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HICON - New knowledge and ignition modelling concept

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Contents

- Ignition sources and mechanisms according to EN 1127-1
- Overview of main findings literature review
- Overview of main findings experimental research
- Ignition modelling concept
    - Immediate and delayed ignition
    - Ignition cases
        - Ignition mechanisms generated by the release itself
        - Ignition sources not directly associated with the release itself
    - Possibilities of ignition probability reduction by design and maintenance

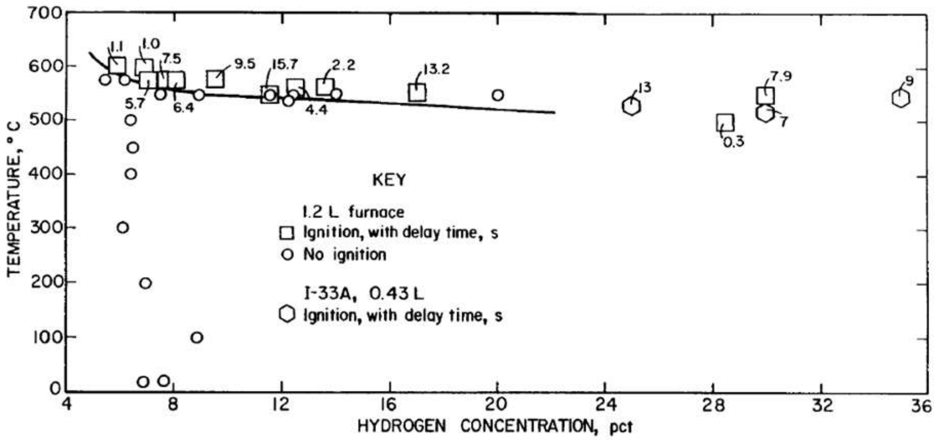
Ignition sources and mechanisms according to EN 1127-1

- Hot surfaces
- Flames and hot gases
- Mechanical friction and impact
- Electrical apparatus
- Static electricity
- Exothermic reactions
- Lightning
- Radio frequency waves
- Electromagnetic waves
- Ionising radiation
- Ultrasonics
- Adiabatic compression
- Stray electric currents

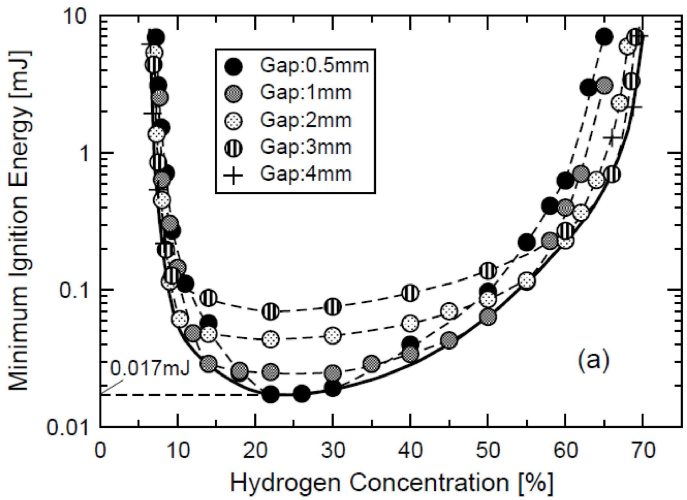
Overview main findings literature review

