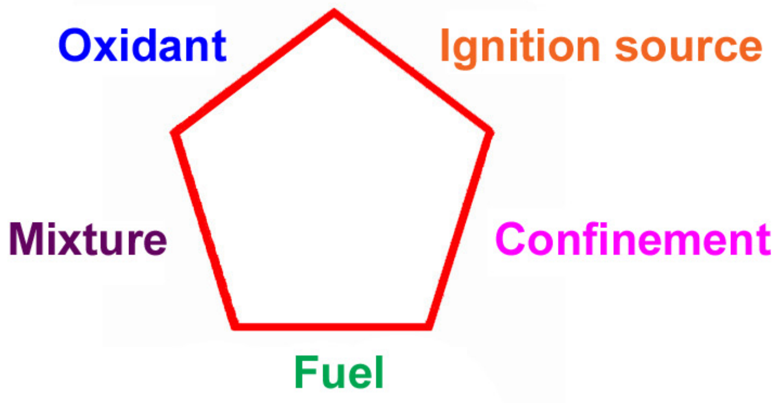


Visual example to show where on the scale % of LEL is measured

Fire triangle and explosion pentagon



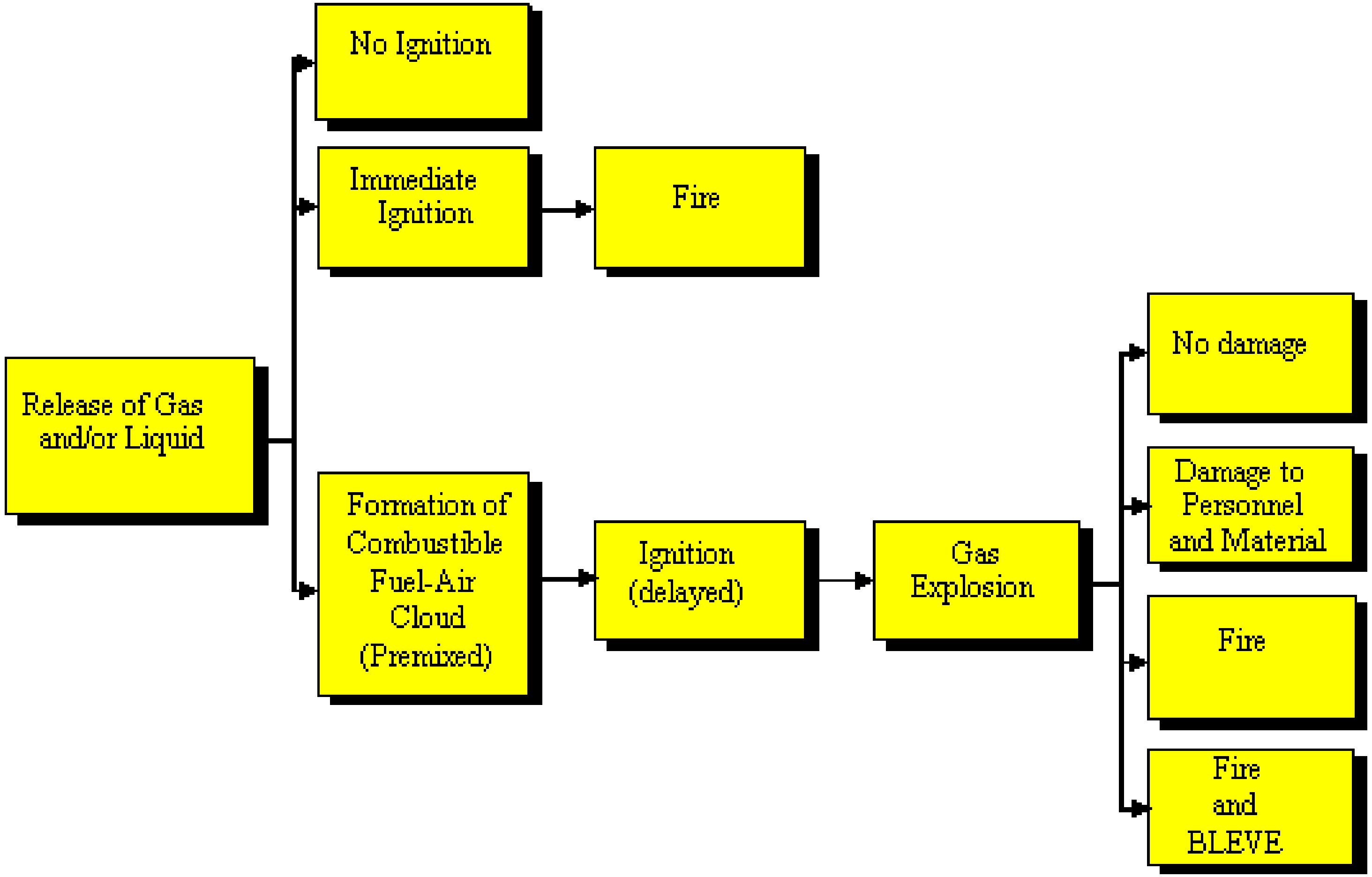
FIRE TRIANGLE



EXPLOSION PENTAGON

GEXCON

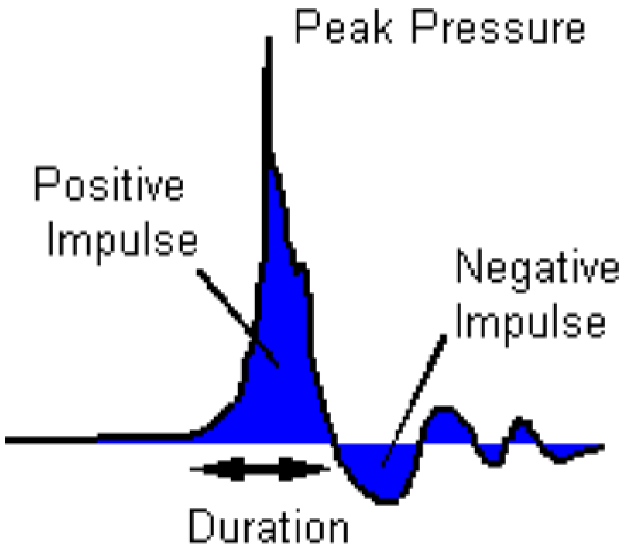
General course of events involving release of flammable gas or liquid

