7 December
2023

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VP Industrial risk

Vysus Group

Ignition of hydrogen releases. What can we do to prevent it from happening?

Our legacy and global scale

We are a leading, independent provider of digitally enabled, engineering and technical consultancy expertise, supporting owners and developers of energy, power and complex industrial assets and infrastructure.

Established in November 2020 from the sale of the Lloyd's Register Energy division to Inspirit Capital, we have amassed a wealth of deep technical and regulatory expertise.

80+ years

Heritage

1930 – Lloyd's Register Energy

2005
- Capstone
- ODS

2008
- Human Engineering
- Celerity3
- ModuSpec

2010
- Scandpower

2012
- West Engineering

2013
- Senergy

2020 – Vysus Group

2021
- Promaps Technology

Our services

Asset Management Consulting

Improve reliability, optimizing production, reducing cost and increasing profitability.

Drilling Rig Integrity and Assurance

ModuSpec ensures the integrity, reliability and optimization of your drilling, completions and intervention equipment and systems.

Survey and GeoEngineering

Navigate hazards and avoid risks with accurate offshore subsurface surveys, ensuring confidence in your offshore construction and decommissioning projects.

Risk Management

Our services help control risks to life, the environment and assets, ensuring compliance to regulatory and market requirements.

Well Engineering, Operations and Project management

Enhance the planning and performance of well operations, from initial conceptual well design through to well construction and ultimate suspension or abandonment.

Energy Transition

Power the transition to clean energy by reducing project risk and optimising the asset performance of your transition and renewable assets.

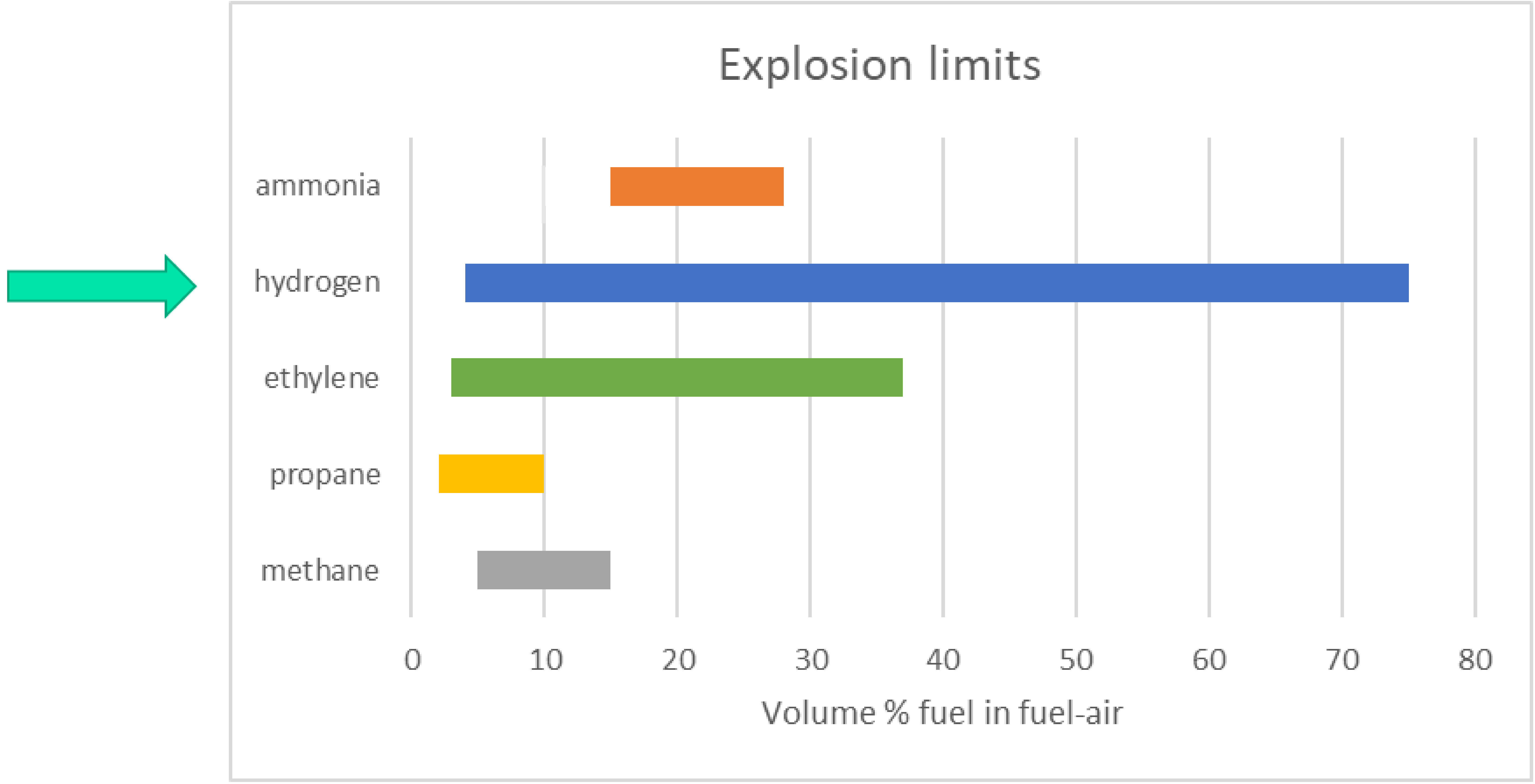
Grid Connection

Manage the integration of complex power systems into grid infrastructure to ensure stability and maximise power throughout. Accurately monitor and predict disruption in electricity grid systems with advanced real-time risk calculations using our power system reliability software, Promaps^{TM}.

Contents

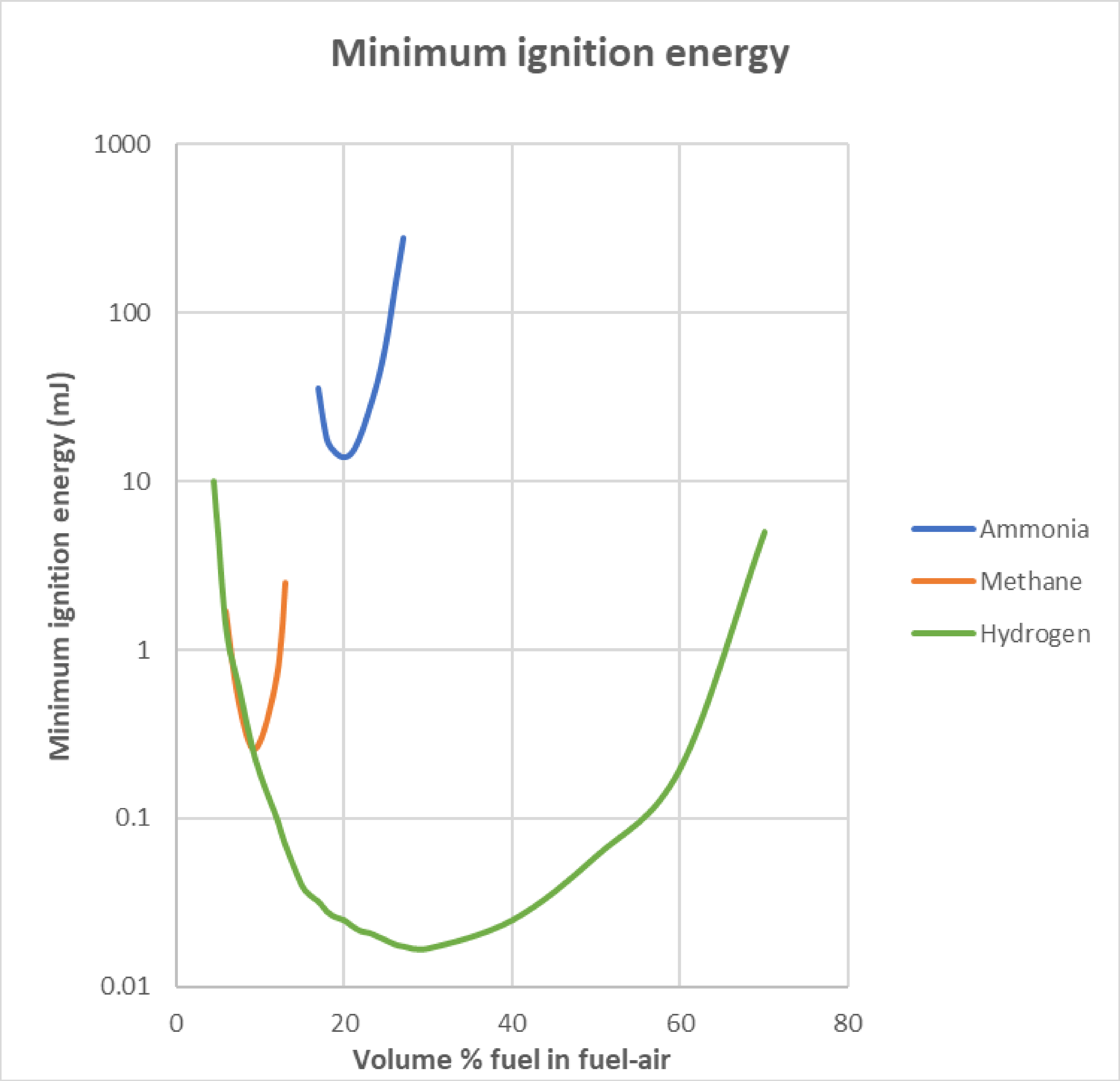
Hydrogen properties

Explosive part of cloud



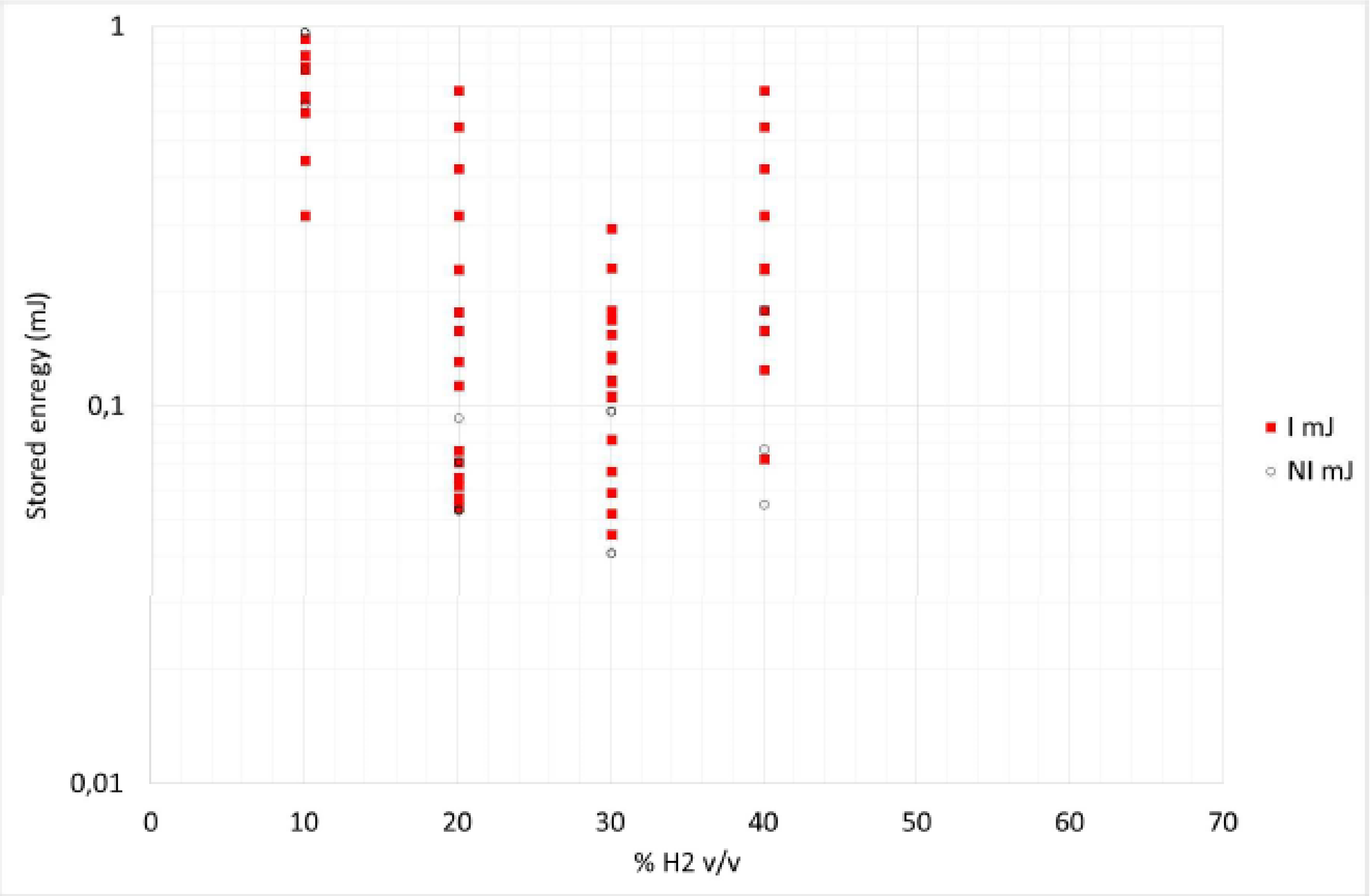
Minimum ignition energy and explosion limits: hydrogen vs methane

Minimum energy of an electrical spark able to start combustion



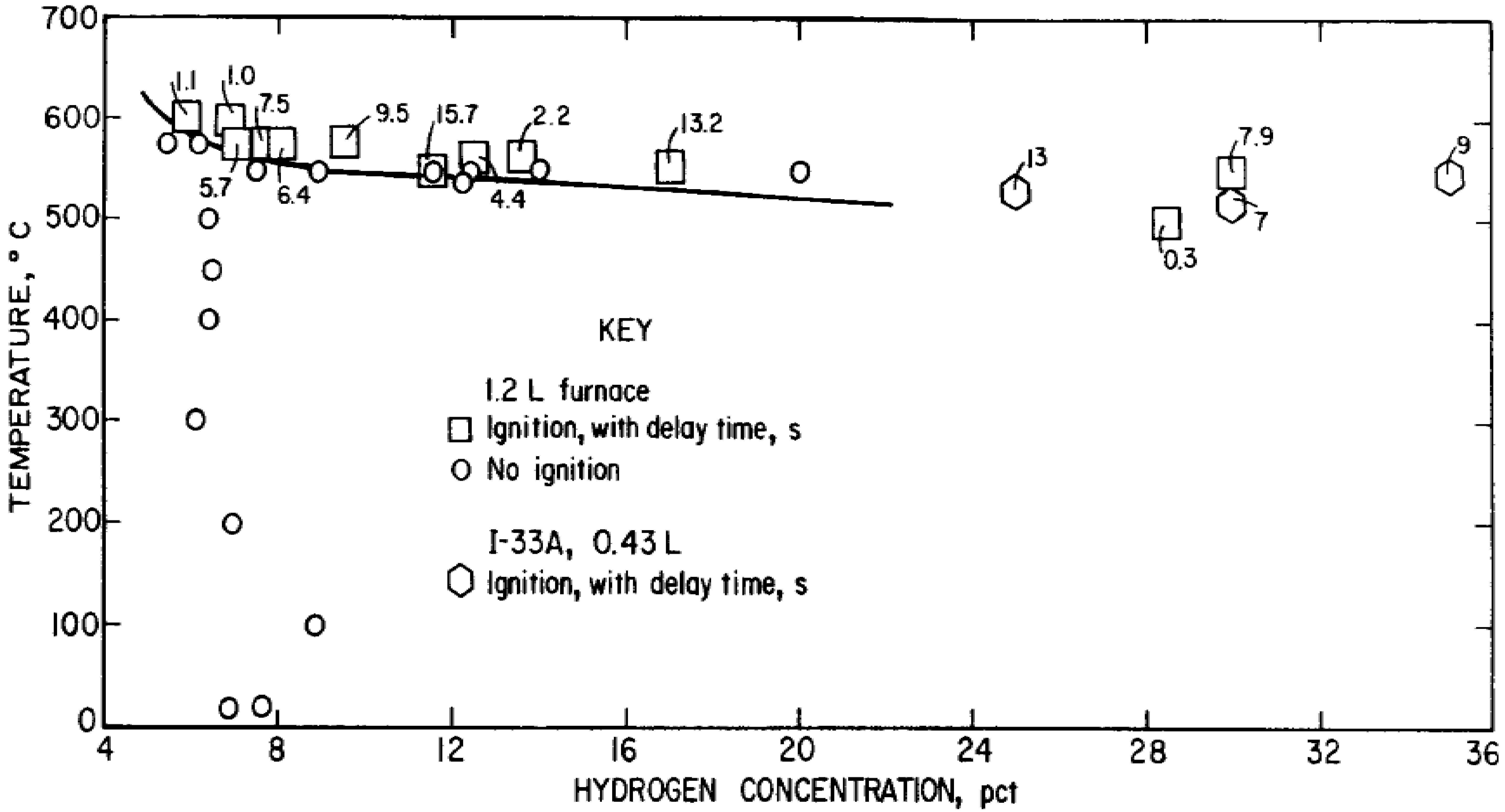
Minimum ignition energy
Ammonia: 14 mJ
Methane: 0.26 mJ
Hydrogen: 0.017 mJ