- Ignition properties
- Existing knowledge ignition sources/mechanisms

Ignition properties

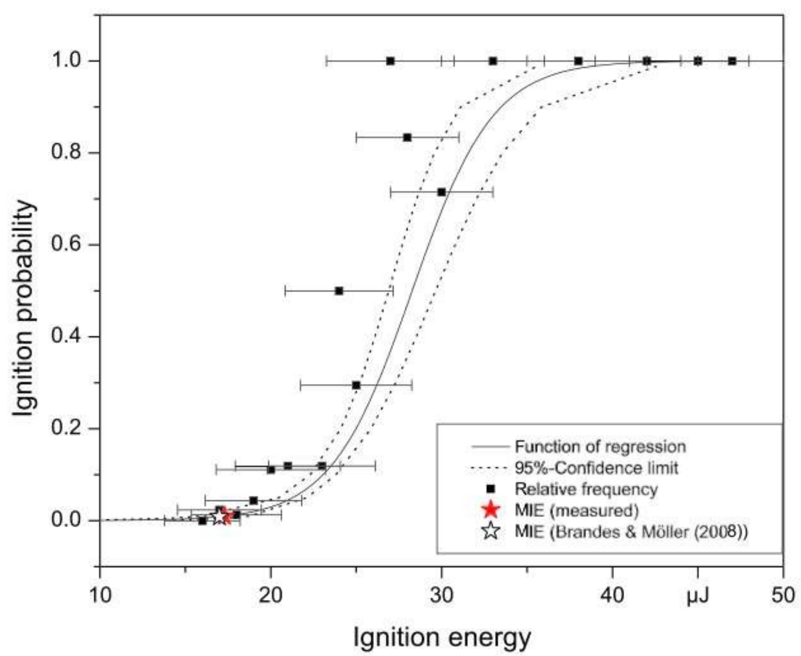


Auto-ignition temperature (Conti, 1988)

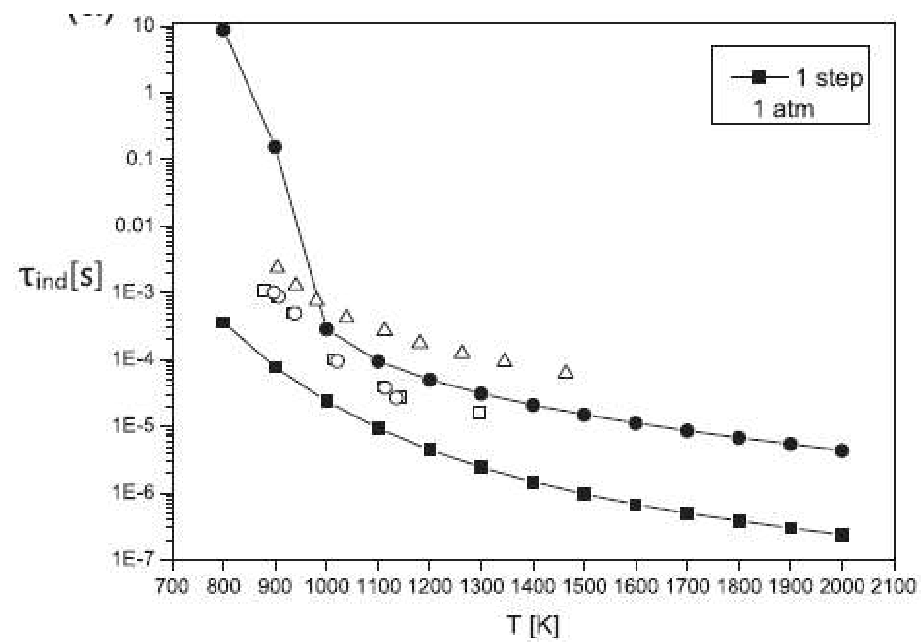


Minimum ignition energy (Ono, 2008)

Ignition properties



Ignition probability near MIE (Wahner, 2013)



Induction time (Liberman, 2018)