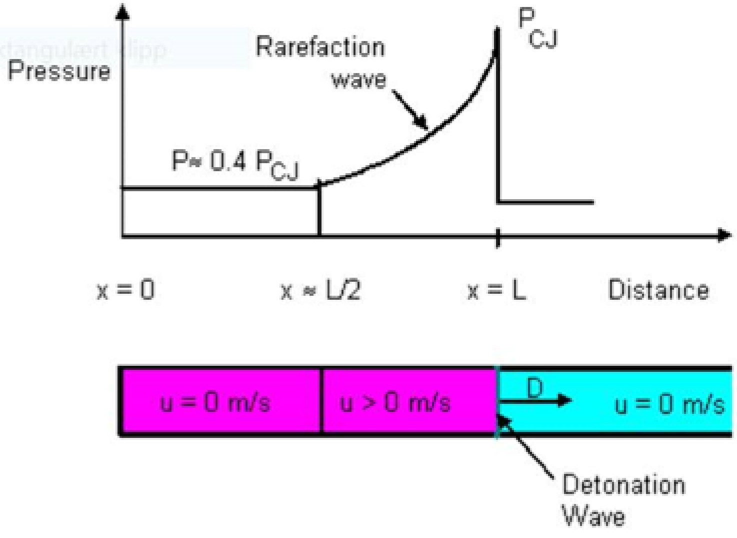


Definition explosion

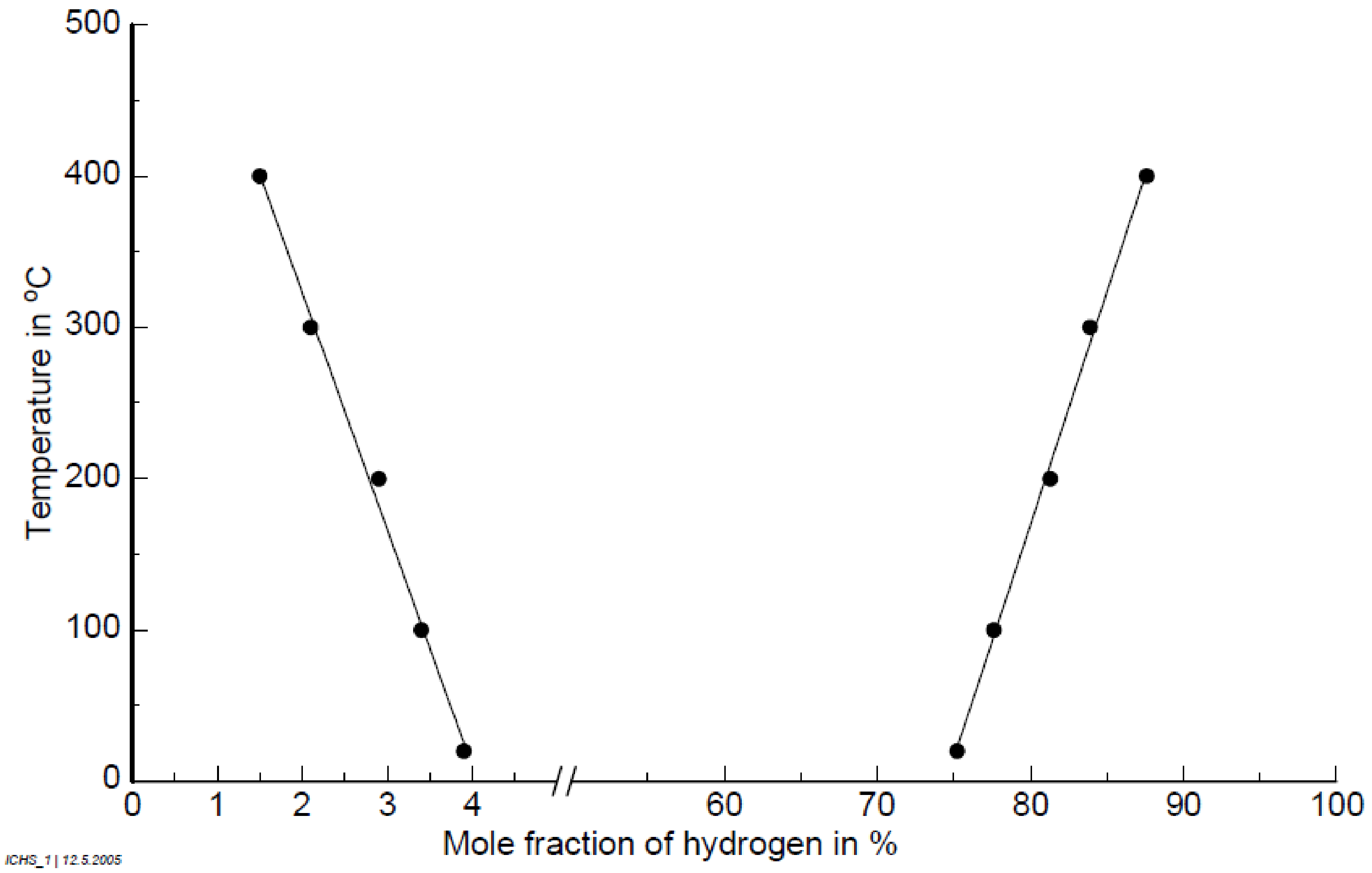
“An explosion is a chemical process which causes a very fast and considerable pressure increase”

1. Deflagration
2. Detonation

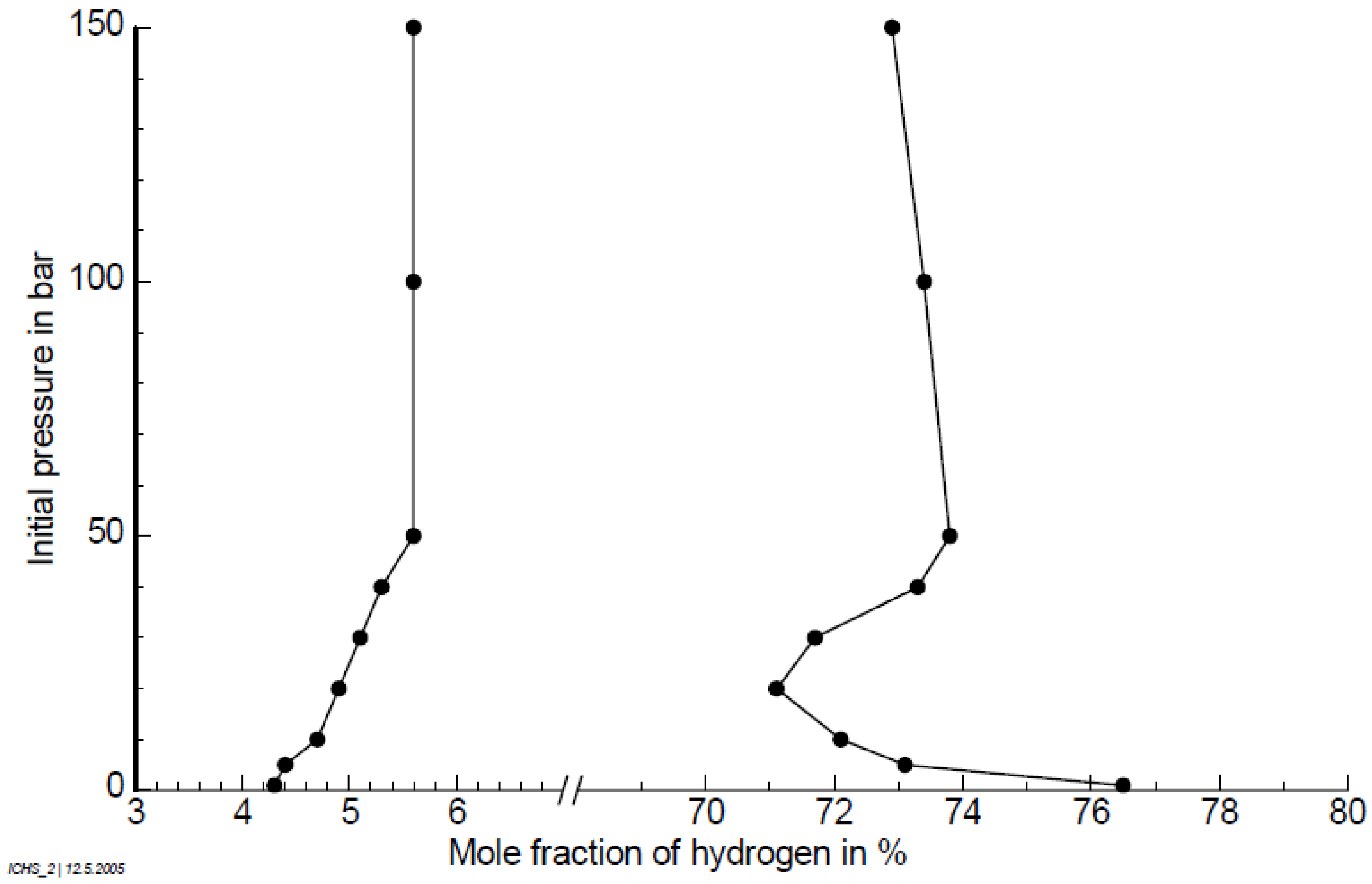




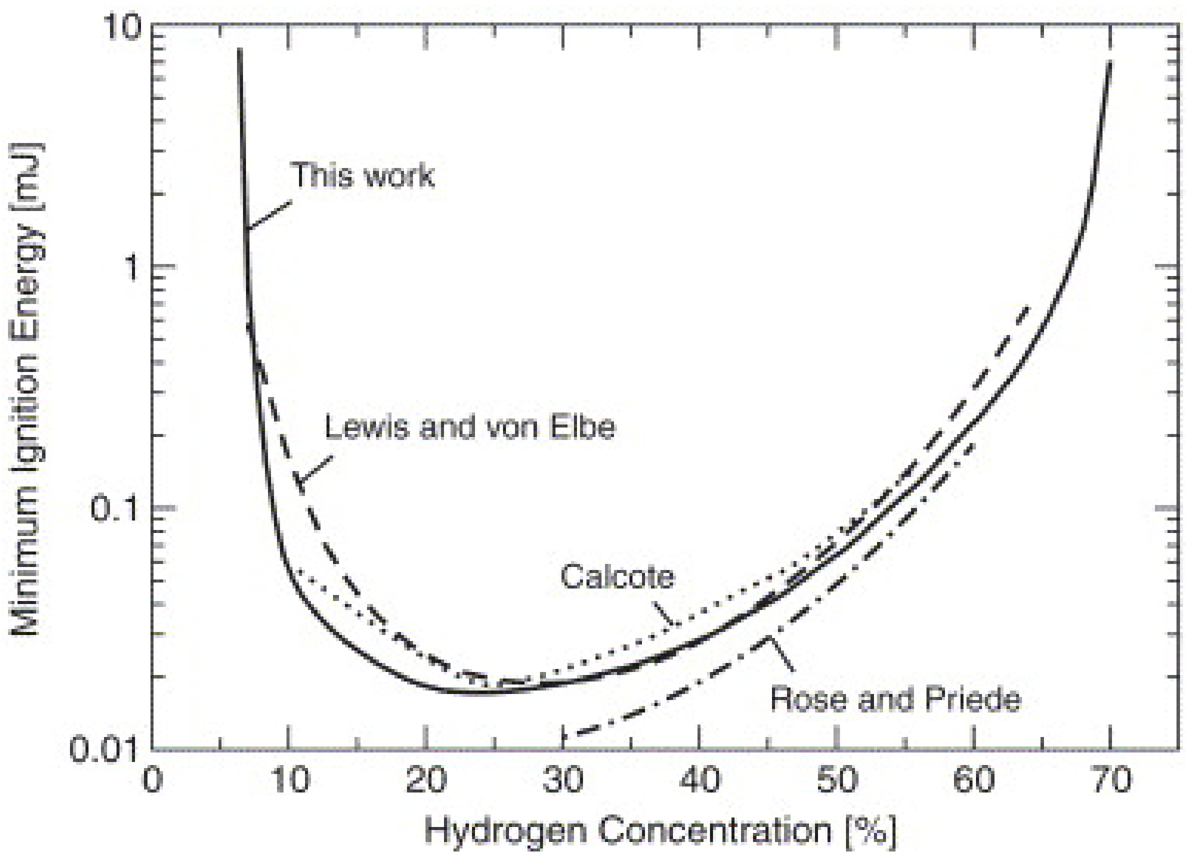
Effect of temperature on explosion limits hydrogen