Minimum ignition energy H2-air at -100 °C = 50 µJ



Proust_2018

Auto-ignition temperature



Conti,1988

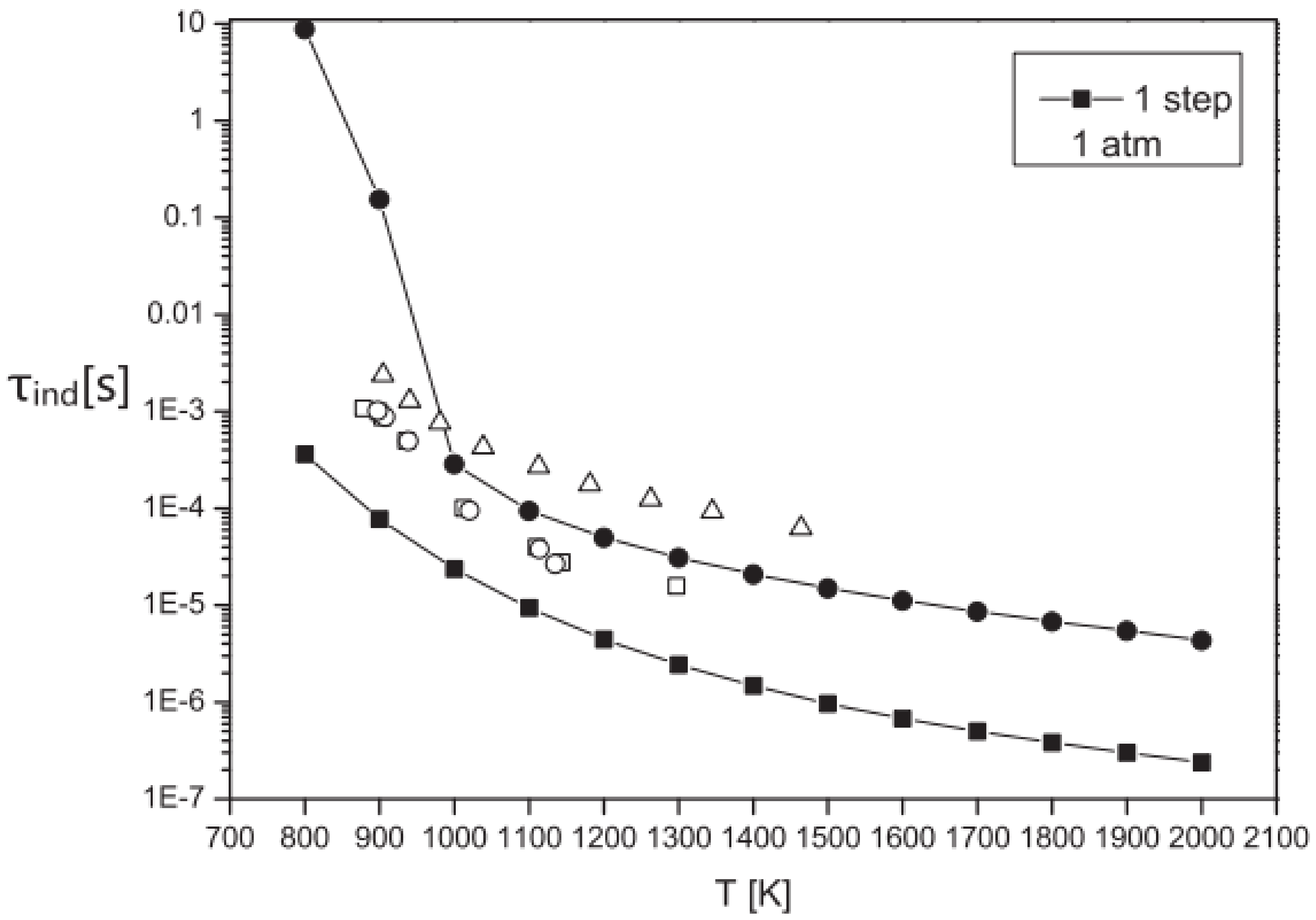
Auto-ignition temperature:

Hydrogen: 520 °C

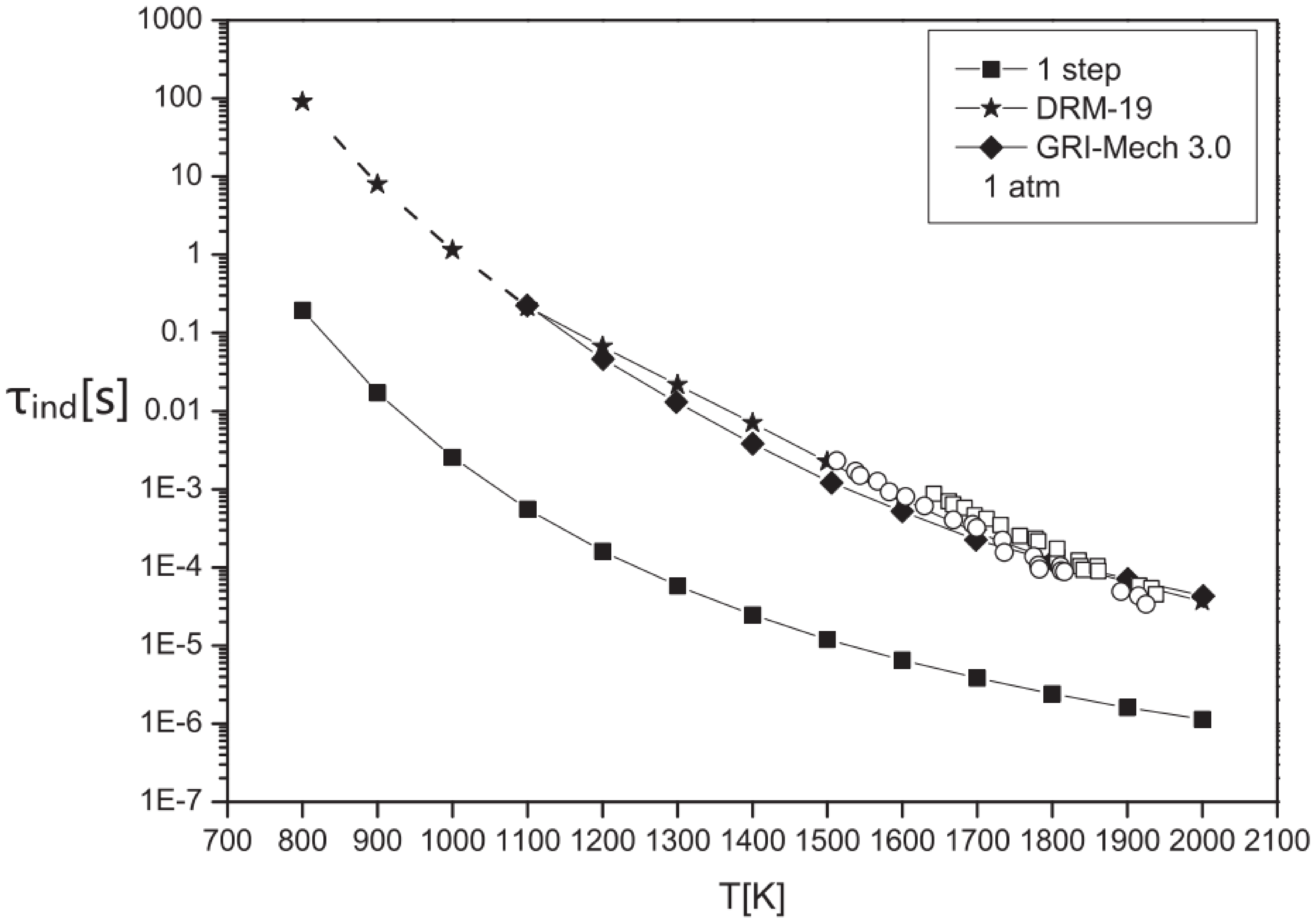
Methane: 600 °C

Ammonia: 650 °C

Induction time



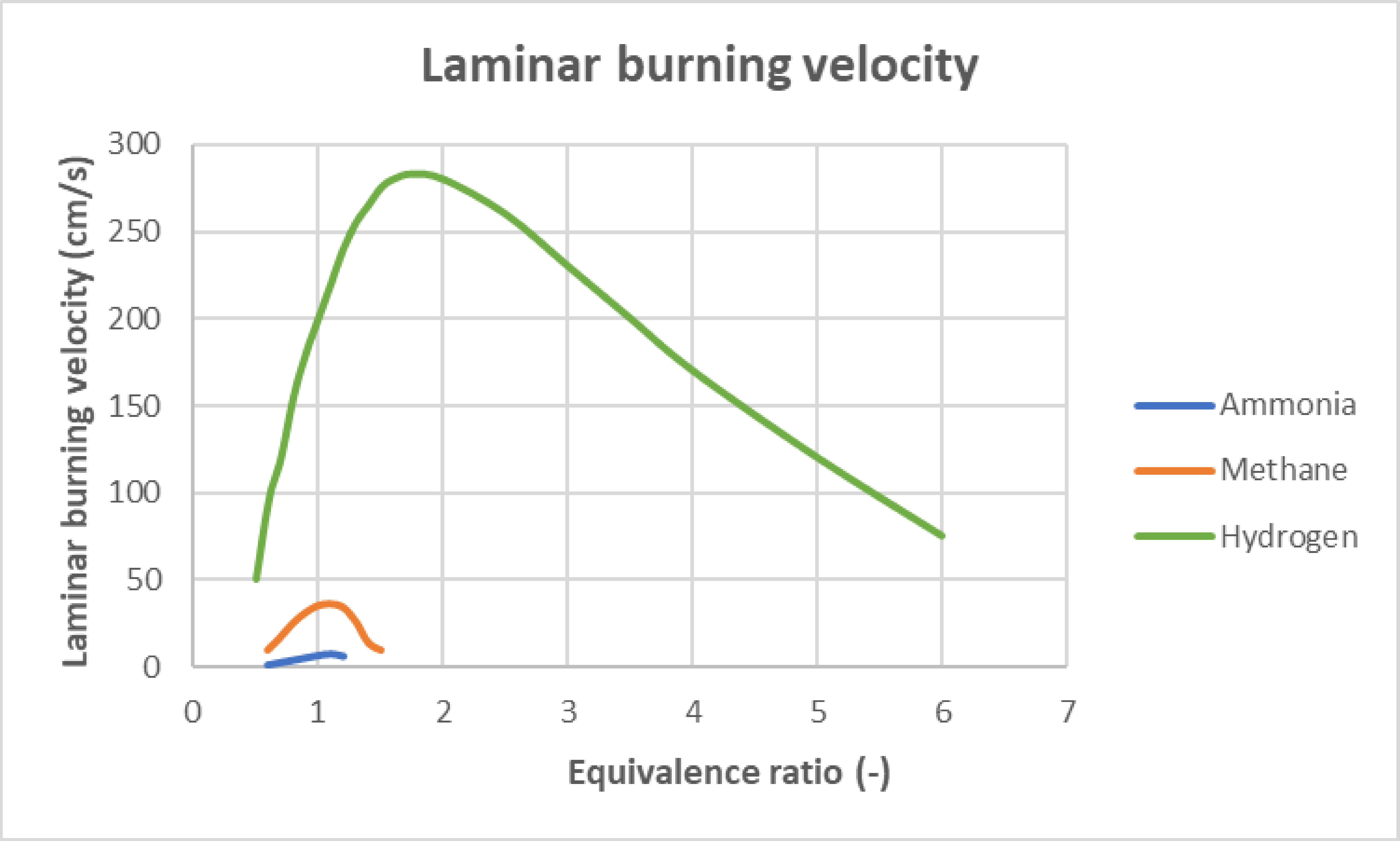
Hydrogen



Methane

Libermann_2018, the “open data points” in the graphs are experimental data

Laminar burning velocity



Laminar burning velocity:

Hydrogen: 286 cm/s

Methane: 36 cm/s

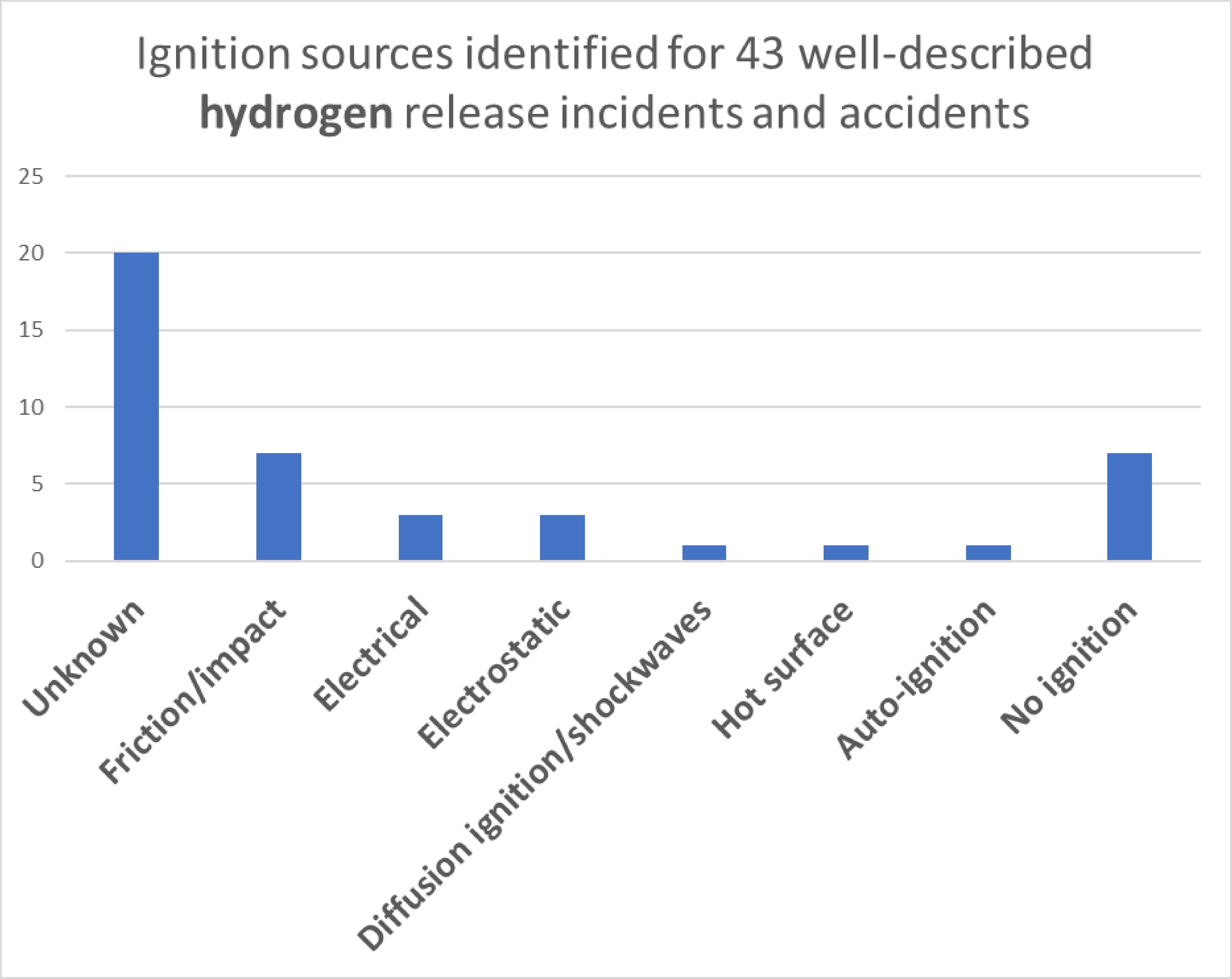
Ammonia: 8 cm/s

Ignition sources

Ignition sources – EN 1127-1:2019

- **Hot surfaces**
- Flames and hot gases
- **Mechanical sparks**
- **Electrical equipment**
- **Static electricity**
- Lightning
- Exothermic reactions & self-ignition
- Radio frequency waves
- **Electromagnetic waves**
- Ionizing radiation
- Ultrasonics
- **Adiabatic compression**
- Stray electric currents

Accident review: which ignition sources were identified?