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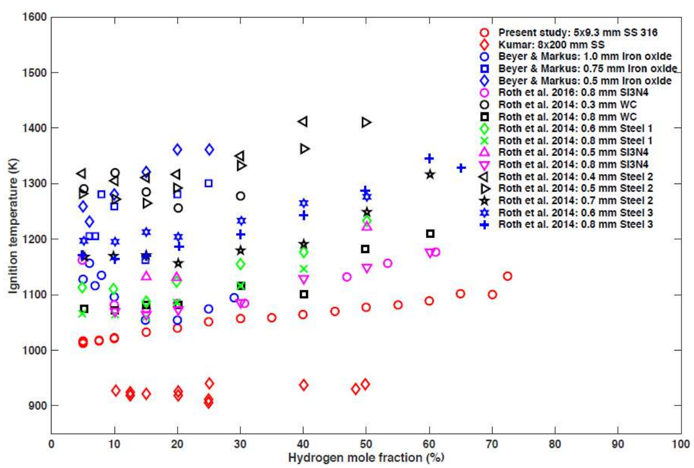
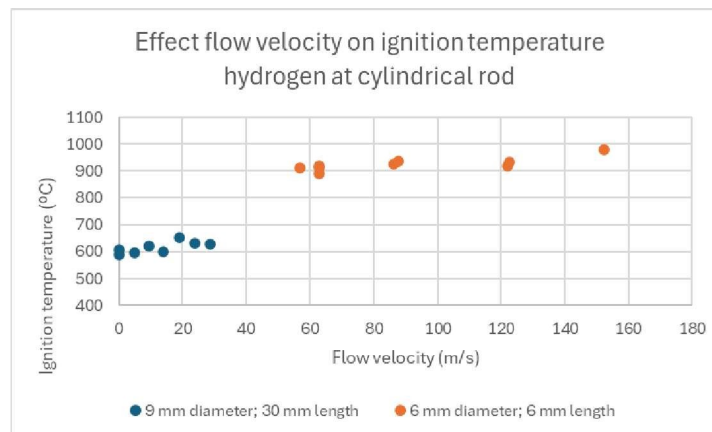
Hot surfaces

Hot surfaces can include parts of process equipment, electrical equipment, etc.



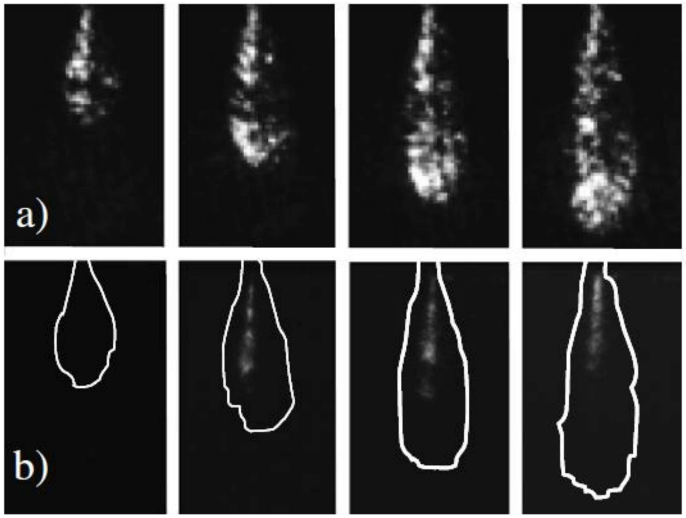
Effect of geometry/surface area on IT (Mevel, 2019)



Effect of flow velocity on IT (Proust, 2019; Mullen, 1948)

Flames and hot gases

- Flames are considered to be a 100 % probability ignition source
- Hot gases:
  - jet of hot hydrogen (syngas) mixing with air
  - jet of hot gas mixing with hydrogen-air mixture, e.g. gas from exhaust
  - Tests: temperature shall be higher than 641 °C, mixing rate is determinant