Effect of pressure on explosion limits hydrogen



Minimum ignition energy (electric spark)



- Acetone 1.15 mJ
- Methane 0.28 mJ
- Butane 0.26 mJ
- Ethylene 0.07 mJ
- Acetylene 0.017 mJ
- **Hydrogen 0.011 - 0.017 mJ**
- Carbon disulphide 0.009 - 0.015 mJ

Auto-ignition temperature (hot surfaces)

The lowest temperature of a hot surface
at which a mixture of fuel and air can ignite

Hydrogen	**580 ^{o}C**
Methane	537 ^{o}C
Propane	493 ^{o}C
Acetone	535 ^{o}C
Ethanol	363 ^{o}C
Petrol	ca 250 ^{o}C
Diesel	ca 220 ^{o}C

Chemical reaction

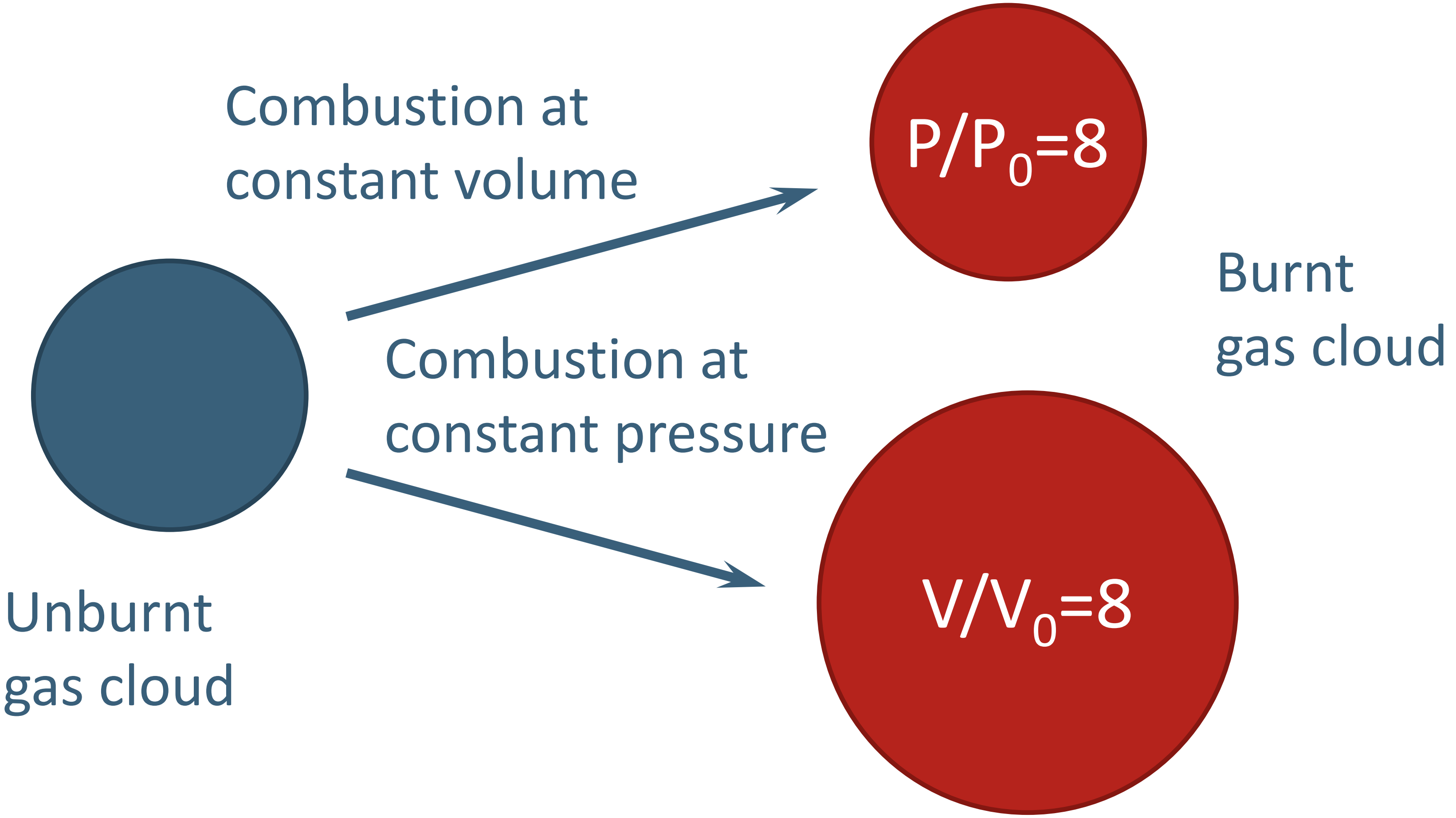
Simplified equation:

$$2H_2+O_2+3.76N_2 \Longrightarrow 2H_2O+3.76N_2 + \textbf{heat}$$

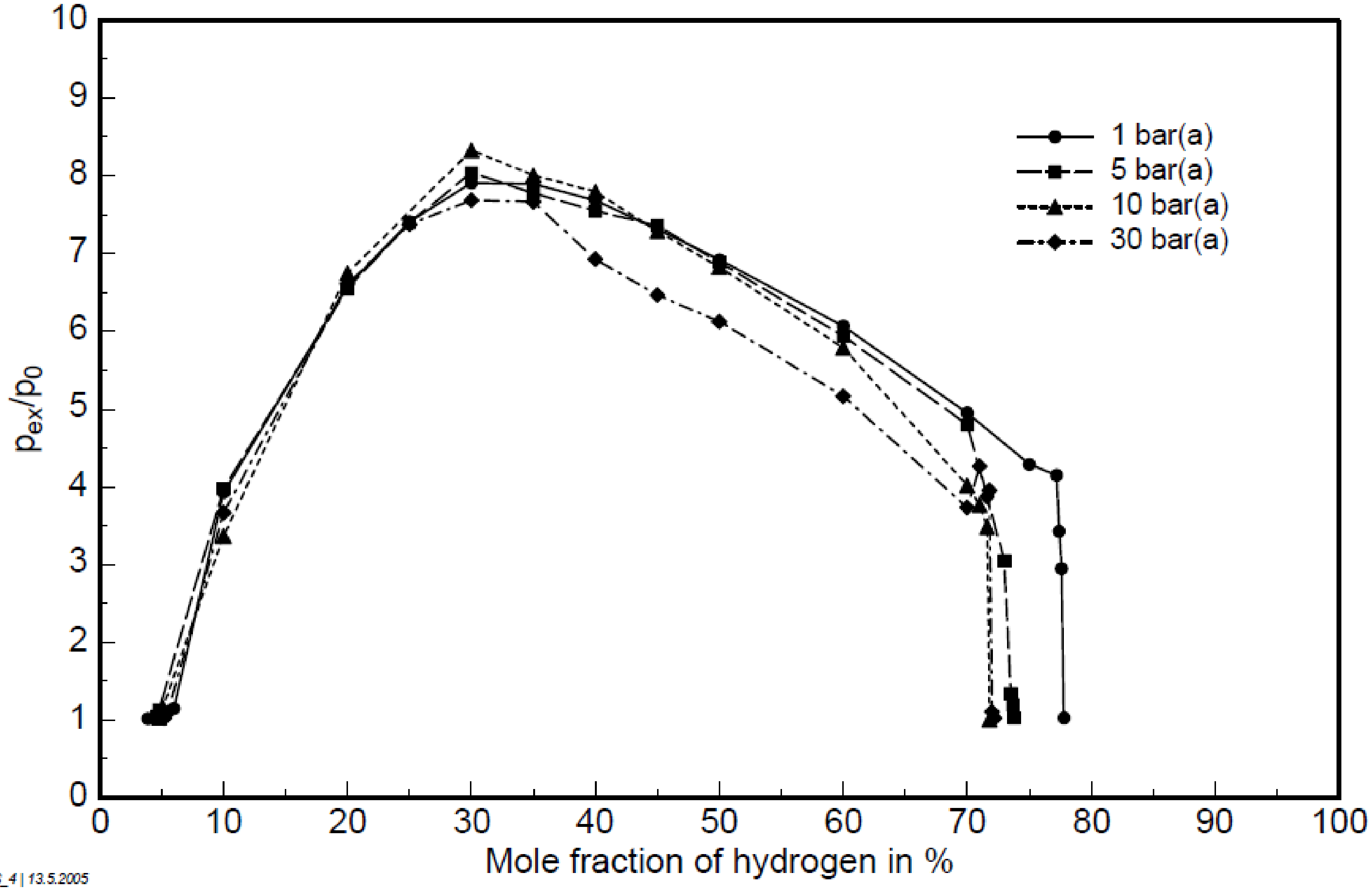
In reality: ≈57 reactions, 268 species equations