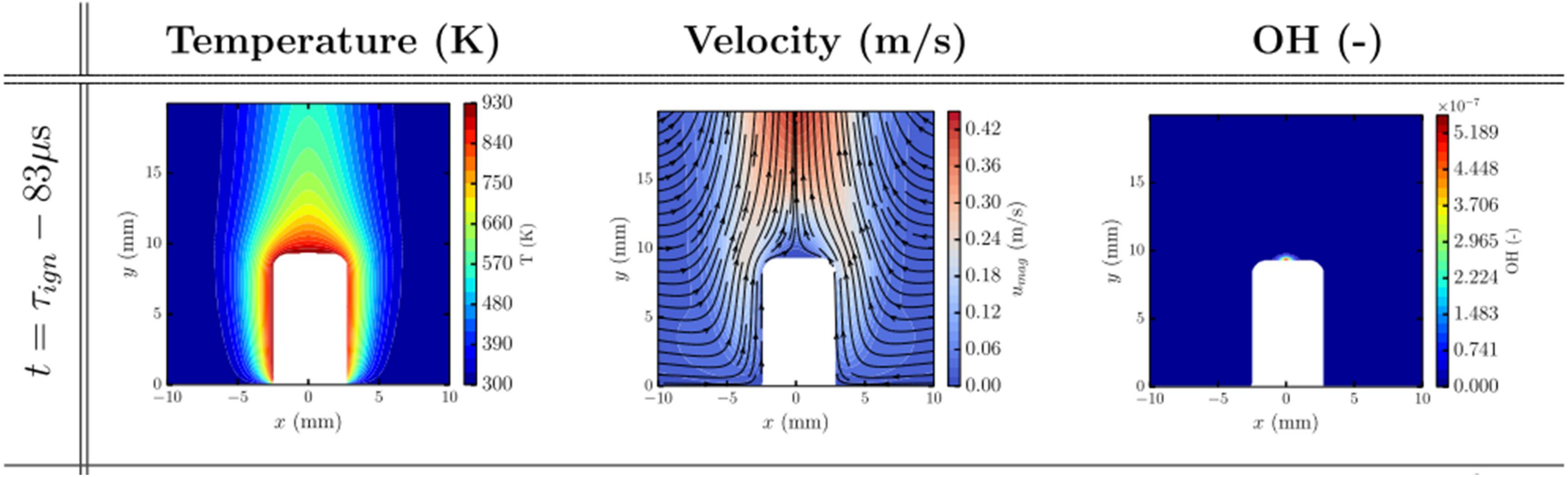


Hot surfaces

Hot surfaces

- Flow conditions at surface (heat transfer) and induction time are the decisive physical parameters for ignition (contact time vs induction time)
- Ignition occurs when enough energy has been transferred to local volume of the premixed cloud
- Practical situations
  - Faulty equipment with excessive temperature above AIT (e.g. pump)
  - Material heated due to maintenance activity in area (e.g., welding)
  - Equipment parts heated due to friction
  - Objects with high surface temperature under normal operation (e.g. gas turbines, exhaust duct, heating equipment, electrical equipment)

Ignition by hot surfaces

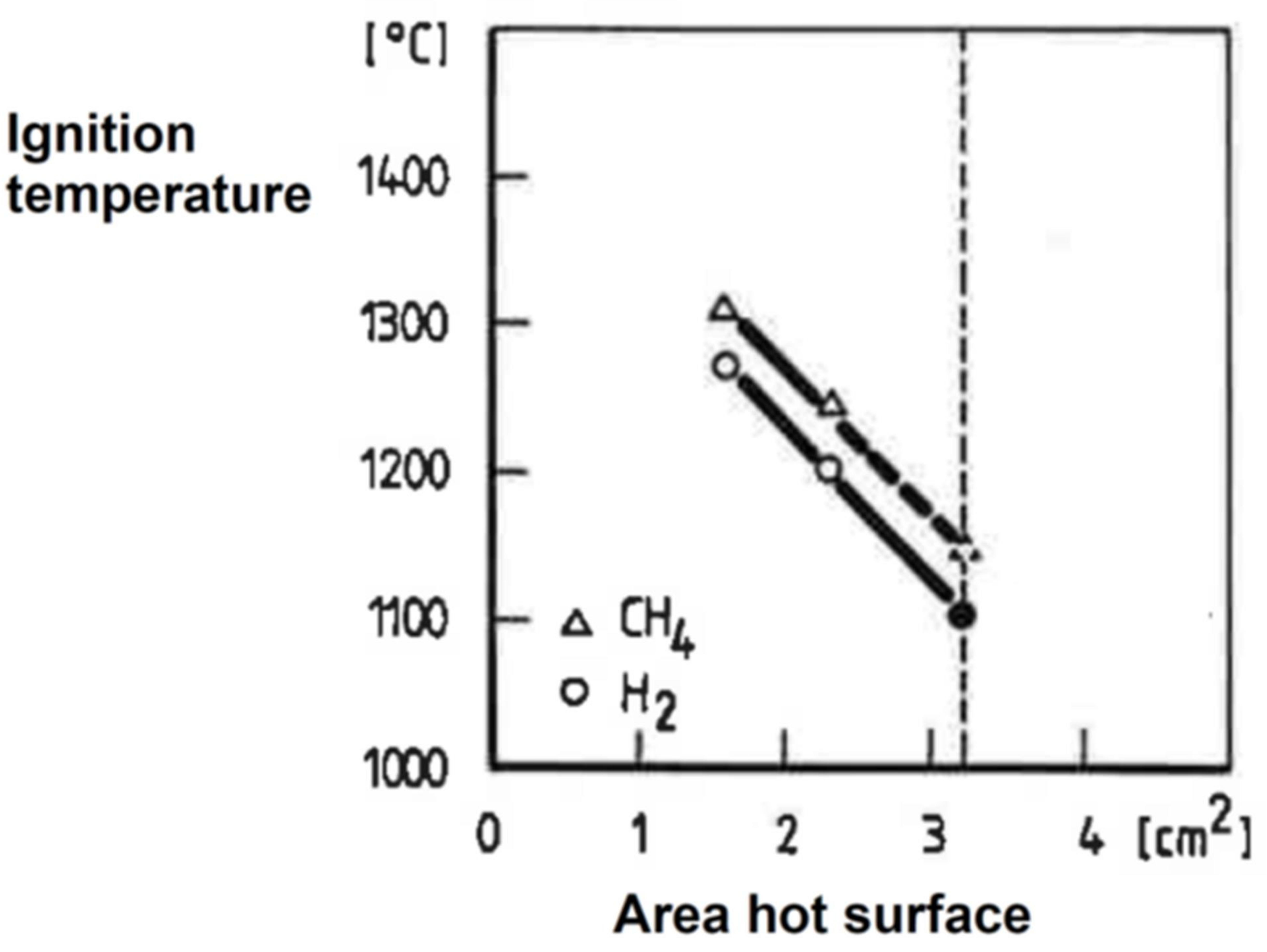


Glowplug of height 9.3 mm, and diameter 5.1 mm

Surface temperature ~938 K

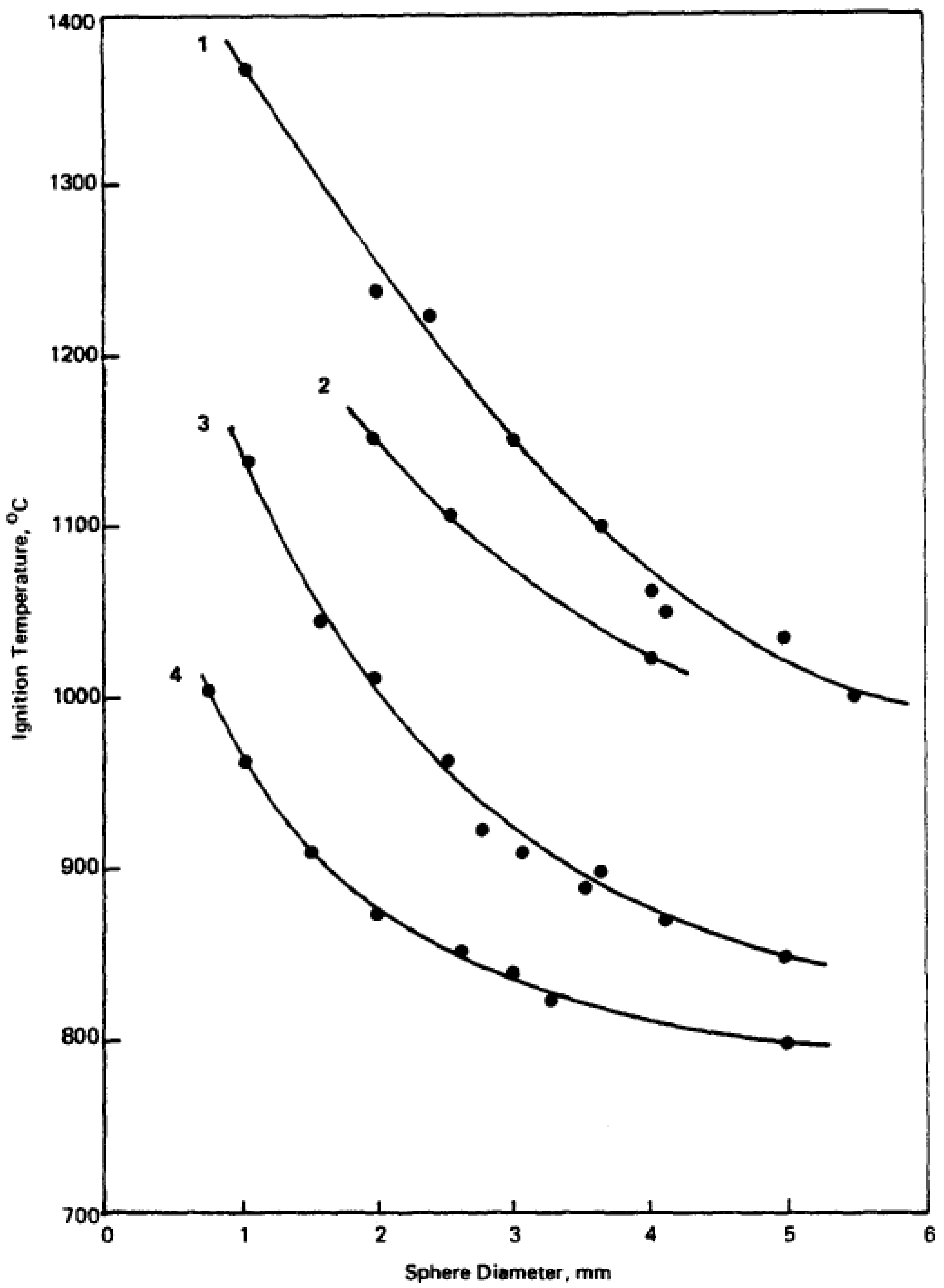
Melguizo-Gavilanes, 2017

Effect of hot surface area (flow conditions)