Sadanandan, 2007

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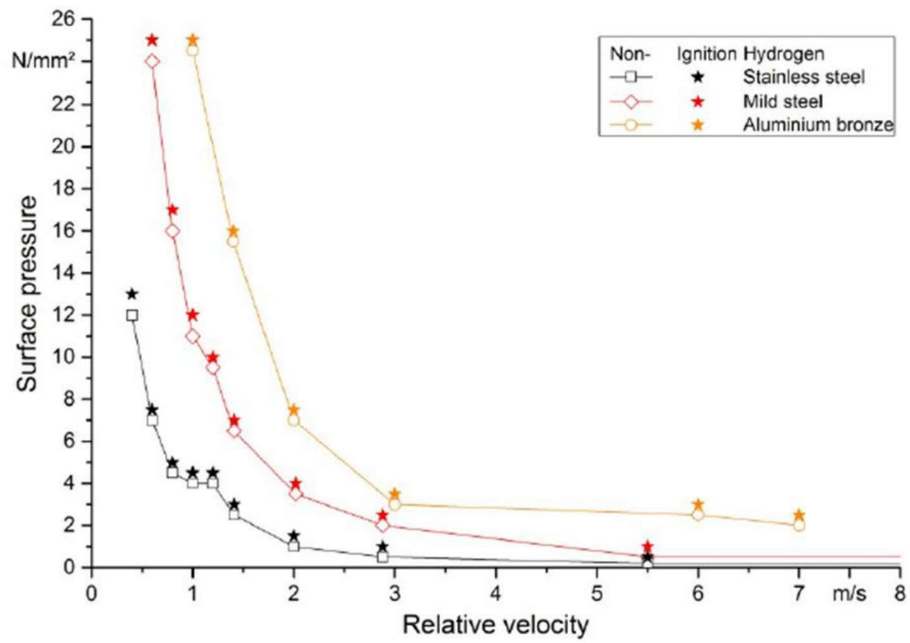
Mechanical friction

- Causing hot surfaces and/or mechanical sparks
- Material combinations, forces, relative speed
- Material hardness, heat conductivity
- Examples of incendive material combinations:
  - Steel 1.4571 – screed concrete
  - Copper-beryllium (CuBe) – screed concrete
  - Aluminium-bronze (AlBr) – screed concrete
  - Auer flint – grinding disc
  - Zirkonium – grinding disc



Meyer, 2017

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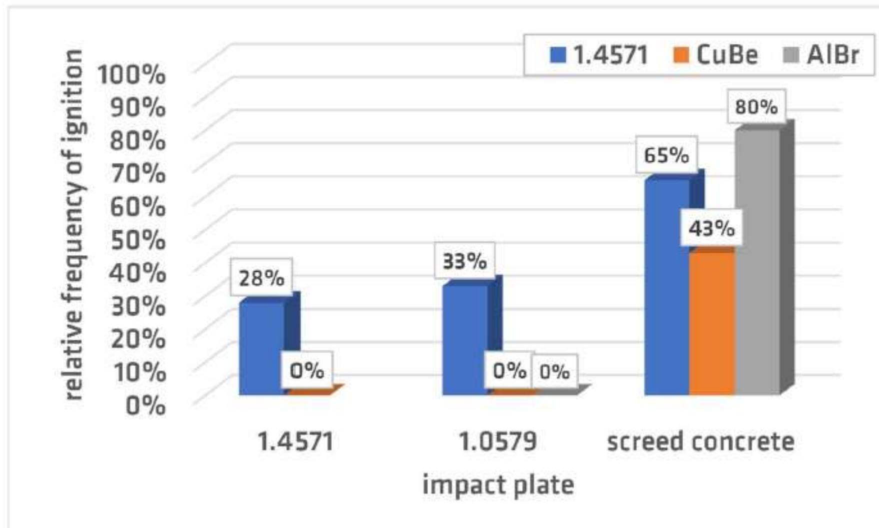
Mechanical impact

- Causing hot surfaces and/or mechanical sparks
- Material combination, kinetic energy
- Material composition, conductivity, hardness
- Incendive material combinations:
  - Steel-sandstone
  - Steel-red granite
  - Aluminium-rusty steel
  - Aluminium bronze-concrete