Product composition depends on mixture, temperature, pressure

Combustion at constant pressure and volume



Closed vessel explosion: maximum explosion pressure



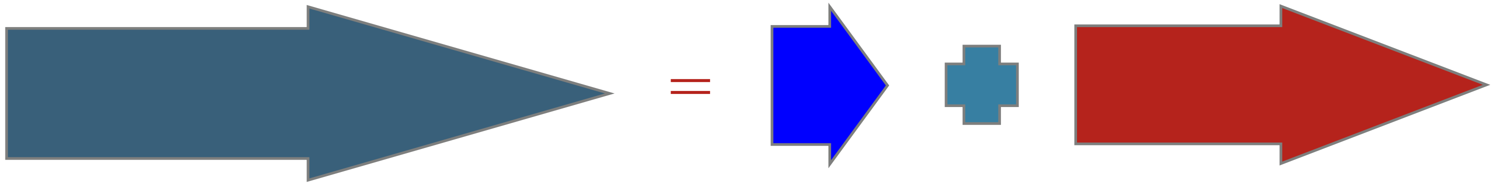
ICHS_4 | 13.5.2005

Flame propagation and acceleration mechanisms

- Laminar combustion
- Flame instabilities
- Explosion generated turbulence dominated flame propagation
- Deflagration-Detonation-Transition (DDT), Detonation
- Detonation

Laminar flame propagation

- Slow process (dominated by diffusion)
- Typical velocities (burning velocities) for HC: 0.5 m/s
- Velocity for Hydrogen: 3,25 m/s
- Expansion velocity for HC: total velocity becomes: 3-4 m/s
- Expansion velocity for Hydrogen: 24 m/s
- Total Velocity for Hydrogen: 3,25 + 24 = 27,25 m/s



$$S_f = S_u + S_g$$

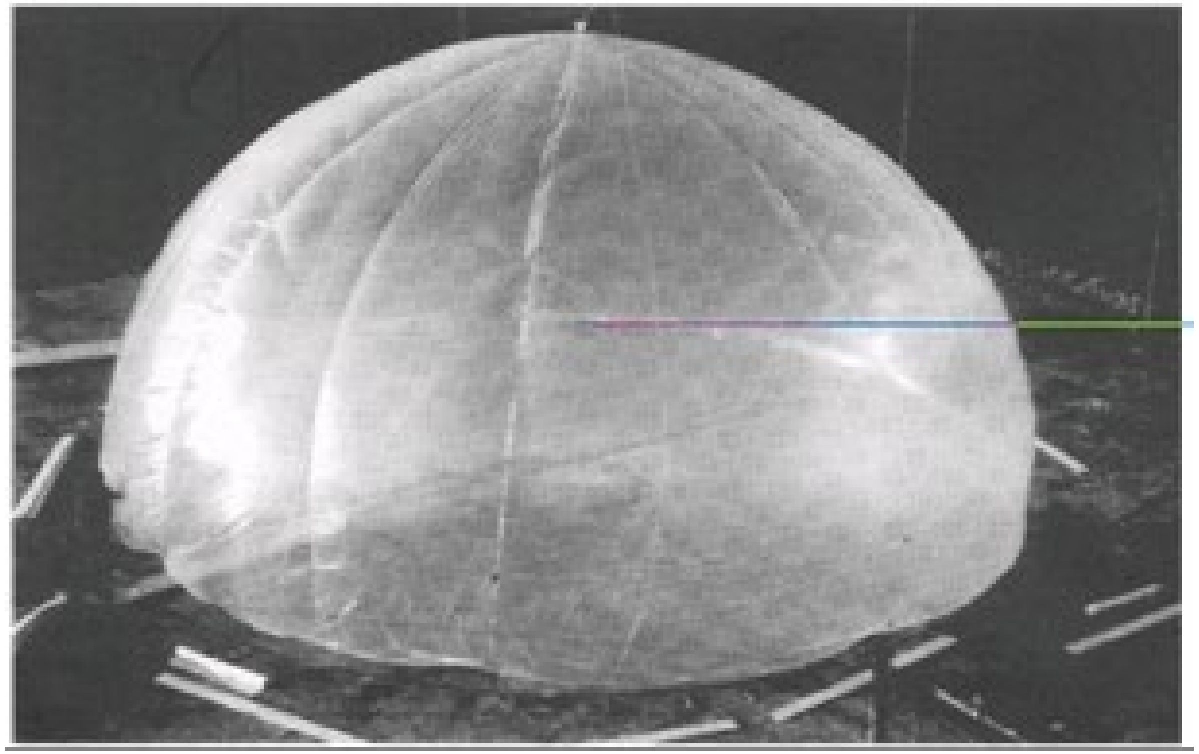
$$S_f = S_u \rho_u / \rho_b$$

Laminar combustion

- Typical laminar burning velocities
  - methane: 0.40 m/s
  - propane: 0.46 m/s
  - ethylene: 0.75 m/s
  - acetylene: 1.55 m/s
  - **hydrogen: 3.25 m/s**

- Expansion ratio typically 7-10 ($a=n_2T_2/n_1T_1$)

Intrinsic flame instabilities: DDT?



Ignition of optimal hydrogen-air mixture in 20m diameter balloon (Fh-ICT, 1982) resulted in max. 60 mbar overpressure

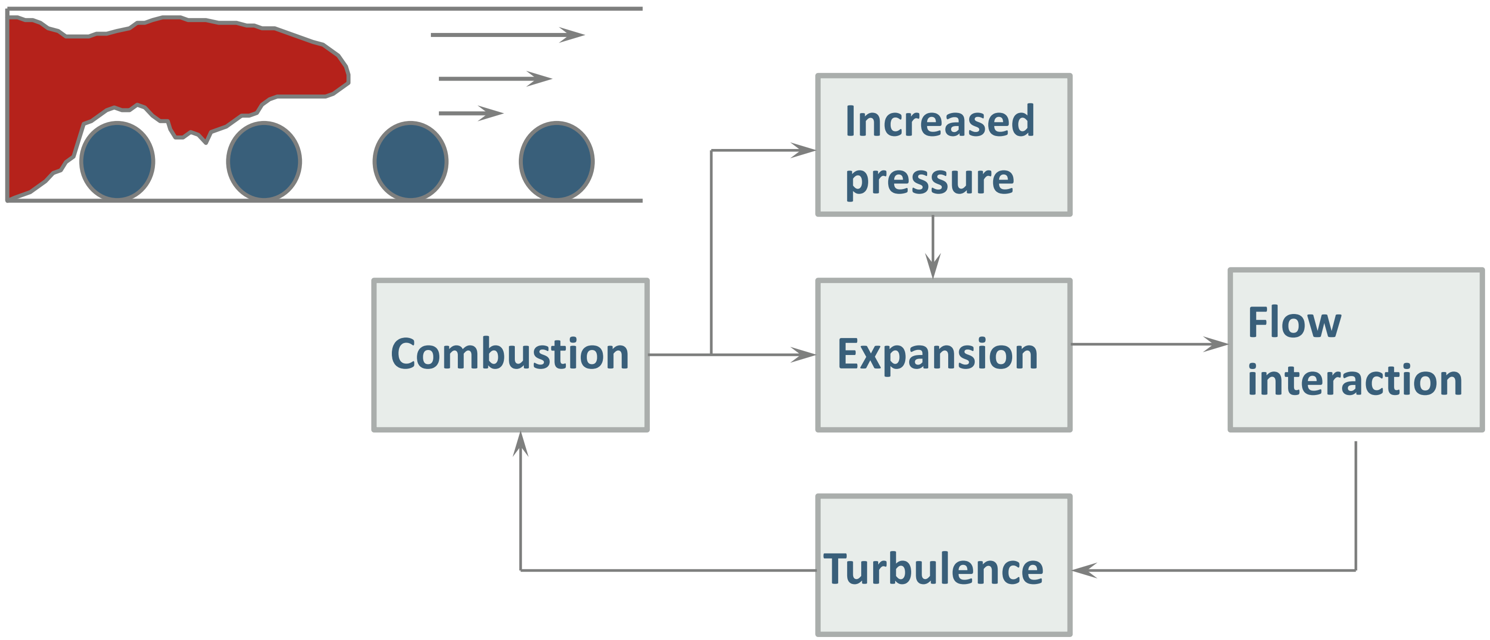
GEXCON

Turbulent combustion

- Turbulence causes an increase of burning velocities due to mixing of combustion products and reactants and due to an increase of the flame surface area
- Flame speeds (expansion + combustion) can vary from 5-600 m/s
- Flame Speed for Hydrogen (expansion + combustion) can vary from 27-600 m/s