Bartknecht, 1993

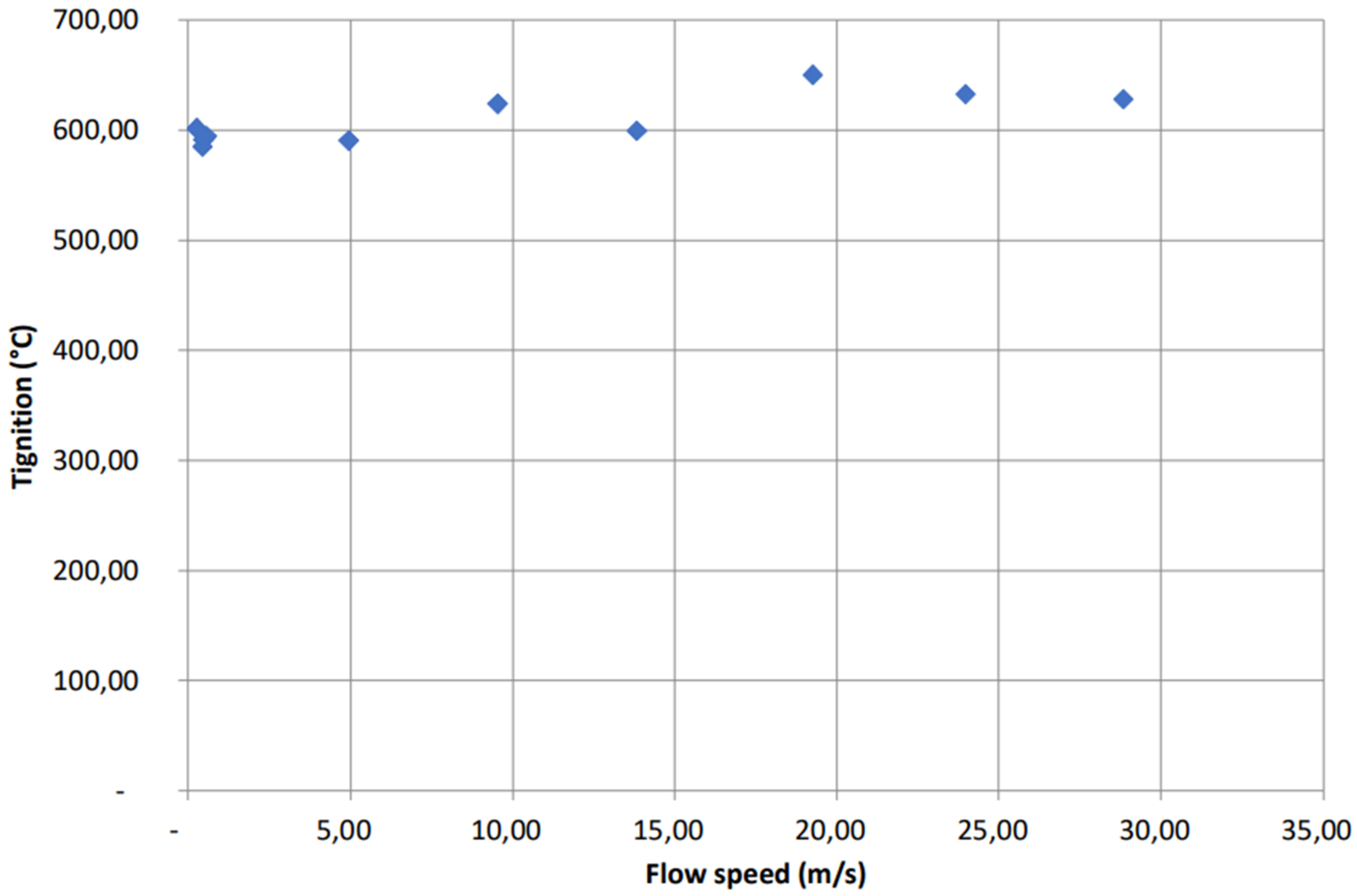
Ignition temperature at spheres



Laurendeau_1982

4= coal gas-air mixture at 1.2 m/s

Effect of flow velocity over hot surface on ignition temperature



Proust, 2019

Preventive measures

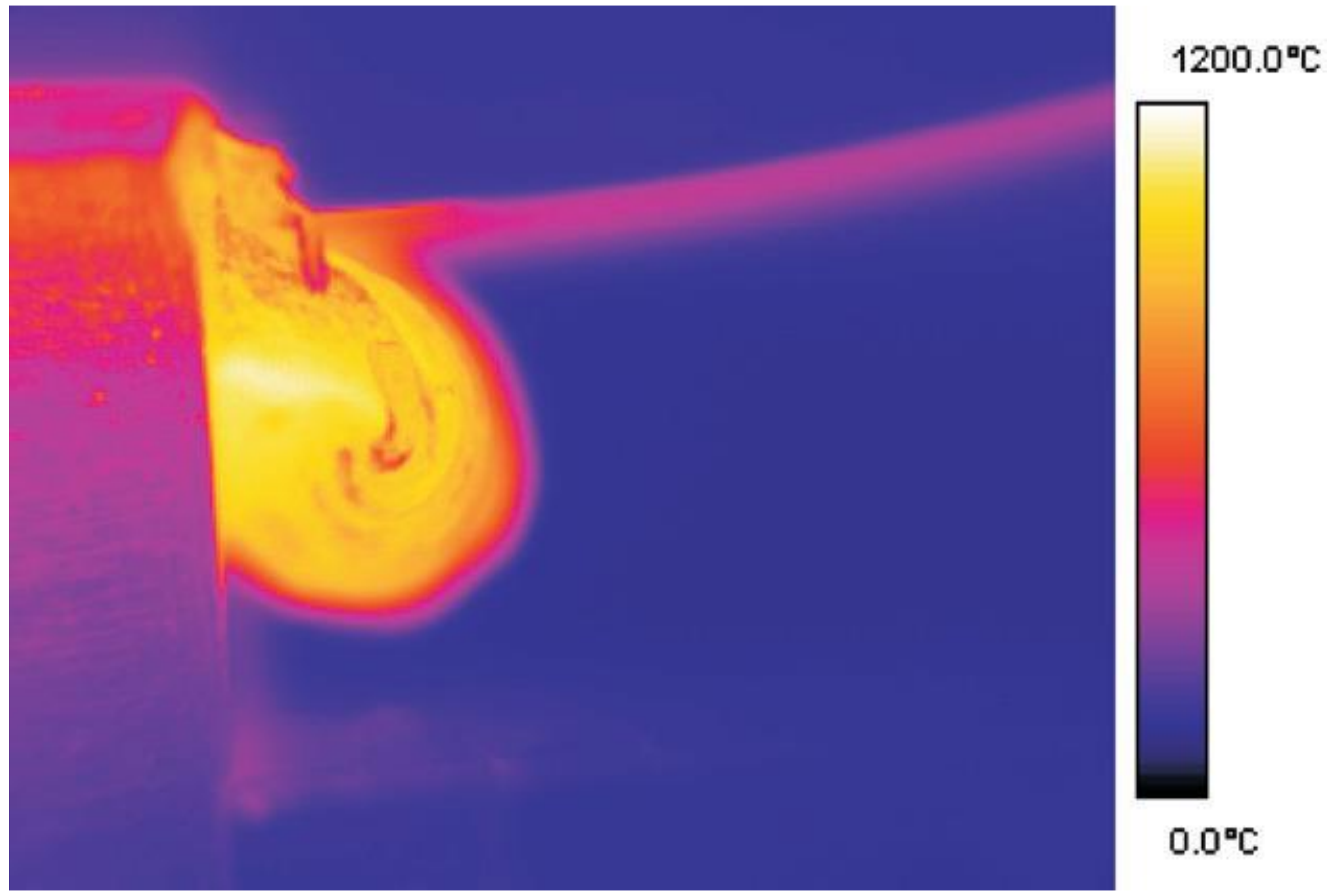
- Choose equipment with maximum temperature below AIT
- Hot surface ignition temperature small hot surfaces is higher but depends on local flow velocities and confinement
- More research is necessary to understand effect of flow speed and hot surface ignition temperature
- Good maintenance is important
- Hot work permits

Mechanical friction and impact

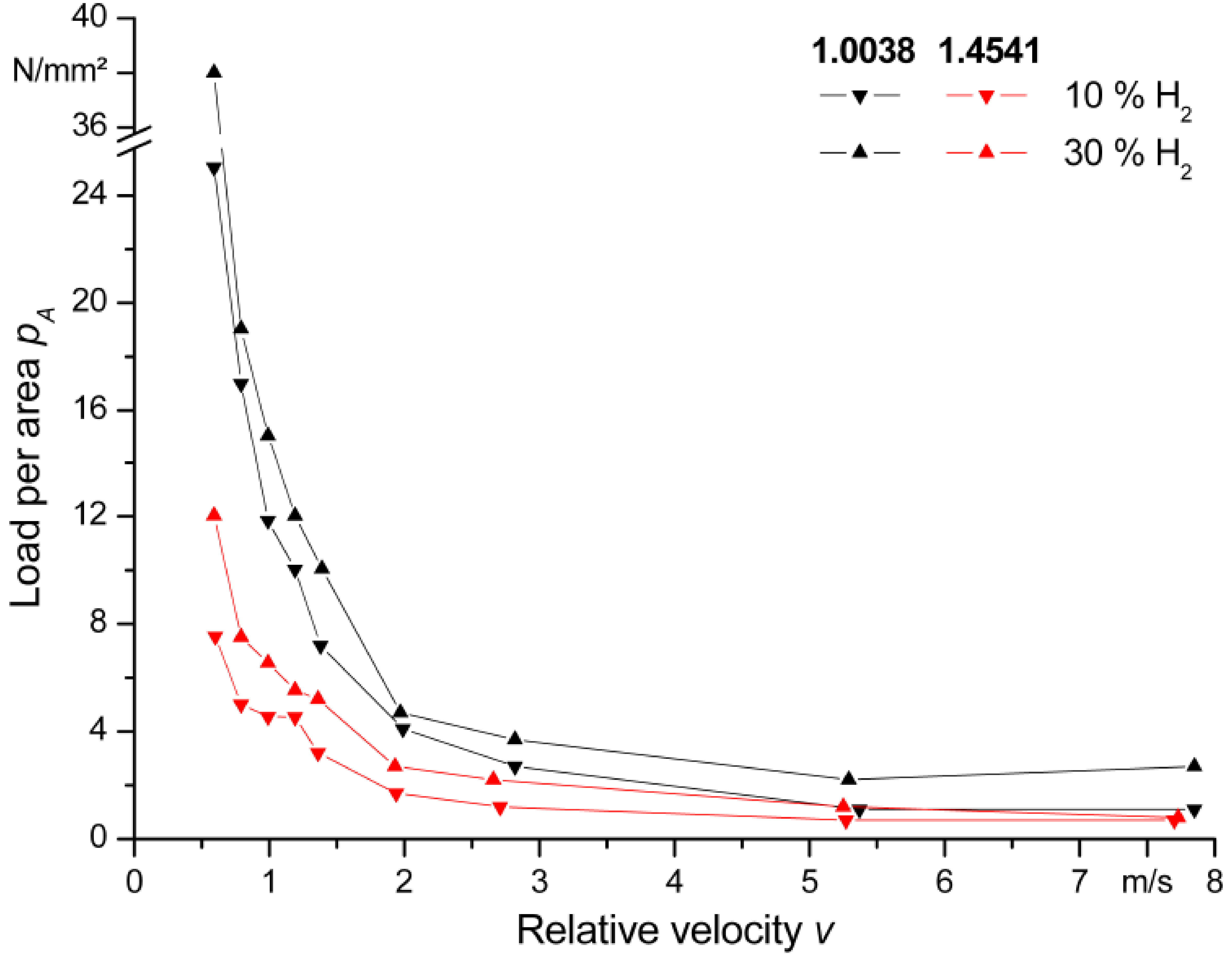
Ignition by mechanical friction or impact

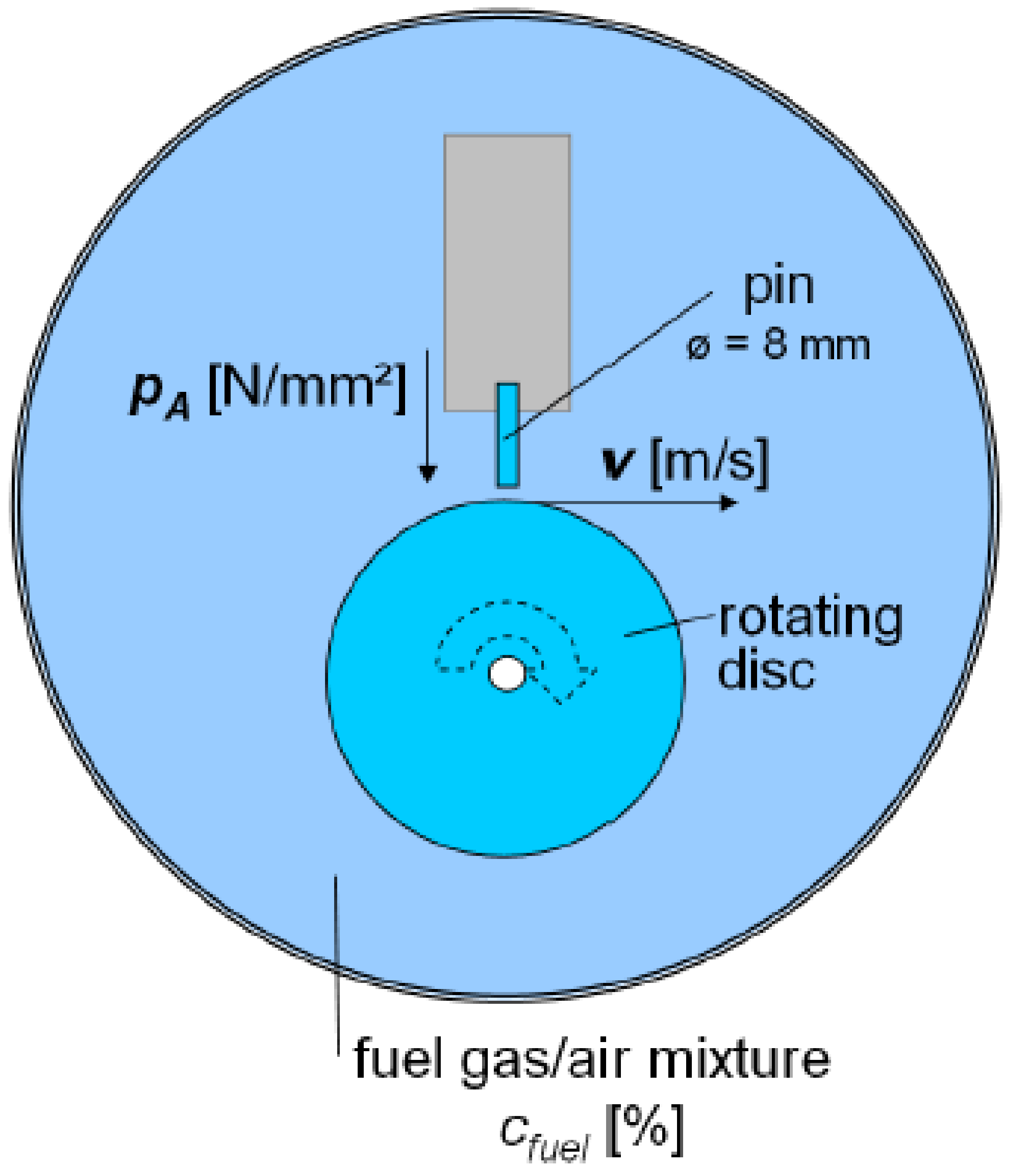
- Arises due to friction between two moving objects or due to a collision (single impact).

- Two potential ignition sources can occur:
  - Mechanical sparks (frictional sparks)
  - Hot surfaces



Mechanical friction: hot surfaces and mechanical sparks

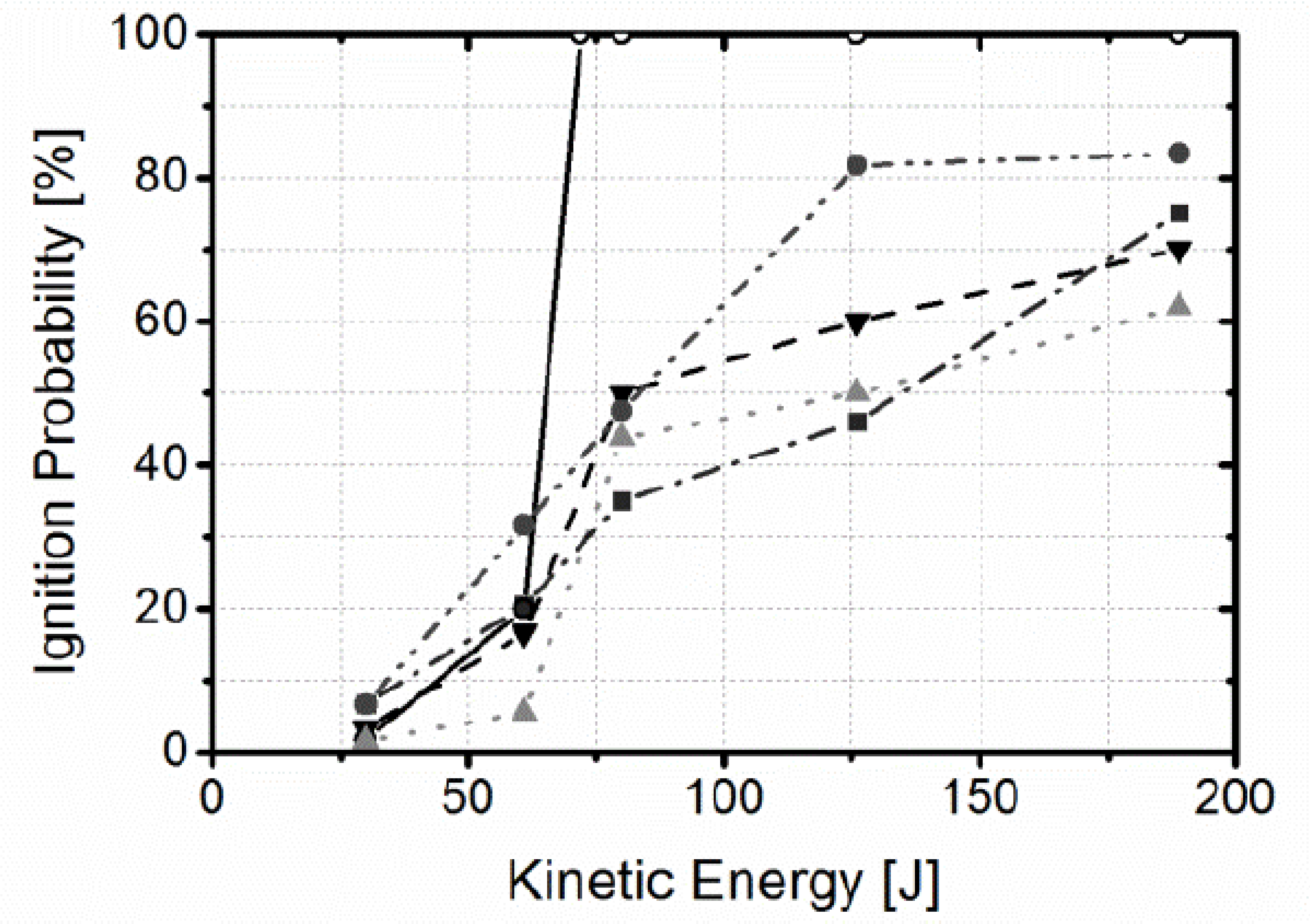




10% H_2, mild steel: always spark ignition
30 % H_2, mild steel: always hot surface ignition
Stainless steel: always hot surface ignition

Welzel et al. (2011)