Askar, 2023

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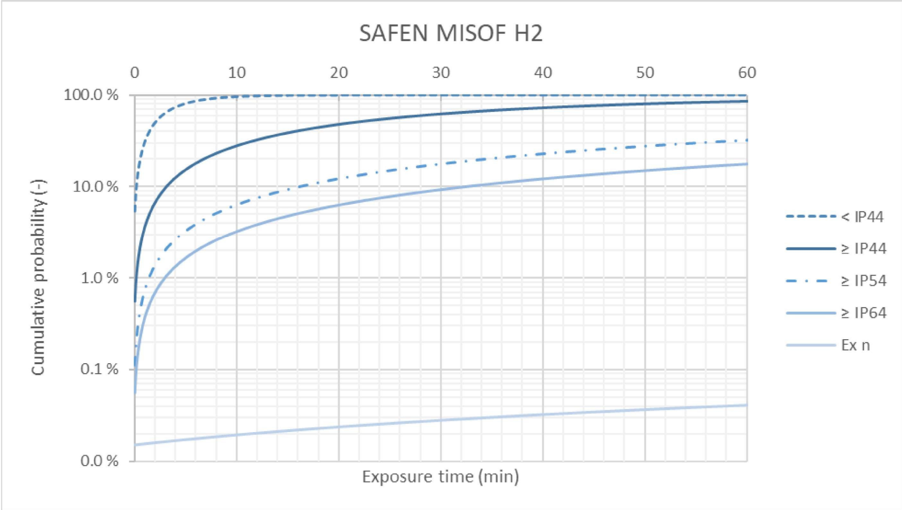
Electric equipment

- Probabilities of ignition by equipment approved for use in potentially explosive atmospheres caused by hydrogen is known
- Suggestion made for non-approved equipment based on tightness (IP-grade) in Fossan (2024)



Fossan, 2024

Stray electric currents

- Stray electric currents are unintended flows of electricity outside their designated pathways originating from e.g. faulty electrical systems, improperly installed or maintained wiring and power lines.
- These ignition sources may be present in the vicinity of hydrogen installations, e.g. due to nearby electric welding operations, nearby electric power lines, cathodic protection of pipelines, storage tanks or the metal reinforcement bars in concrete of nearby buildings. Stray currents can also arise in alkaline water electrolysis systems.
- Apart from correct design and installation of electric systems the most important countermeasure is good earthing and bonding of the electric systems.
- Especially sparks need to be prevented in the light of the low minimum ignition energy of hydrogen but strong currents through e.g. thin wires/high resistances can give rise to high temperature/hot spots causing ignition as well.

Electrostatics

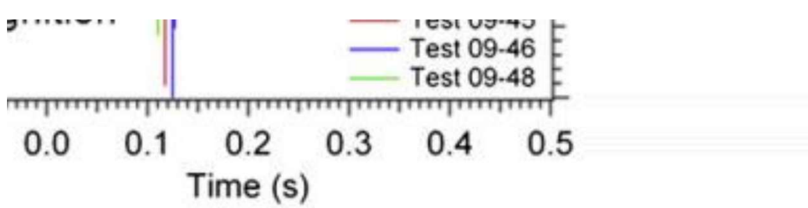
- Electrostatic sparks
- Brush discharges
- Corona discharges
- Lightning-like discharges

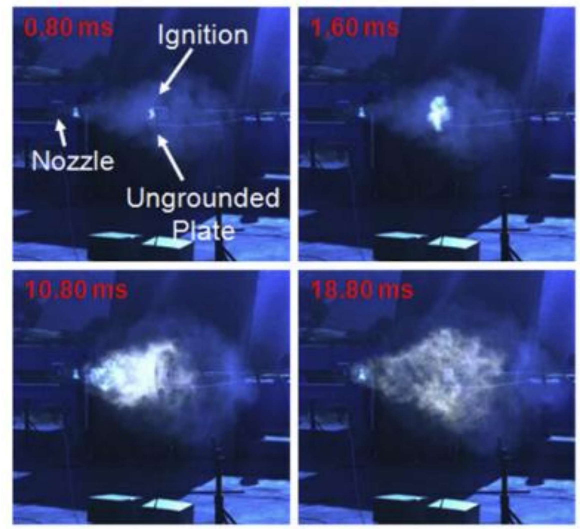
Electrostatics

Electrostatic sparks: tribo-electric effect

Object	Capacitance (pF)	½CV² at various voltages (kV)		
		10	20	30
Single bolt	1	0.05	0.2	0.45
Flange (100 mm)	10	0.5	2	4.5
Small container (bucket, 50 ltr drum)	10-100	0.5-5	2-20	4.5-45
Drum (200 ltr)	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 tankers	1000	50	200	450