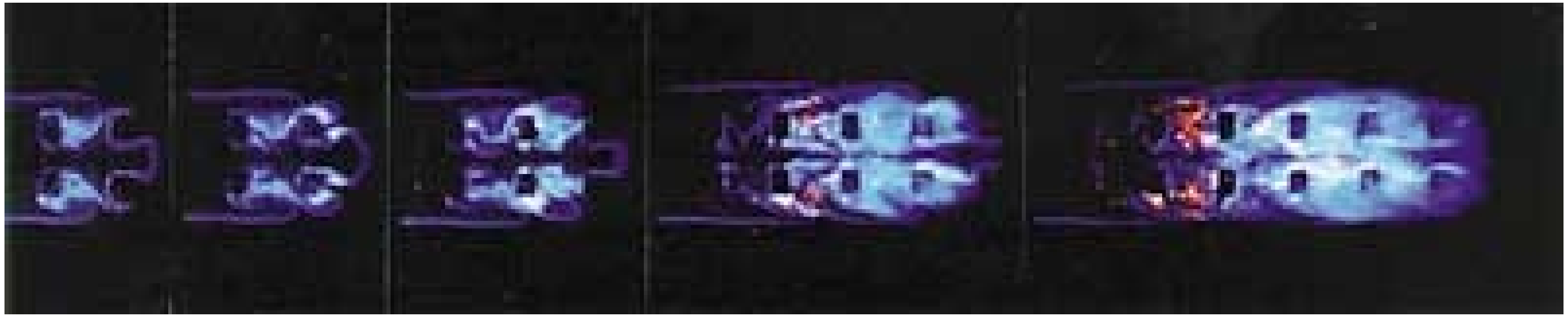
Explosion generated turbulence

Positive feedback mechanism of explosion generated flow and combustion

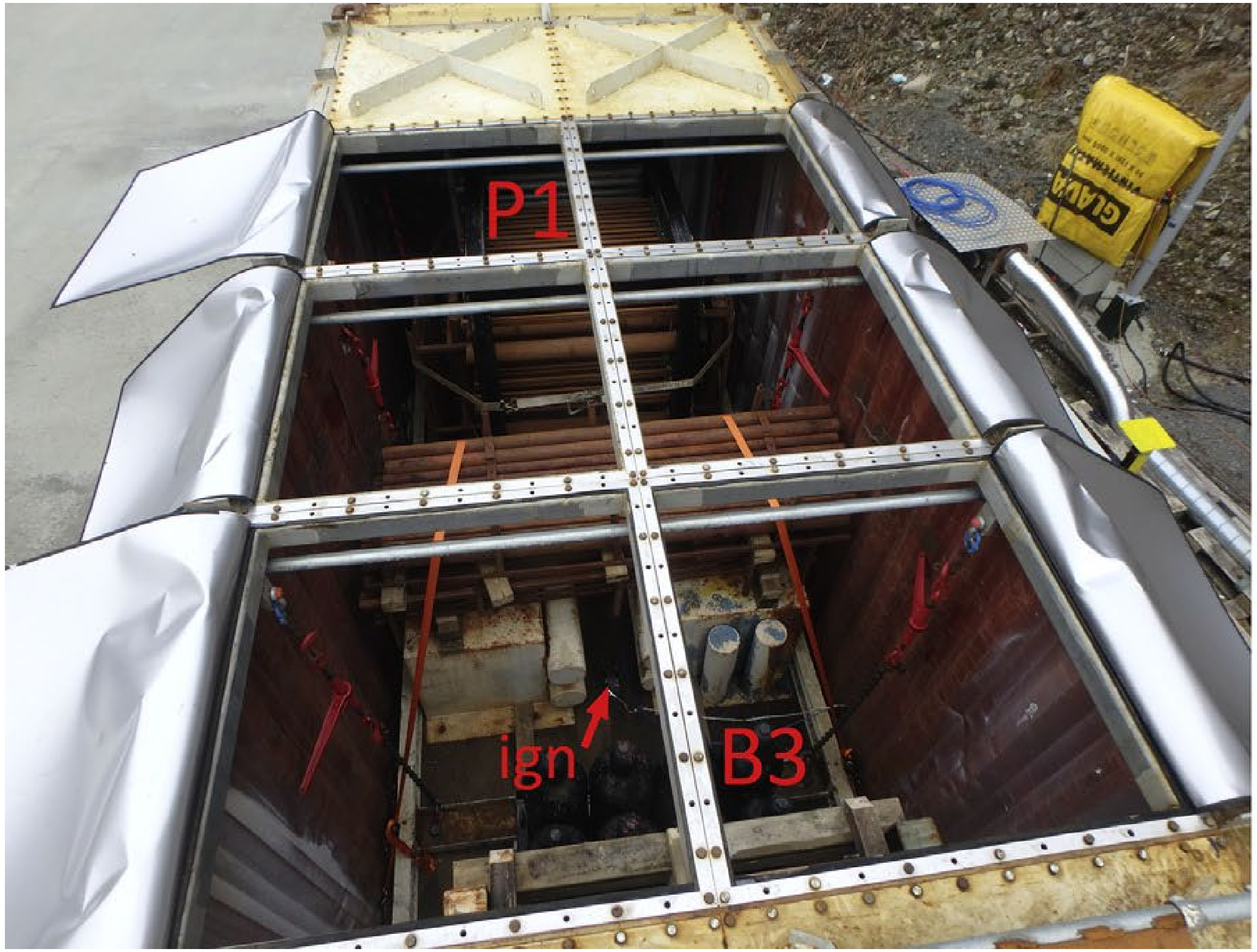


Explosion generated turbulence

Positive feedback mechanism of explosion generated flow and combustion



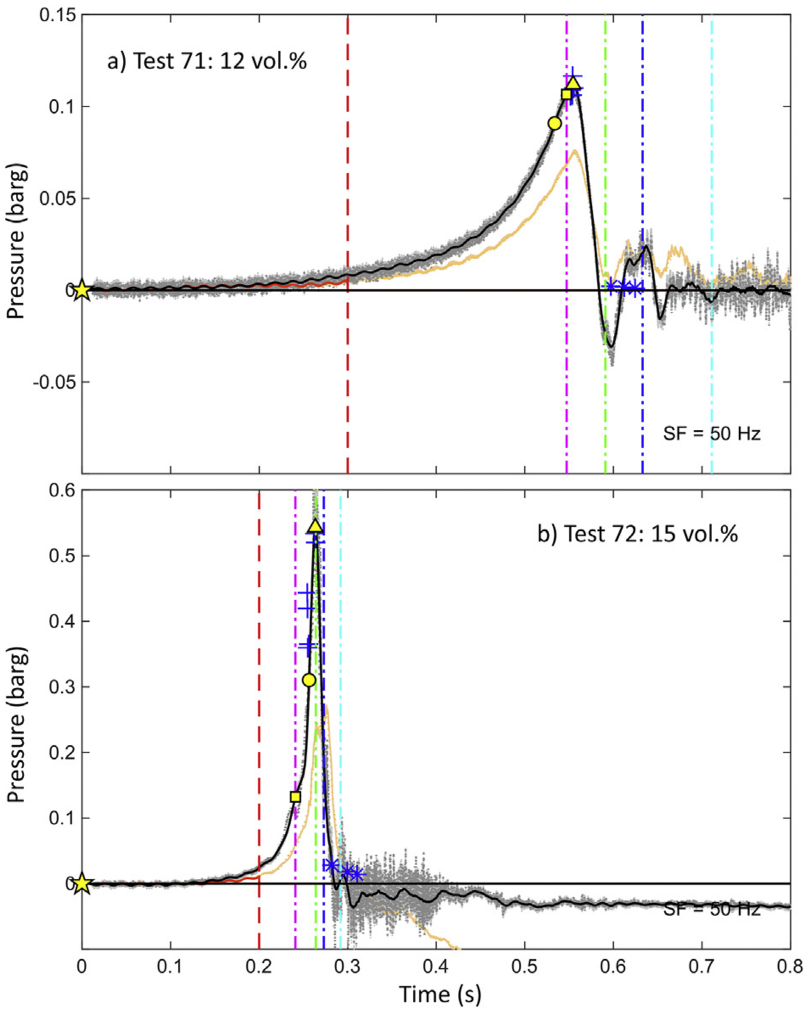
High congestion inside module



12 vol.% hydrogen, high congestion

15 vol.% hydrogen, high congestion

Comparison pressure-time histories



Ignition sources

- Electrostatics
- Frictional heat and sparks
- Spontaneous ignition

Electrostatic sparks

- Discharge occurs between two electrically **conducting** materials
- ”All” available energy is discharged
- Yield sparks having high energy-content
- Energy can be calculated from capacitance and potential difference