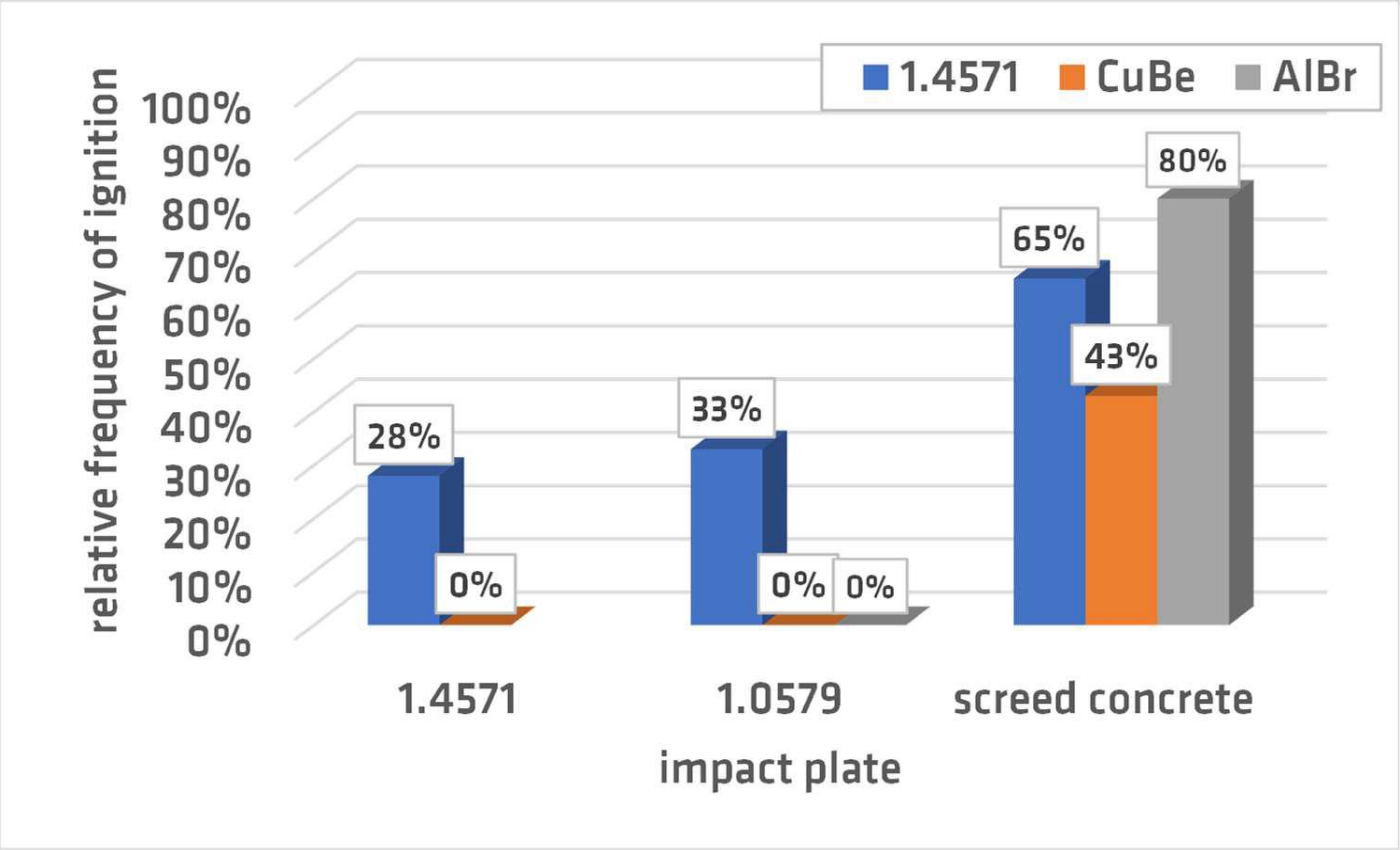
Ignition of 10 % hydrogen-air by single impact



Stainless steel1.4307 (▼)
1.4313 (▲)
1.4462 (●)
1.4541 (■)
Mild steel 1.0570 (○)

Holländer_2016

Impact sparks: other materials



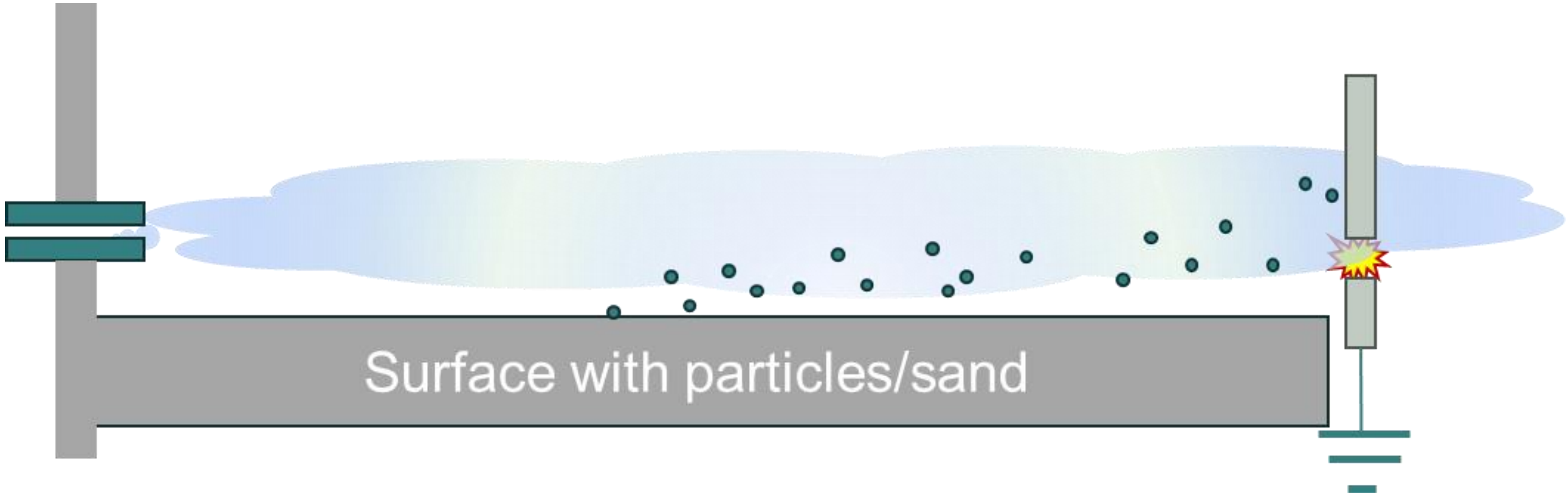
- Stainless steel (1.4571)
- Mild steel (1.0579)
- Copper-beryllium (CuBe)
- Aluminium-bronze (AlBr)
- Concrete

81 % aggregate (containing 5% corundum EKF 10 and 95% quartz sand)
12 % cement
6.8 % water
0.2 % fluxing agent

E_{kin}=61 J

Askar_2023

Can small particles accelerated by release ignite due to single impact?



Using 61 J kinetic energy a sonic release of hydrogen would be able to accelerate a particle weighing 74 mg to cause ignition of hydrogen-air

Preventive measures

- Use of non-electrical equipment approved for hydrogen in classified areas (HAC)
- Limit rotating speeds and forces
- Good maintenance of rotating equipment or any equipment with moving elements

- Avoid loose objects in the vicinity of potential leakage locations
- Avoid the use of certain material combinations. Concrete seems a poor material to be used in combination with metals.

Electric equipment

Electric equipment

- Potential ignition sources:
  - Electric sparks
  - Hot surfaces
- Ignition can be prevented if the equipment is correctly designed, constructed, installed and maintained in accordance with relevant standards (IEC 60079 series) for hydrogen
- Use explosion safe equipment in classified areas (hazardous area classification).
- Extent of classified areas beyond the calculated extents according to standards such as EN 60079-10-1 should be considered

Electrostatic sparks and discharges

Ignition by electrostatic discharges

Spark discharge:

✓Discharge between two electrically conducting materials.

✓Energy can be calculated from the capacitance and potential difference ($E = {}^{1}/_{2}\, CV^2$), in practice max 1 J.

Corona discharge

✓Sharp/pointed conducting object in electrical field.

✓Low energy-content.

Brush discharge

✓Rounded conducting materials approach charged non-conducting materials.

✓Energy-content < 4 mJ.

Electrostatic discharges – spark discharge

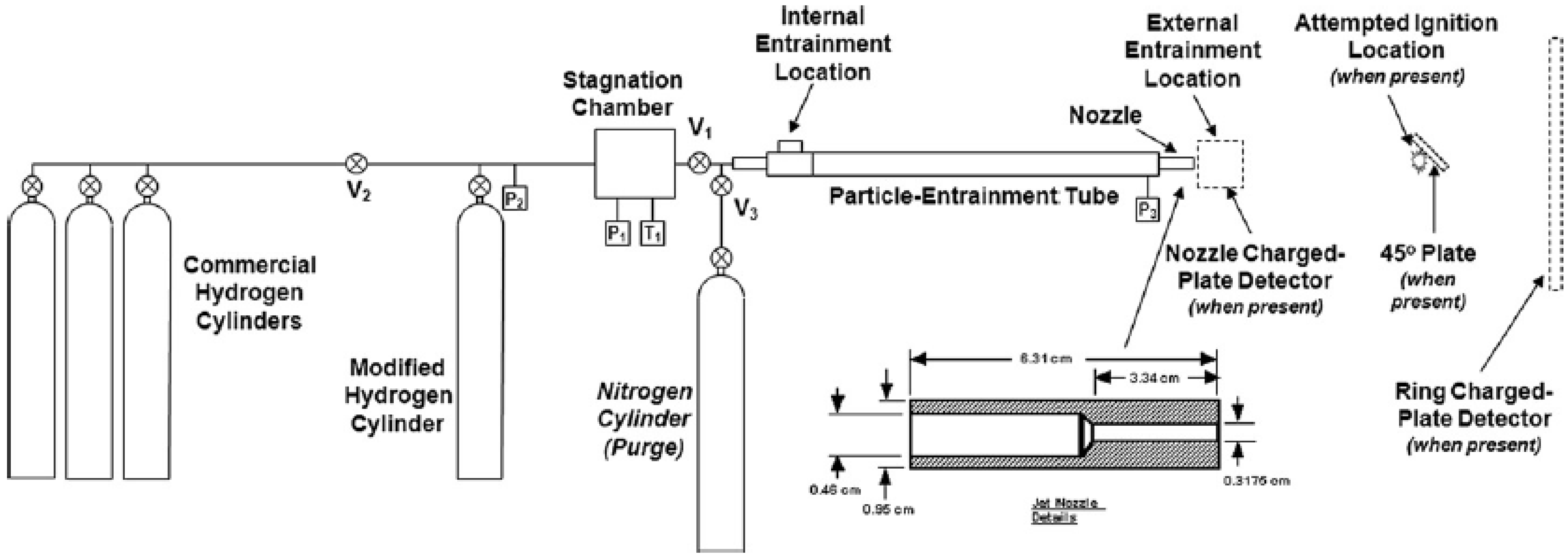
- Electrical field between two conductive objects (one charged, the other earthed) exceeds a certain strength due to large relative difference in electrical potential causing a discharge
- Practical situations
  - Flow of gas containing charged particles can charge non-earthed conductive object and cause discharge to neighbouring earthed object
  - Discharge from personnel

Electrostatic sparks

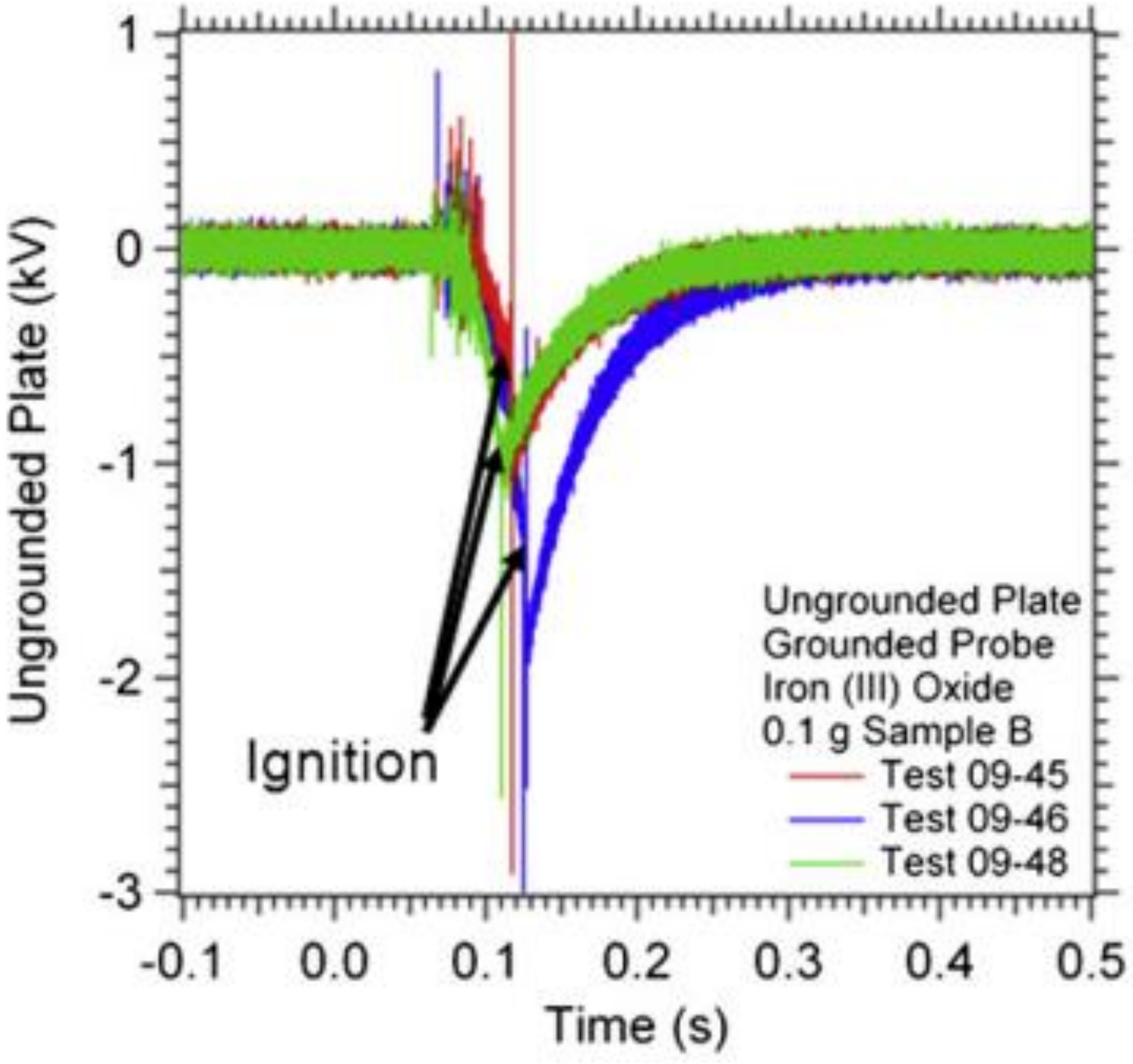
Object	Capacitance (pF)	1/2 CV^2 (mJ) at various voltages		
		10 kV	20 kV	30 kV
Single screw	1	0.05	0.2	0.45
Flange (100 mm nominal size)	10	0.5	2	4.5
Shovel	20	1	4	9
Small container (bucket, 50 litres drum)	10-100	0.5-5	2-20	4.5-45
Funnel	10-100	0.5-5	2-20	4.5-45
Drum (~200 litres)	100-300	5-15	20-60	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