Ignition hydrogen jet by spark from unearthed plate charged by particles drawn along by jet





Merilo_2012

Brush discharges

- Discharge of charged non-conductor to a blunt conductive object moves towards a charged non-conductor. Maximum equivalent energy 3.6 mJ
- Risk reduction possible by limiting the surface area of non-conductive parts of equipment liable to become electrostatically charged coupled to hazardous area classification (ISO80079-36 2016):
  - zone 0 a maximum surface area of 400 mm^2,
  - zone 1 a maximum surface area of 2000 mm^2
  - zone 2 no restrictions have been imposed

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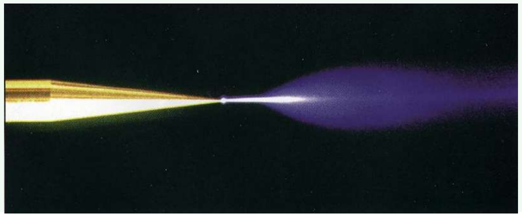
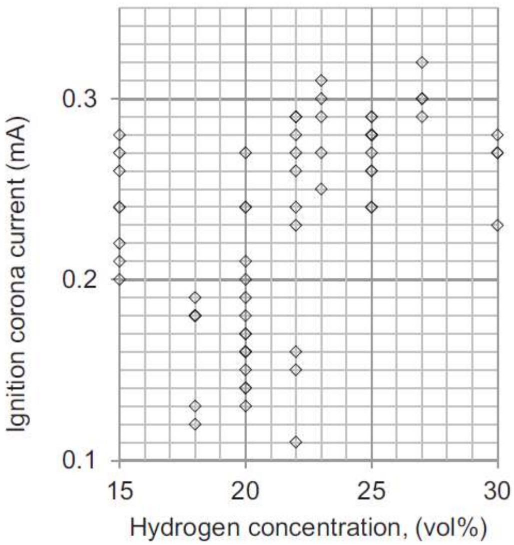
Corona discharges



- Corona discharges occur when the electric field around a sharp-pointed conductor exceeds a critical threshold, causing the surrounding air to ionize and become conductive