($E = ½ CV^2$), in practice max 1 J

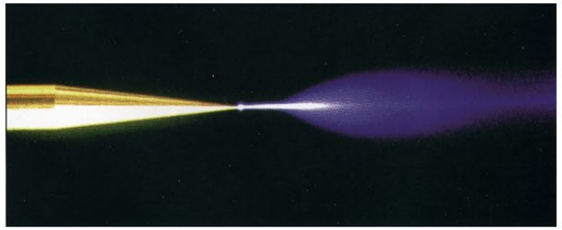
- Can be **avoided** by grounding and bonding of equipment to same electrical potential

Different electrostatic discharges

- Electrostatic sparks
- Corona discharge
- Brush discharge

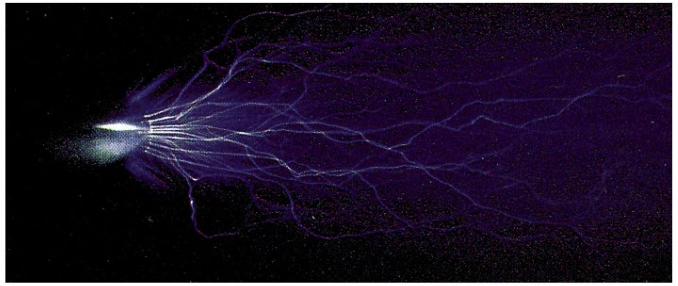
Corona discharge

- Occur when sharp/pointed conducting materials approach charged non-conducting materials
- Low energy-content
- Can lead to ignition of very ignition-sensitive gases like acetylene and hydrogen
- NOT able to ignite methane/propane



Brush discharge

- Usually occurs when rounded conducting materials approach charged non-conducting materials
- Only a limited part of the available energy is discharged
- Energy-content < 4 mJ
- Can ignite hydrogen, hydrocarbon gases and vapours



Electrostatic discharges

Summary

Type of discharge	*Incendivity*	
	Hydrogen MIE = 0.017 mJ	Solvents, hydrocarbon gases MIE > 0.025 mJ
Electrostatic spark	+	+
Brush discharge	+	+
Corona discharge	+	-

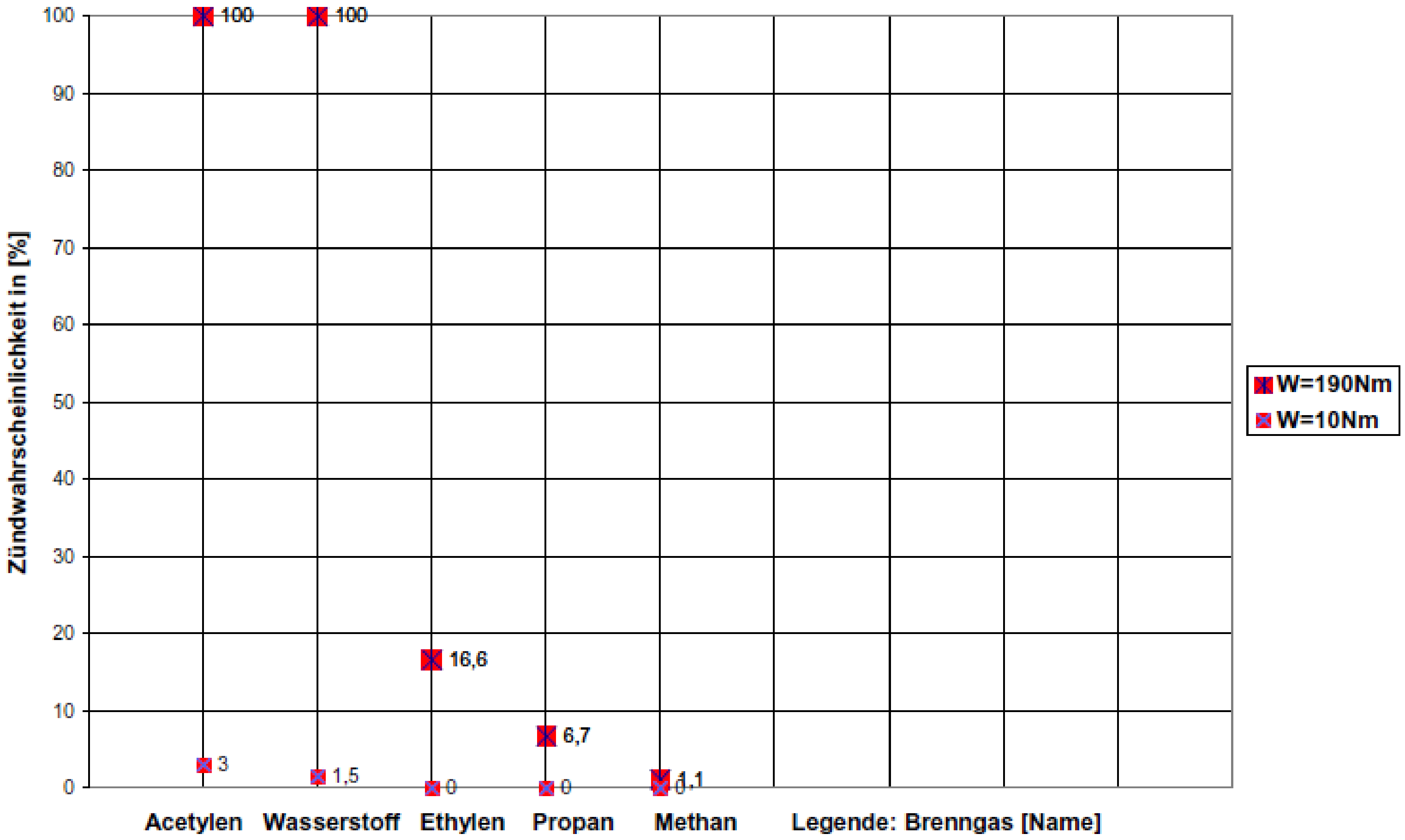
Theoretical spark energy

$E = \frac{1}{2} CV^2$

C = capacitance and V = voltage

Object	Capacitance (pF)	1/2 CV^2 (mJ) at various voltages		
		10 kV	20 kV	30 kV
Single screw	1	0.05	0.2	0.45
Flange (100 mm nominal size)	10	0.5	2	4.5
Shovel	20	1	4	9
Small container (bucket, 50 litres drum)	10-100	0.5-5	2-20	4.5-45
Funnel	10-100	0.5-5	2-20	4.5-45
Drum (~200 litres)	100-300	5-15	20-60	45-135
Person	***100-300***	***5-15***	***20-60***	***45-135***
Major plant items (large containers, reaction vessels)	100-1000	5-50	20-200	45-450
Road tanker	1000	50	200	450

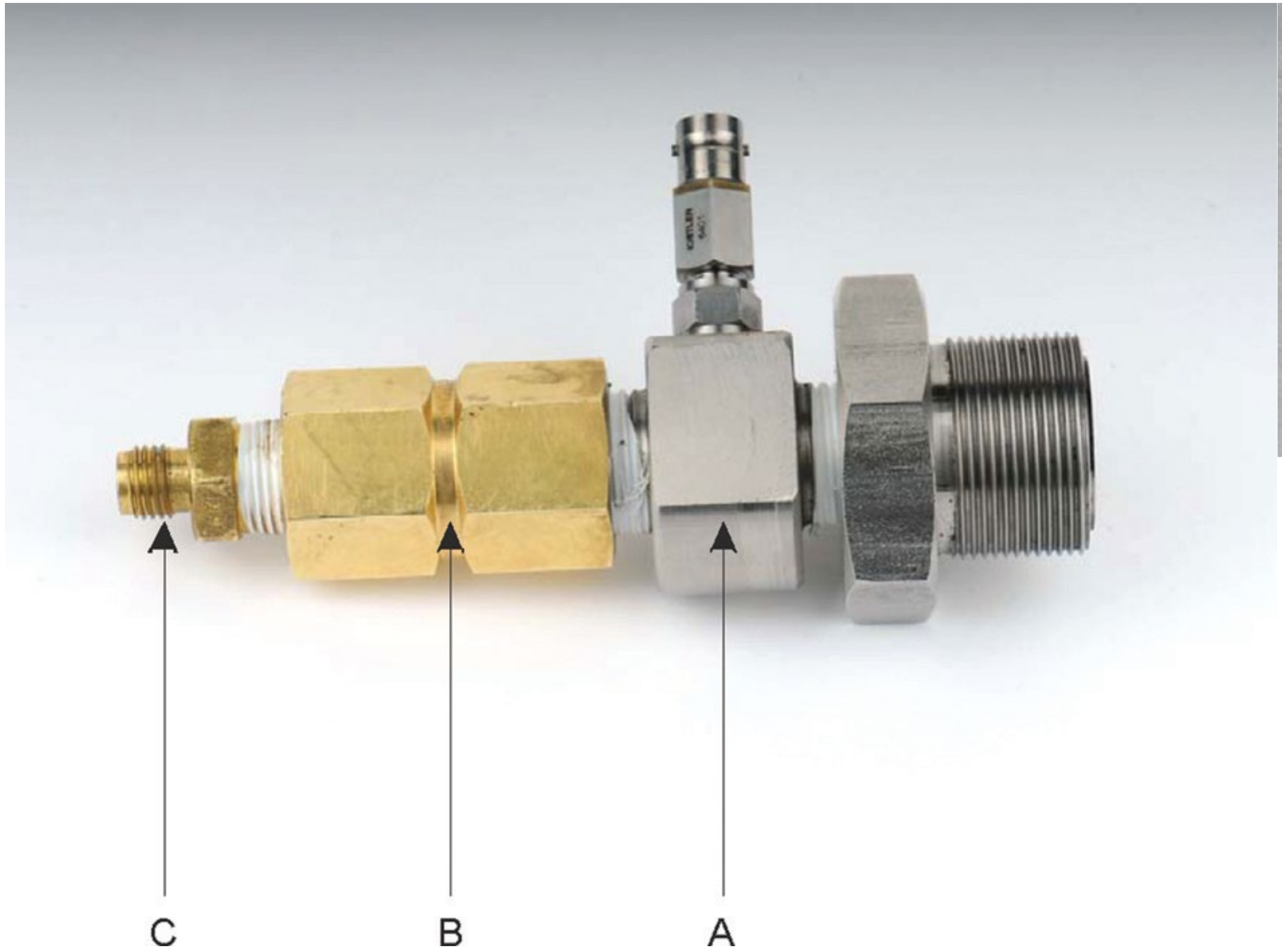
Incendivity single impact sparks (steel-steel) J=Nm