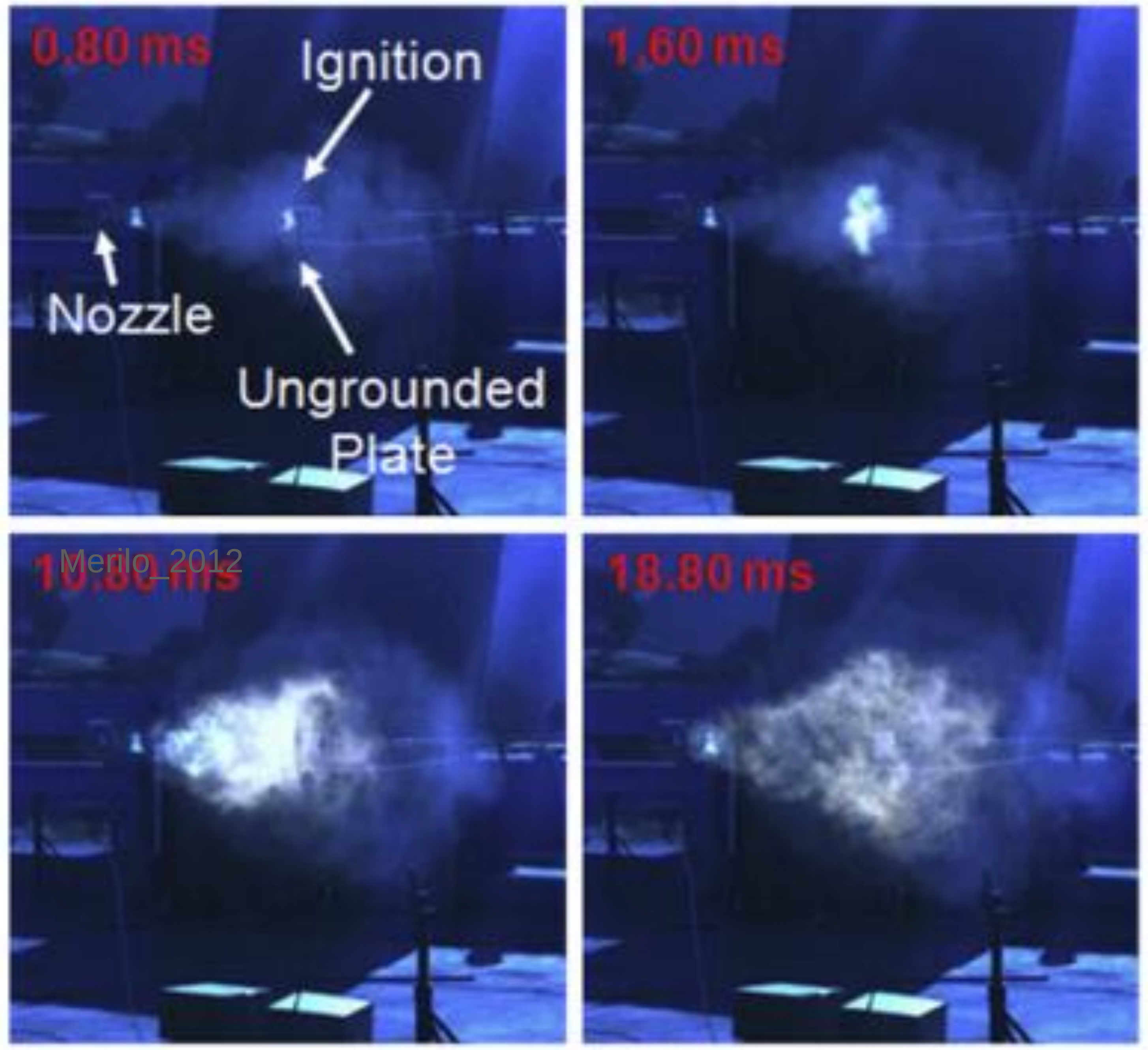
- Hydrogen-air mixtures can be ignited by discharges from small objects

Ignition of hydrogen jet by spark discharge from plate charged by entrained particles



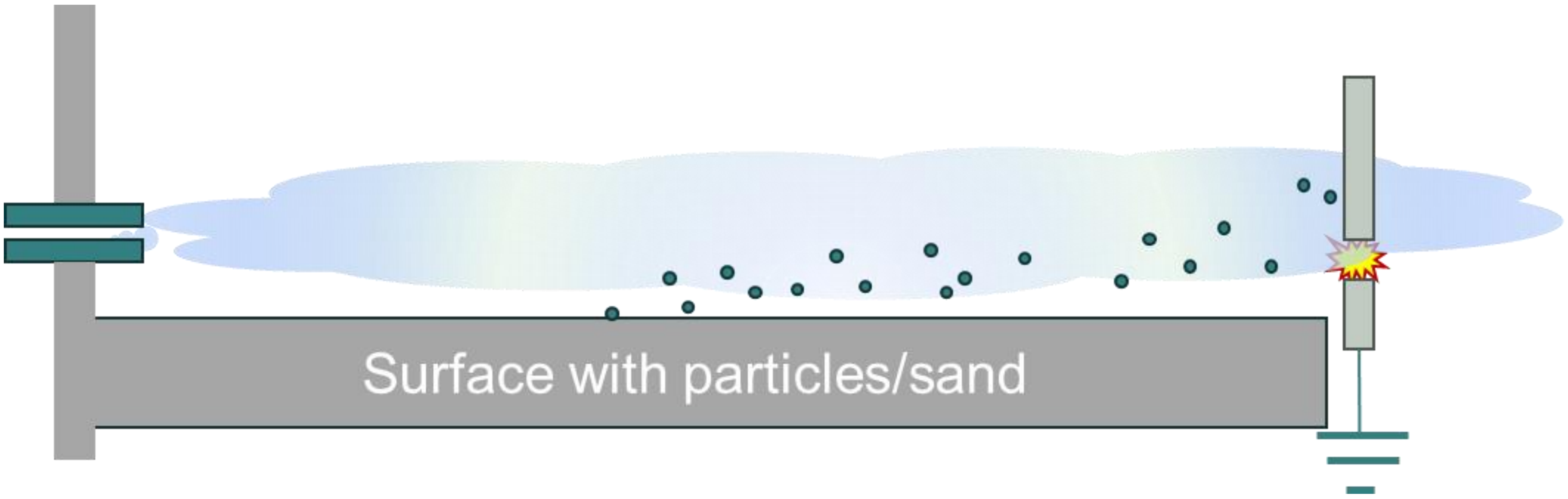
Ignition of hydrogen jet by spark discharge from plate charged by entrained particles





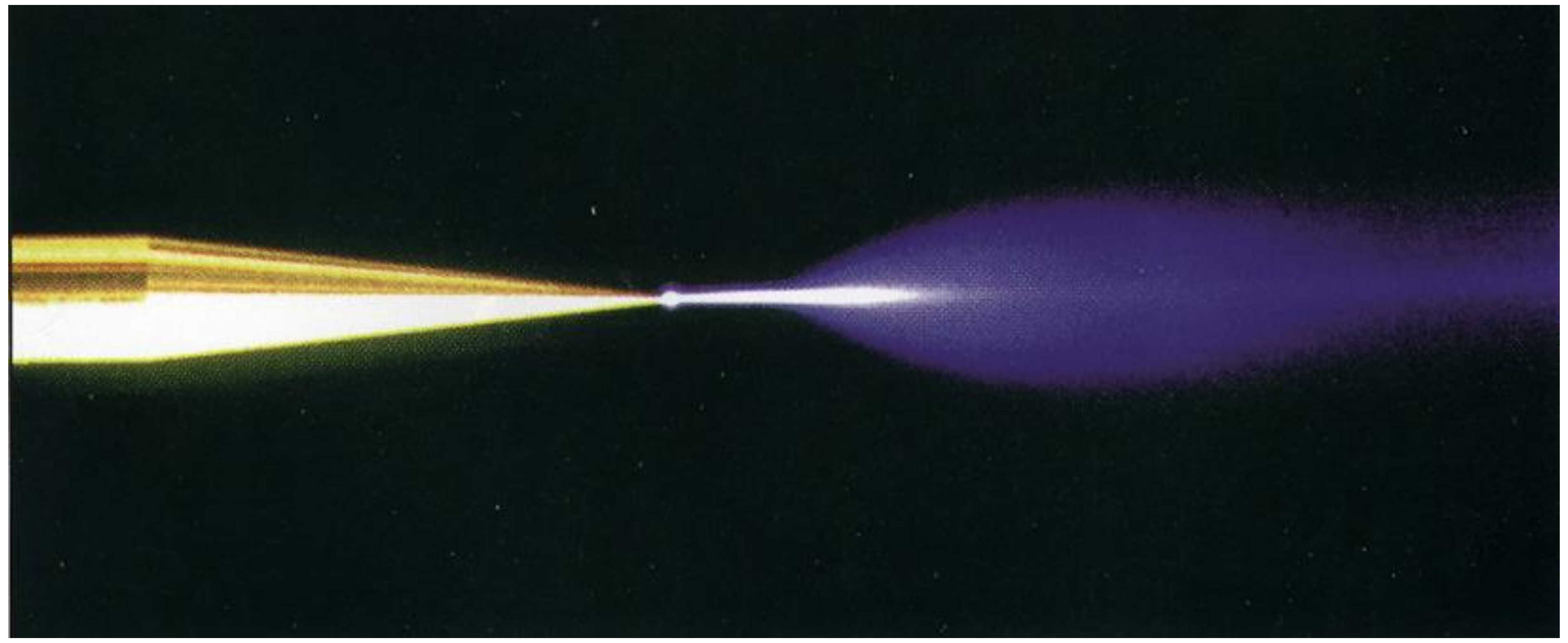
Merilo_2012

Electrostatic charging of non-earthed smaller objects by hydrogen release

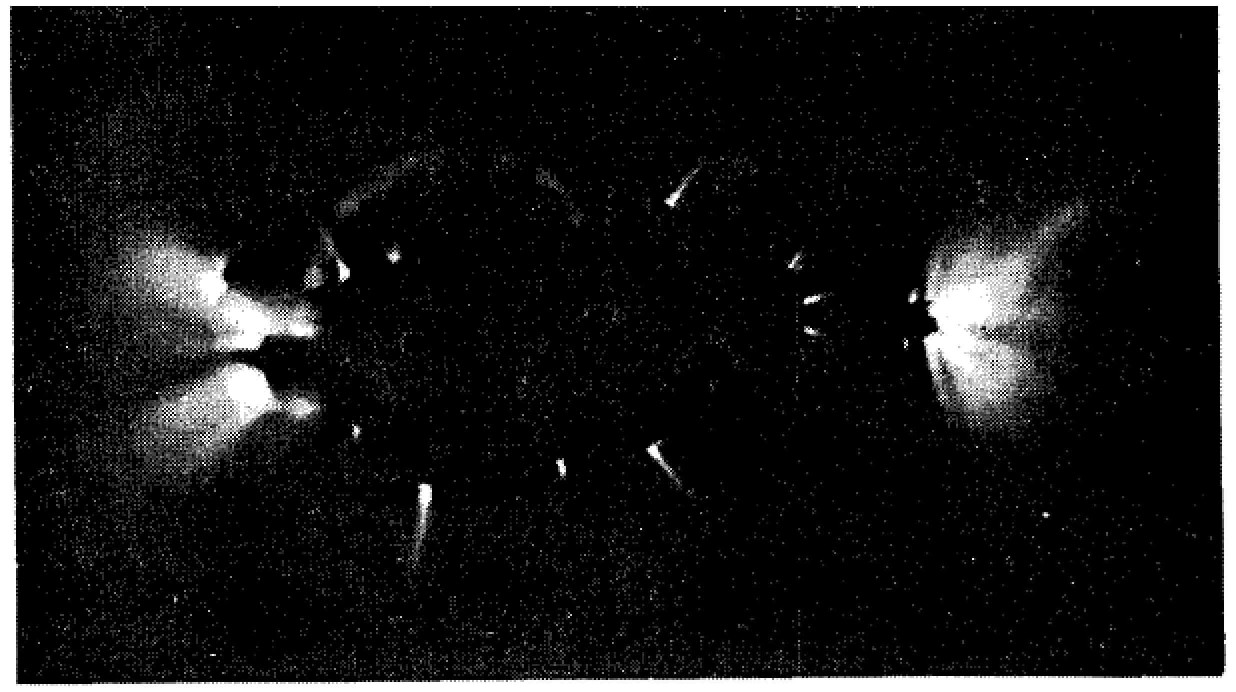


Electrostatic discharges: corona discharge

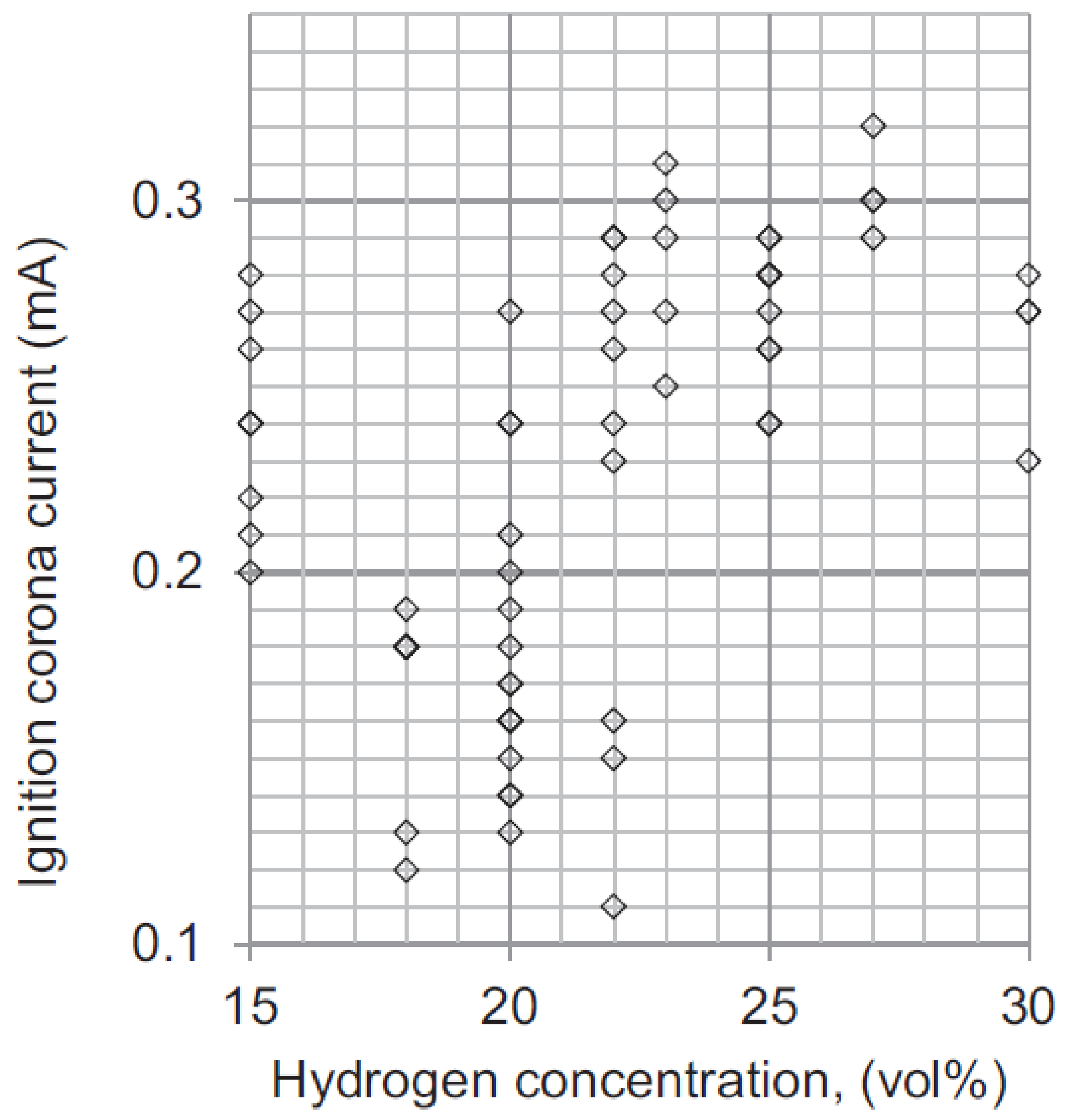
- Occurs at sharp/pointed conducting materials in electric fields, e.g. when approaching charged non-conducting materials
- Low energy-content
- Can lead to ignition of very ignition-sensitive gases like acetylene and hydrogen

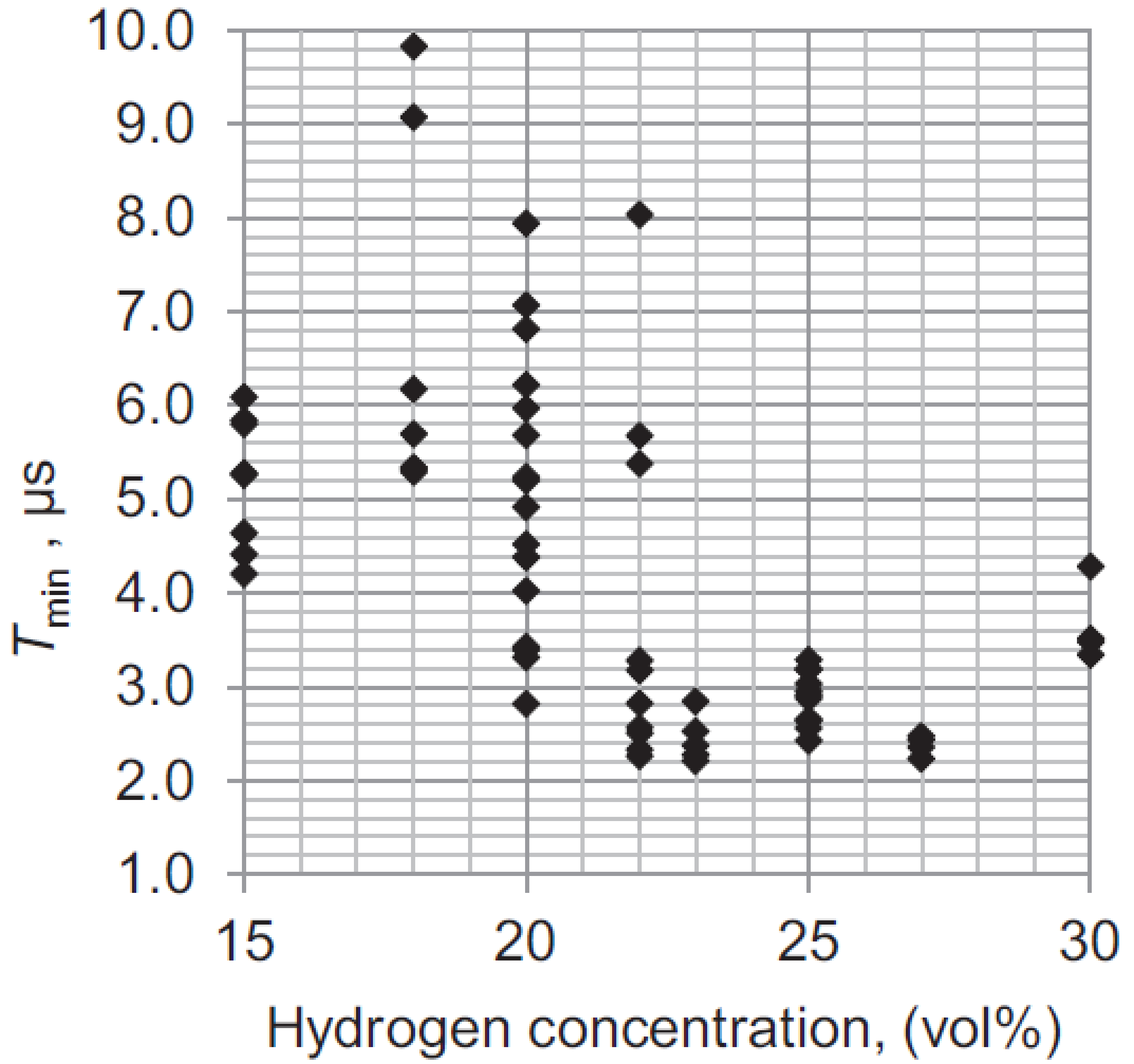


Corona discharges in practice



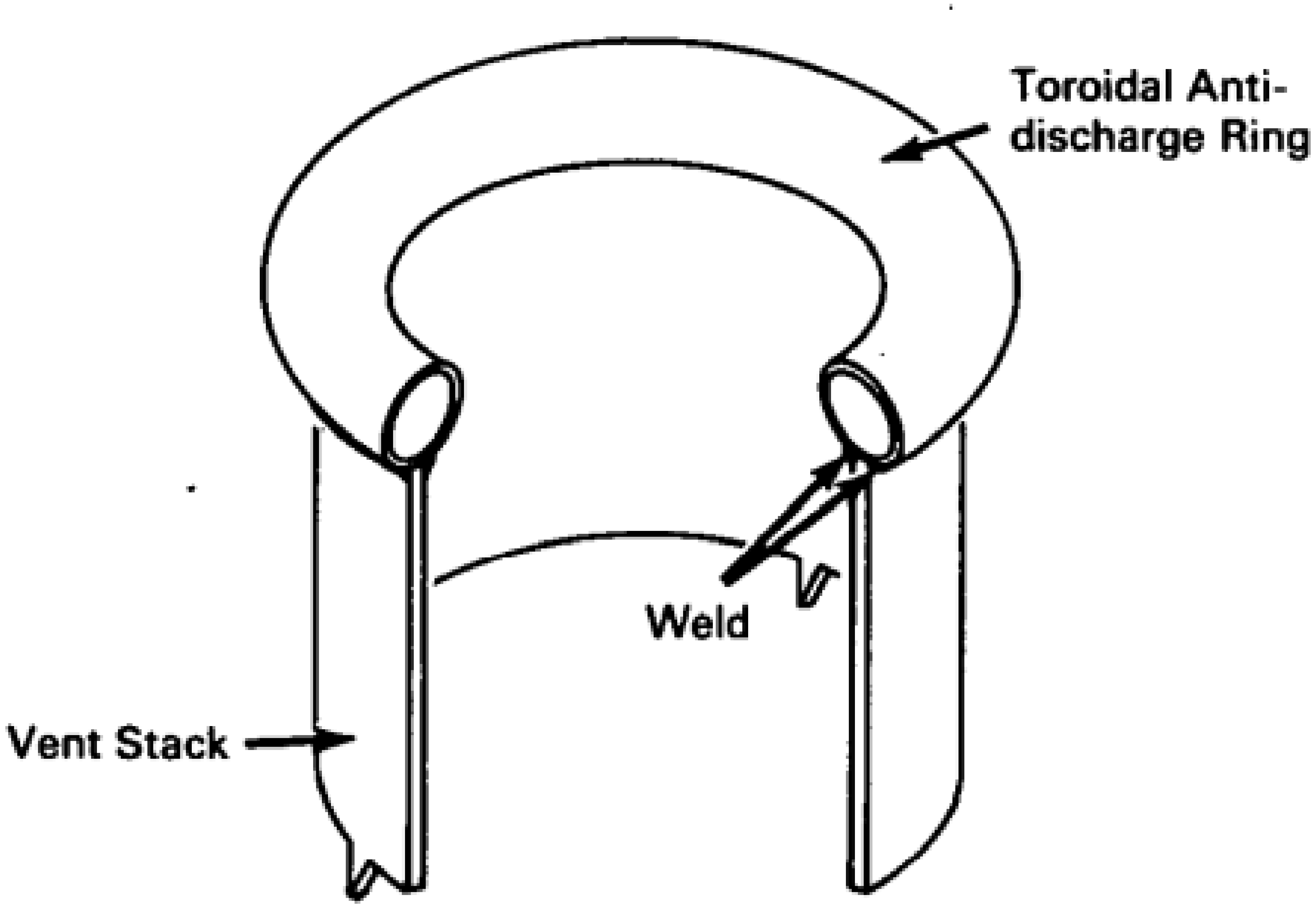
Corona discharges igniting hydrogen-air mixtures





Grabarczyk_2013

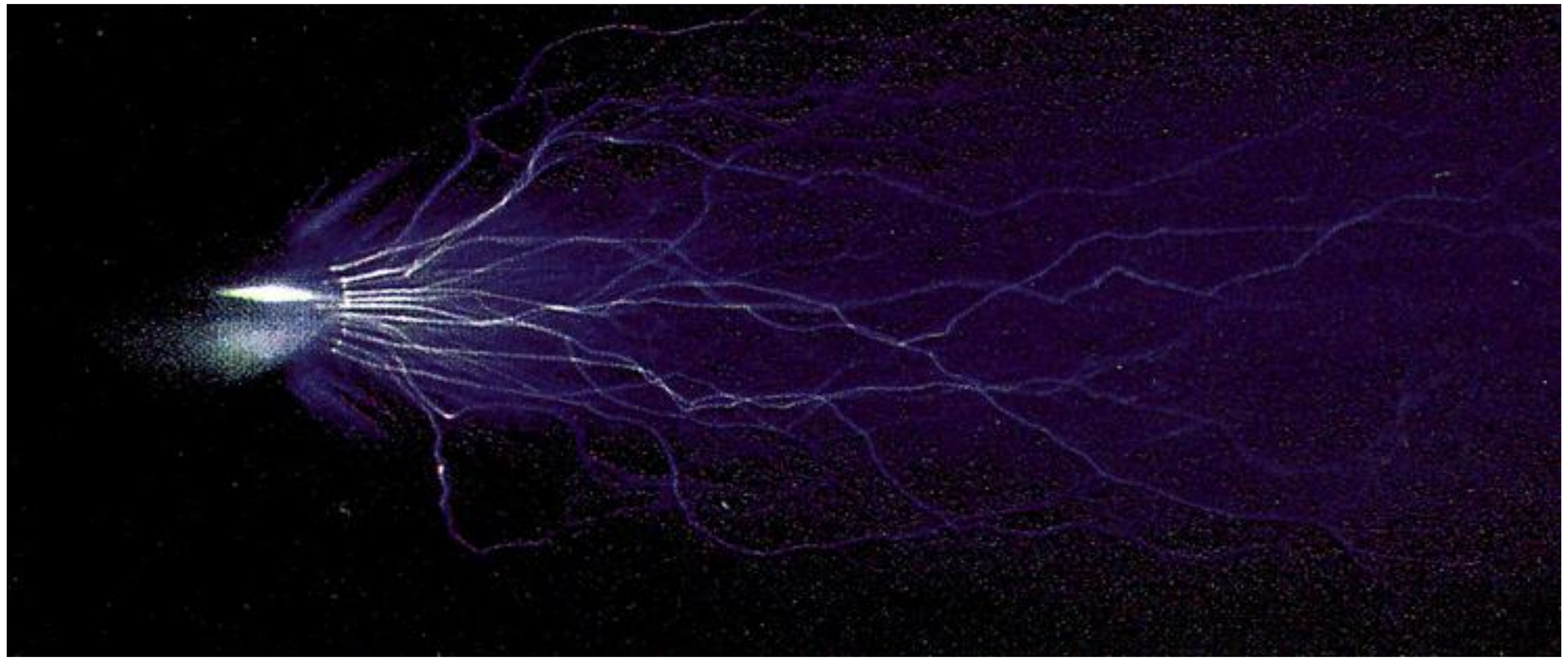
Ring on top of vent stack to prevent corona discharges (NASA)



Spring_1967

Brush discharge

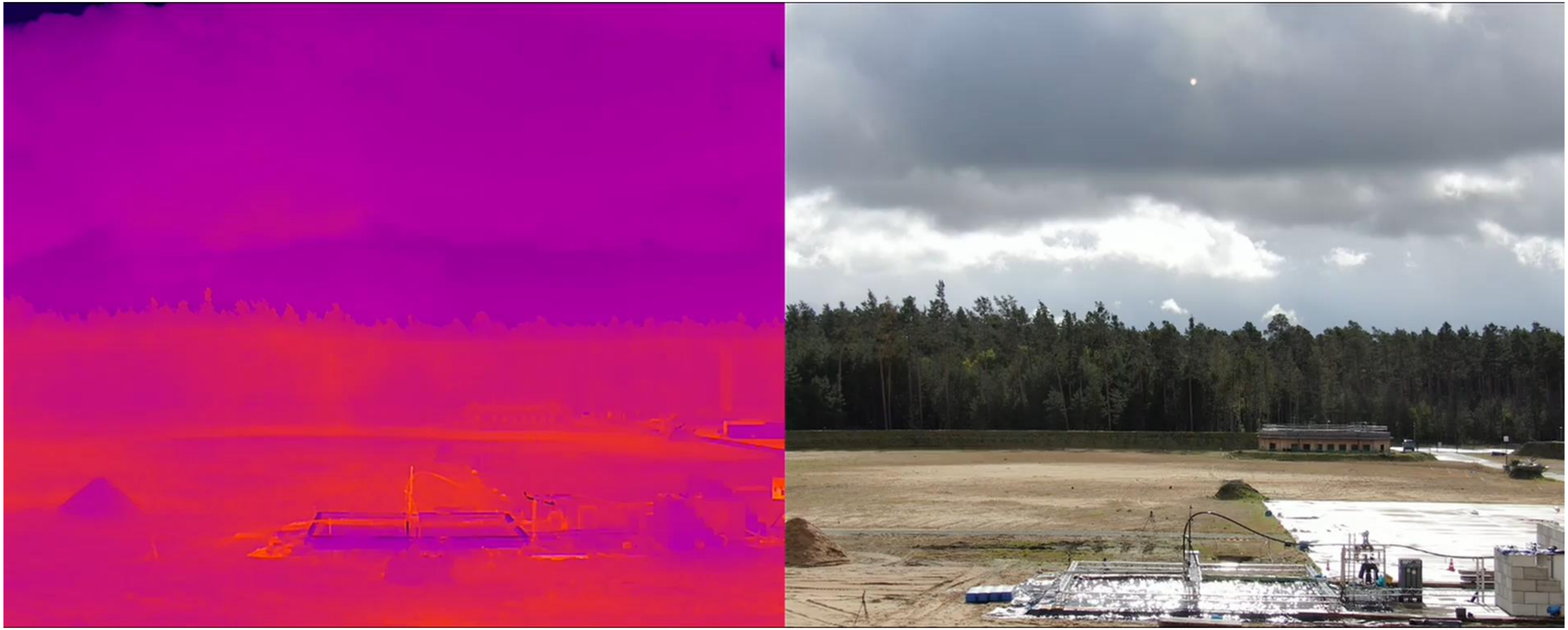
- Usually occur when rounded conducting objects approach charged non-conducting materials
- Only a limited part of the available energy is discharged
- Energy-content < 4 mJ
- Can ignite hydrocarbon gases and vapours and of course hydrogen



Preventive measures

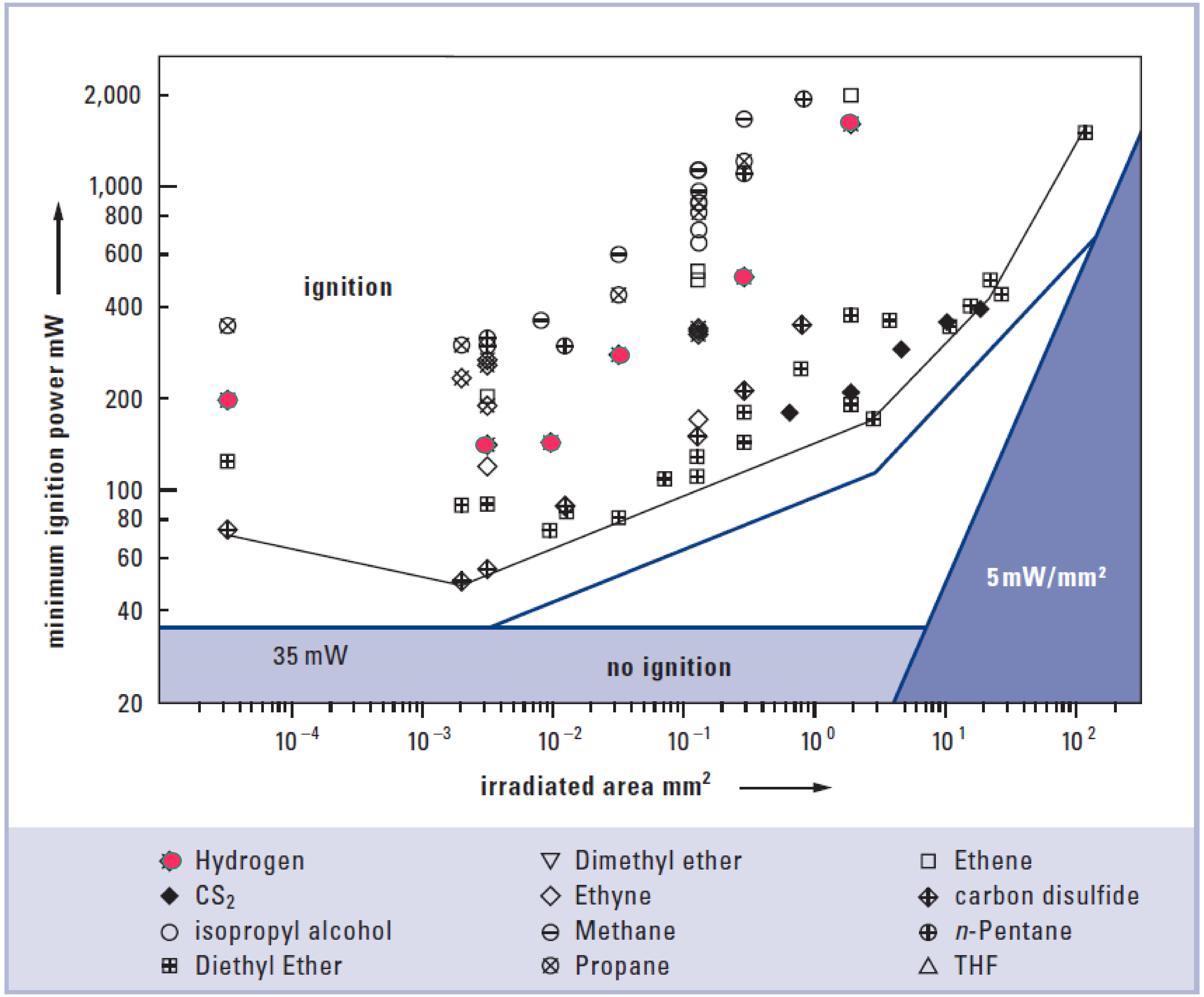
- Grounding and bonding of all conductive parts of an installation (also small elements such as bolts)
- Personnel should wear anti-static foot- and workware
- Avoid the use of non-conductive materials (or keep surroundings clean from dust/other fine material that may be whirled up by a potential release)
- Avoid the presence of sharp, pointed elements at installations (toroidal ring on top of vent line)