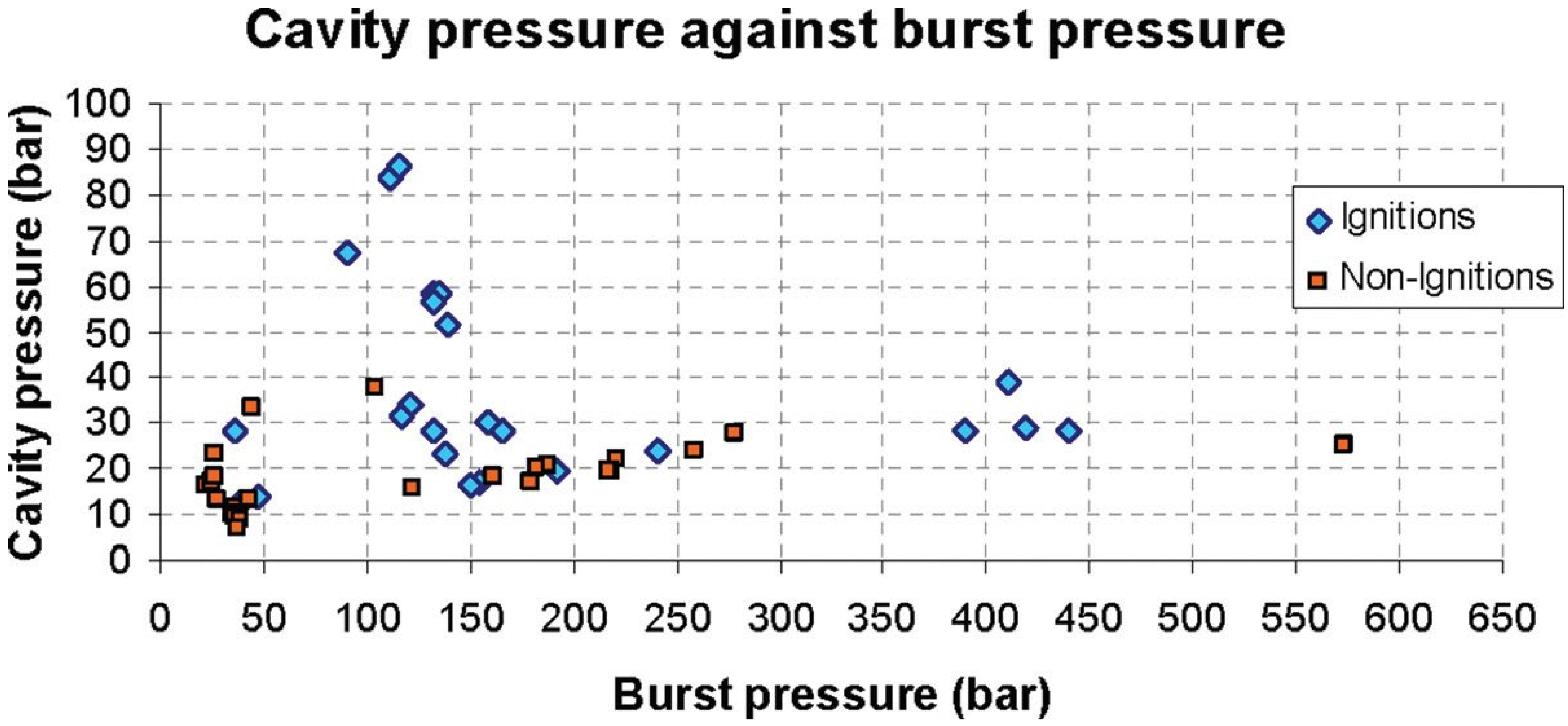
Spontaneous ignition: Experiments by HSL

(Hooker et al., 2011)

ID = 18.3 mm
Length > 300 mm



Conditions resulting in ignition/no ignition



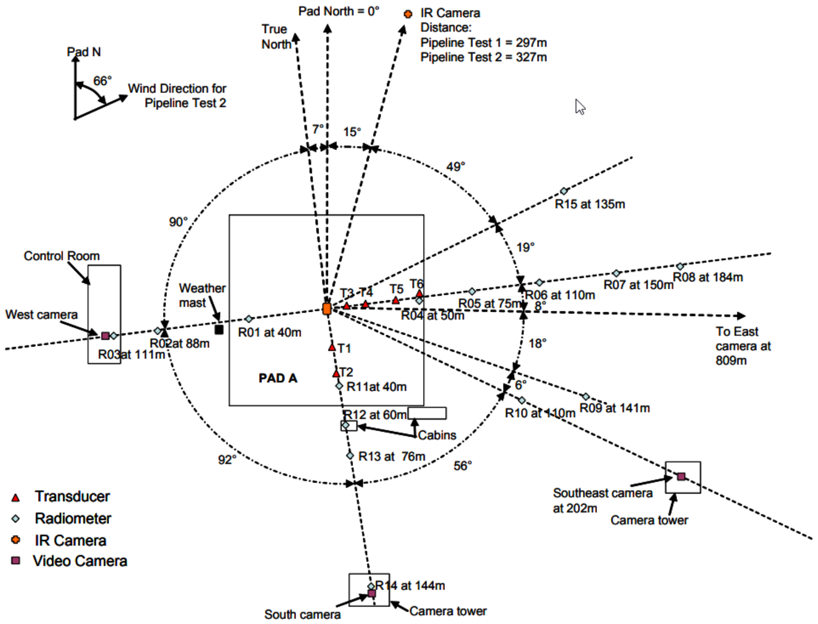
Findings

- With no brass fitting's part (B) & (C) to restrict or reflect the flow, there was no ignition up to 831 bar(g)
- The lowest disc burst pressure at which an ignition was obtained was 35.5 bar(g)

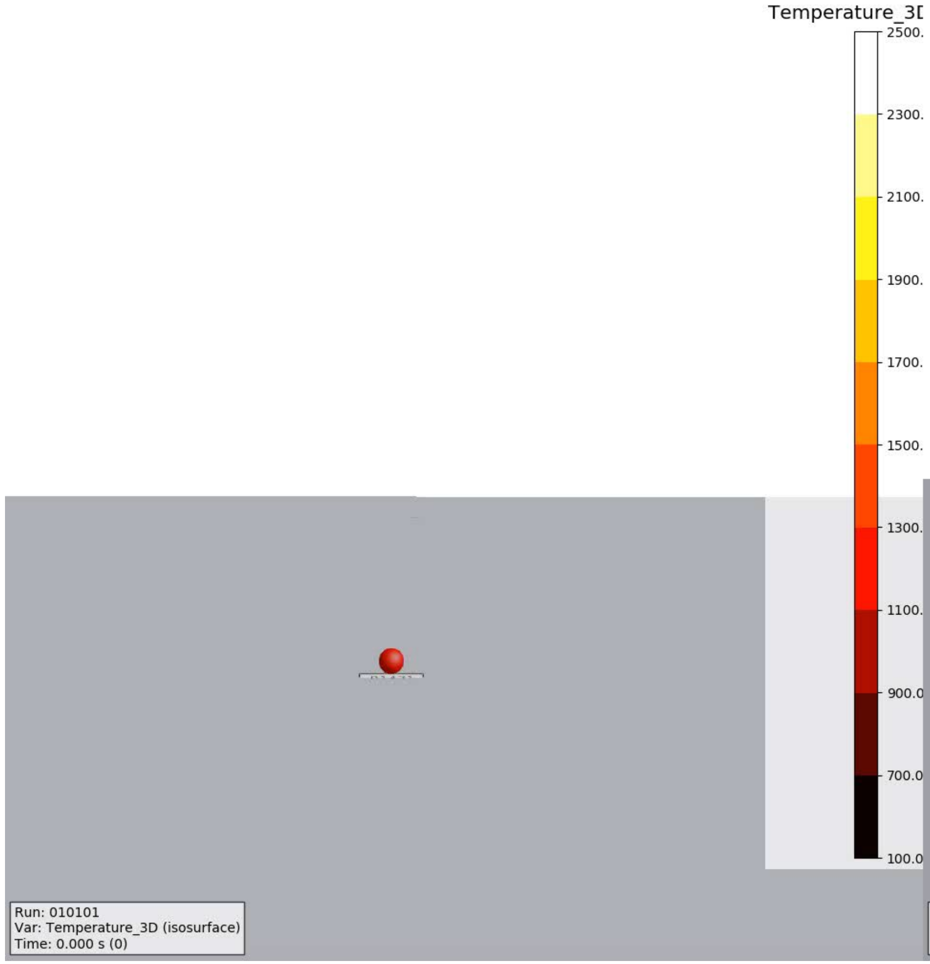
Pipe Rupture Cases

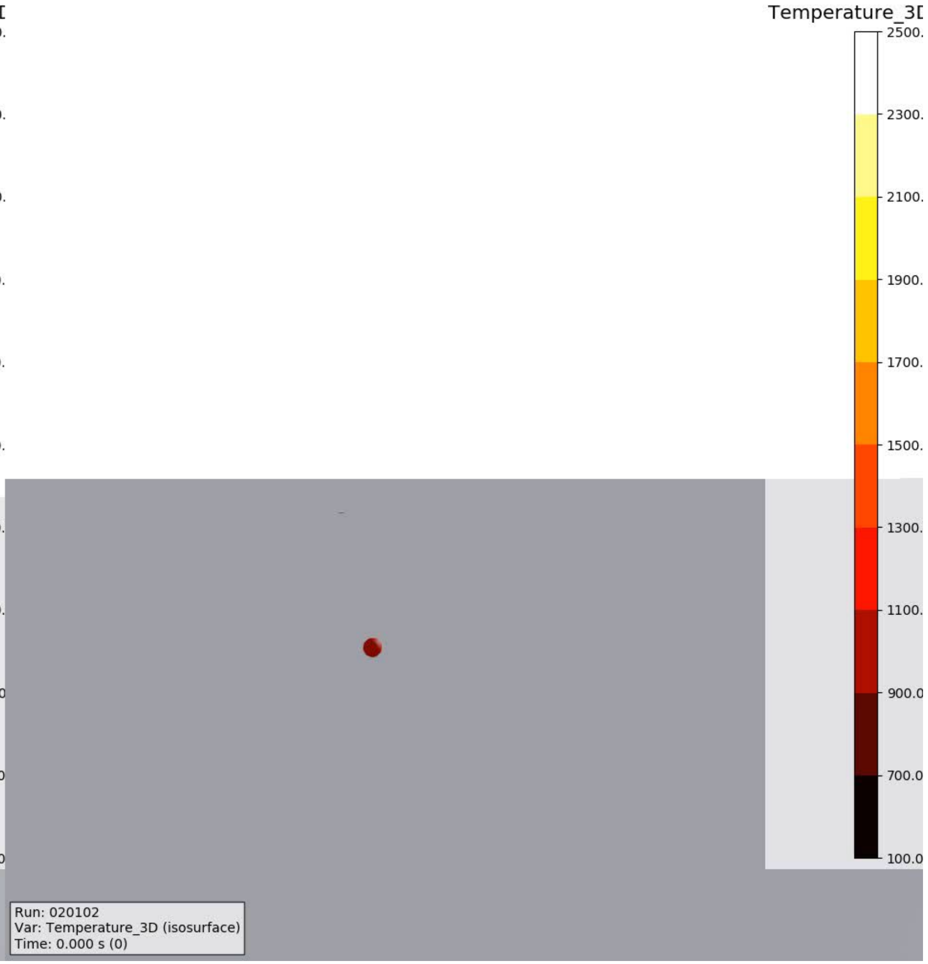
- The pipeline
  - Diameter of 150mm and
  - Gauge pressure of 70 bar
- The pipe was failed catastrophically by removing a 1.67m section using shaped high explosive charges, allowing gas to discharge from both ends of the severed pipe
- Two tests
  - Test 1: 75% natural gas & 25% hydrogen mixture
  - Test 2: natural gas

Condition	Test 1	Test 2
Fuel	77.5:22.5 ($NG:H_2$)	NG
Initial Pressure (barg)	71.4	70.5
Atmospheric Pressure (mbar)	997	1023
Relative Humidity (%)	88	88
Ambient Temperature (C)	3.4	3.5
Wind Direction	318 ±7	246 ±16
Wind Speed @2.9m (m/s)	1.4 ±0.3	4.8 ±0.3
Wind Speed @4.7m (m/s)	1.2 ±0.4	5.1 ±0.4
Wind Speed @8.4m (m/s)	2.0 ±0.3	5.6 ±0.3
Wind Speed @10.9m (m/s)	2.1 ±0.3	5.7 ±0.3



Pipe Rupture cases comparison





Burning velocities for methan and hydrogen mixtures

Laminar-burning velocities of hydrogen–air and hydrogen–methane–air mixtures: An experimental study

M. Ilbas[a,*], A.P. Crayford[b], İ. Yılmaz[a], P.J. Bowen[b], N. Syred[b]

[a]*Department of Mechanical Engineering, Erciyes University, 38039 Kayseri, Turkey*
[b]*School of Engineering, Cardiff University, CF24 OYF, Cardiff, UK*

Received 15 November 2005
Available online 14 February 2006

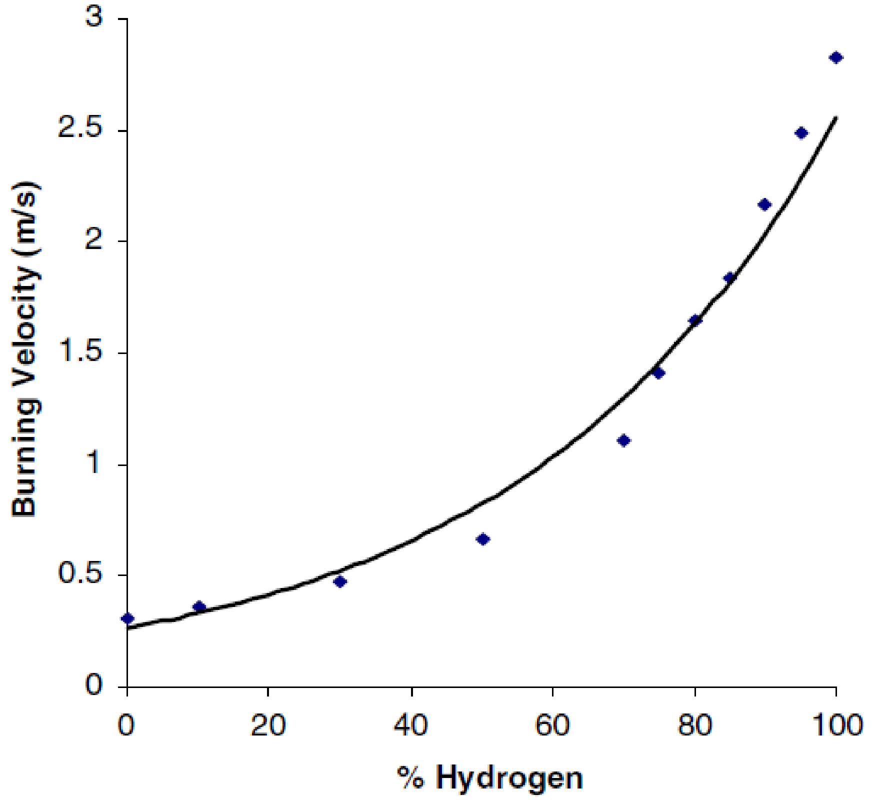


Fig. 16. Burning velocities for different percentage of hydrogen, $\varnothing = 1.0$.

Conclusions

- Light gas: reducing likelihood of generating large gas clouds in the open (unless liquified)
- Wide explosive range
- High reaction rate
- Easy to ignite by electrostatic sparks/discharges
- Relatively easy to ignite by mechancial sparks
- Less easy to ignite by hot surfaces
- «Spontaneous ignition» only possible in case of presence of obstructions in vicinity of leak position

Tack för din uppmärksamhet

Jonny Danielsson

Jonny.Danielsson@gexcon.com

Regionchef

Gexcon Fillial Sweden