SH2IFT: release of liquified hydrogen (1 kg/s) onto or under water



Electromagnetic radiation

Optical radiation

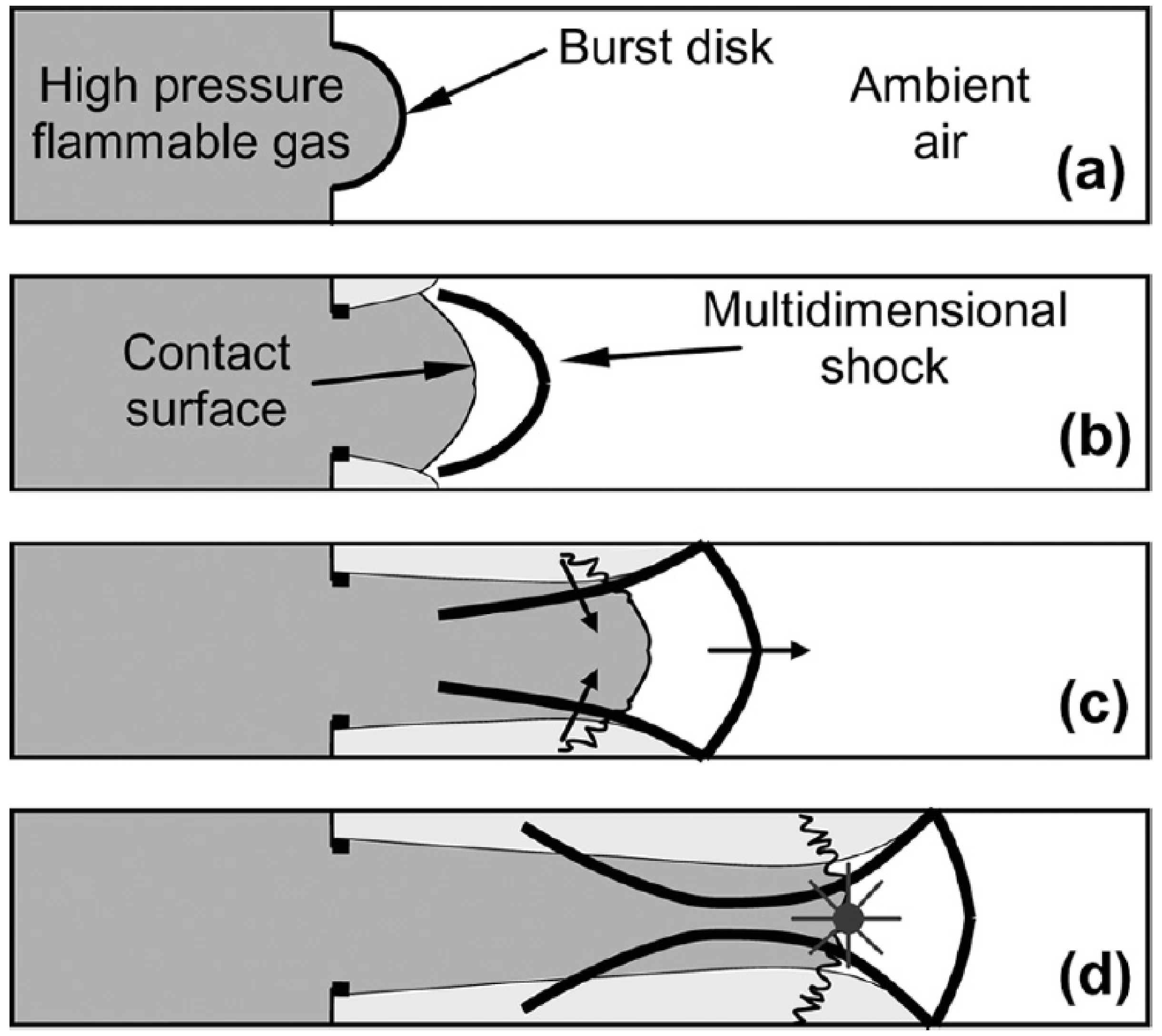


Bothe_2008

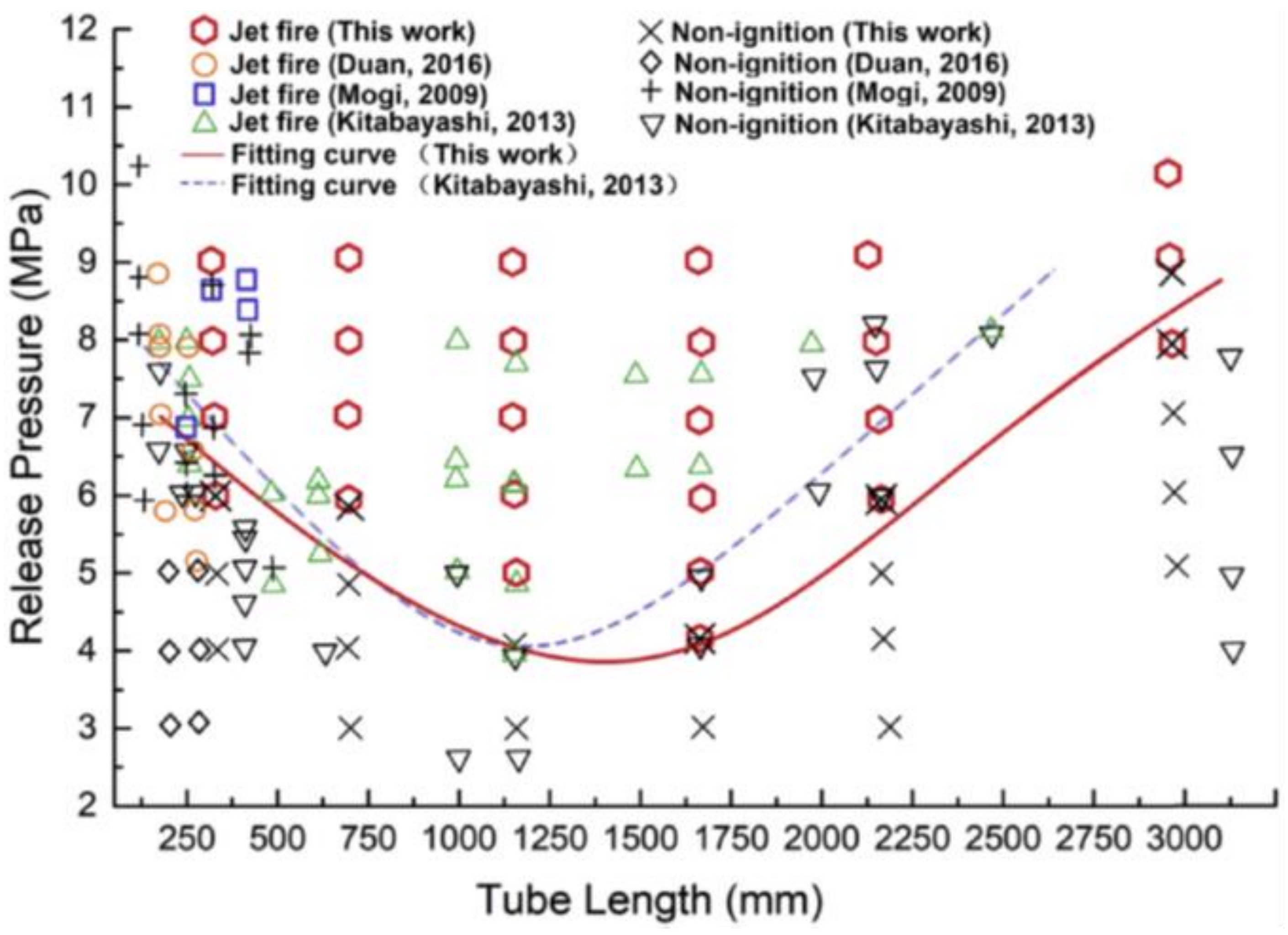
Adiabatic compression and shockwaves

Adiabatic compression and shockwaves

- Ignition of hydrogen upon the sudden release from a high-pressure container connected to a venting line has been observed in
- Most probable cause are shock wave reflections igniting the hydrogen at the interface between hydrogen and air where due to diffusion a flammable mixture has arisen
- Spontaneous ignition seems to occur predominantly in thin vent lines connected to a high-pressure chamber (> approx. 20 bar) protected by a bursting disk
- Up to a certain length increase of the length of the vent line promotes ignition
- Also obstructions/bends in the vent line appear to promote ignition

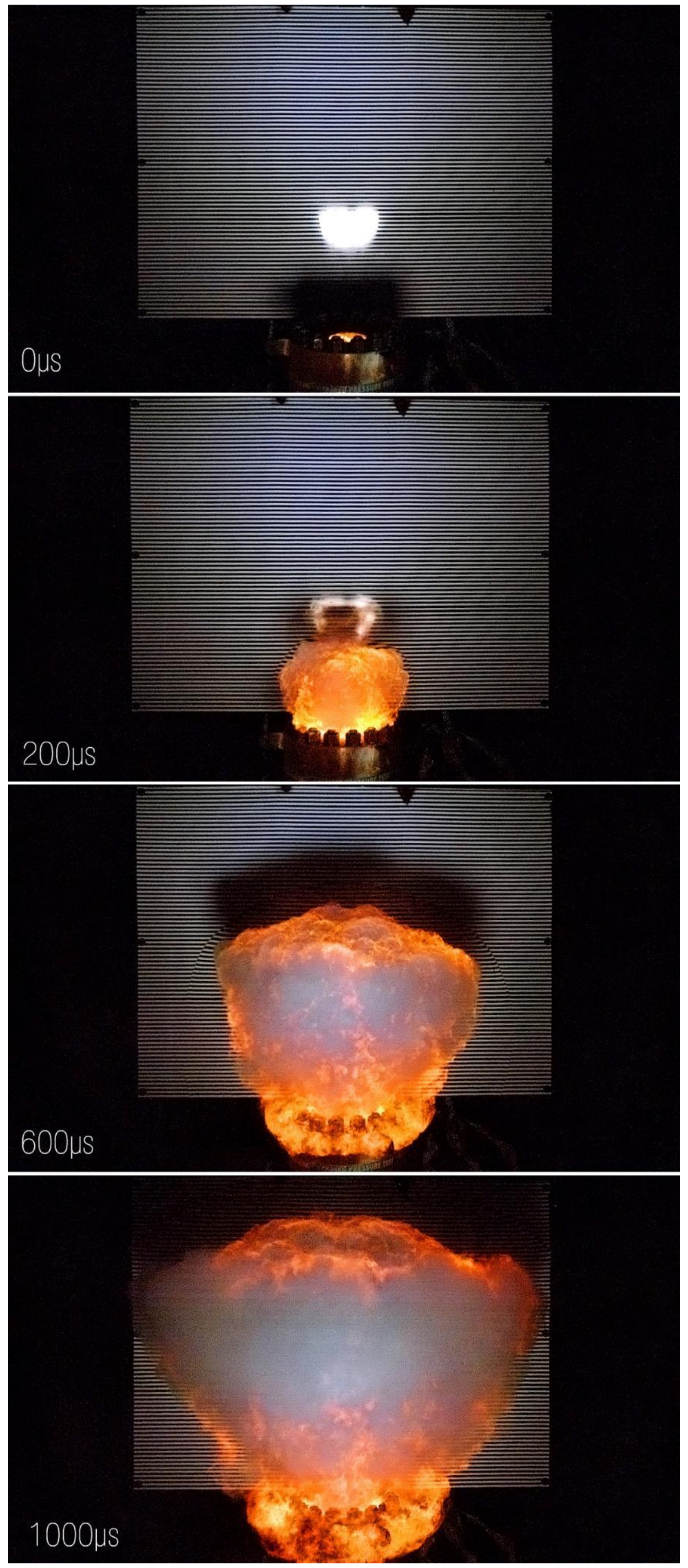


(Dryer_2007)



10 mm vent line, Gong, 2017

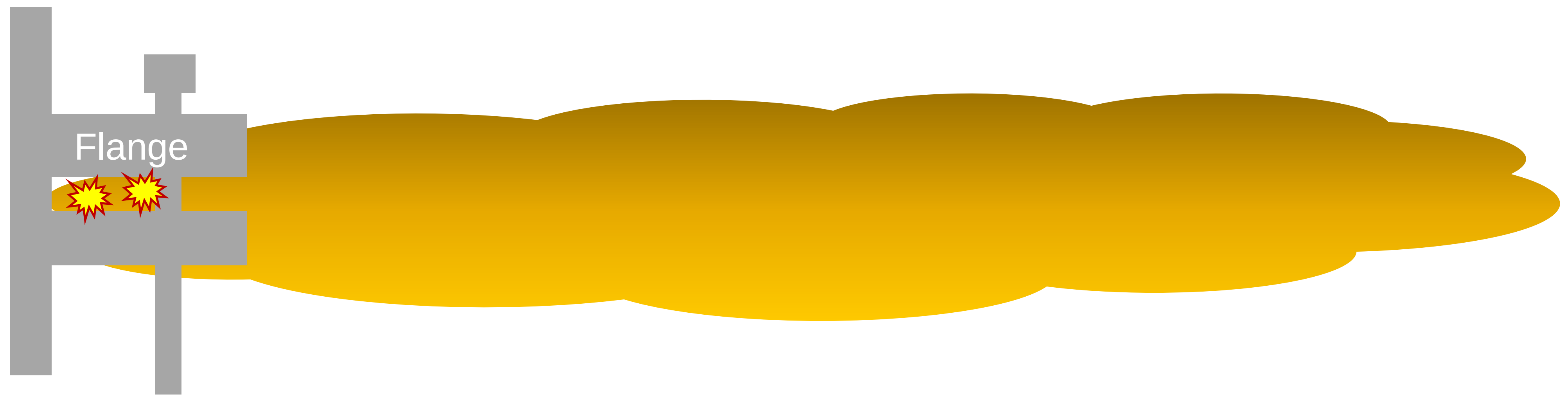
Recent experiments HSE in tunnel



- 13 tests with pressure vessels (5 l, 12 l and 18 l) inside tunnel
- Release pressure between 460 bar and 660 bar
- Ignition in every experiment

Lyons_2023

SAFEN: Ignition by shock wave reflections due to sudden flange gasket failure



- Shock waves caused by sudden failure of high pressure reservoir mix hydrogen with air due to diffusion and shock wave reflections cause ignition
- Demonstrated within thin vent lines, but can it occur in other practical situations, such as
    - Between flange surfaces in case of gasket failure
    - And under which conditions?

Preventive measures

- Avoid use of bursting disc connected to thin vent line if bursting pressure > 20 bar.
- A relief valve (with an opening time > some ms) will avoid ignition
- Good maintenance, regular replacement of e.g. gaskets
- Spontaneous failure of high pressure reservoir has a low probability
  - Choice of material (hydrogen embrittlement)
  - Inspections

Conclusions

Conclusions

- Hydrogen is currently enjoying unprecedented political and business momentum as a viable, low-carbon energy source for industrial and transportation uses
- Safety shall have a high attention to avoid accidents from becoming a showstopper
- First priority is prevention of releases of hydrogen
- Prevention/reduction of the probability of ignition is fully possible but is challenging for a number of potential ignition sources
- More research into ignition of hydrogen-air mixtures increases our level of understanding of safety aspects associated with the handling of hydrogen and contributes to an even better basis for proper safe design of hydrogen facilities, reducing uncertainties

7 December
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Thank you