Grabarczyk 2013

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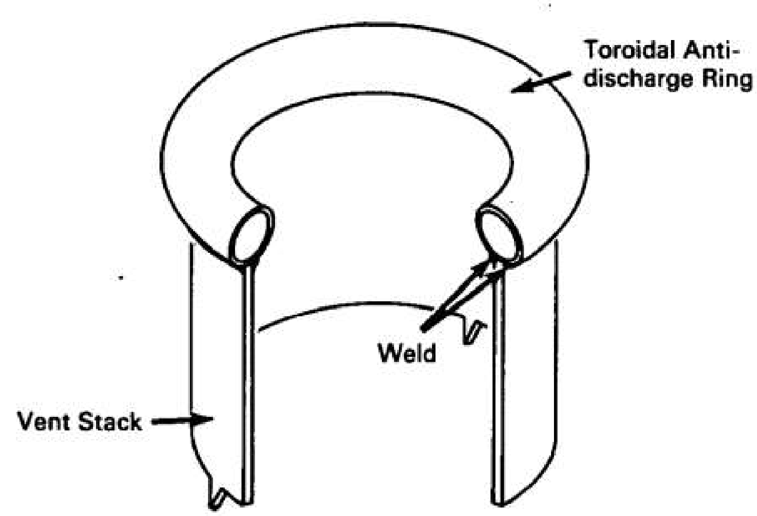
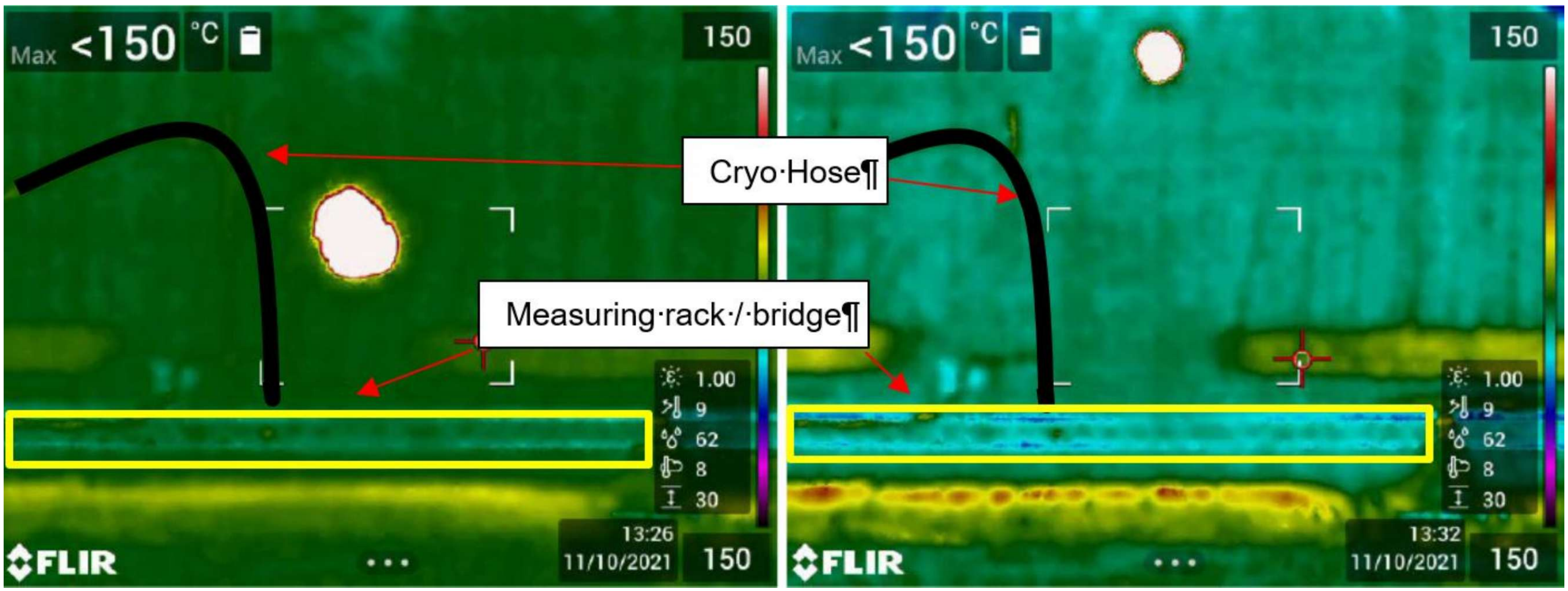
Corona discharges

- Corona discharges from high-voltage lines can ignite
- Corona discharges from needles, leaves, insects cannot ignite
- Corona discharges current depends on capacitance object: sharp edges of larger equipment (vent stack)
- Electric field strength during thunderstorms and blizzards is sufficiently strong
- Electric field generated by ice crystals from equipment containing LH2 drawn along by hydrogen release is also sufficiently strong



Spring, 1967

Ignition of clouds generated by high momentum LH2 jets into water: corona discharges?



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Lightning-like discharges

- Discharge through the atmosphere caused by large clouds of charged droplets between two oppositely charged parts of the cloud.
- Appears not possible for cloud of LH2 droplets (LH2 is a poor conductor) (Hall 2021)

Lightning strike

- Indirect ignition due to stray currents
- Lightning protection according to IEC 62305-1/4 2024 and NFPA 780, 2026
- Geographically dependent

Radio frequency (RF) electromagnetic waves from 10^4 Hz to 3×10^{11} Hz

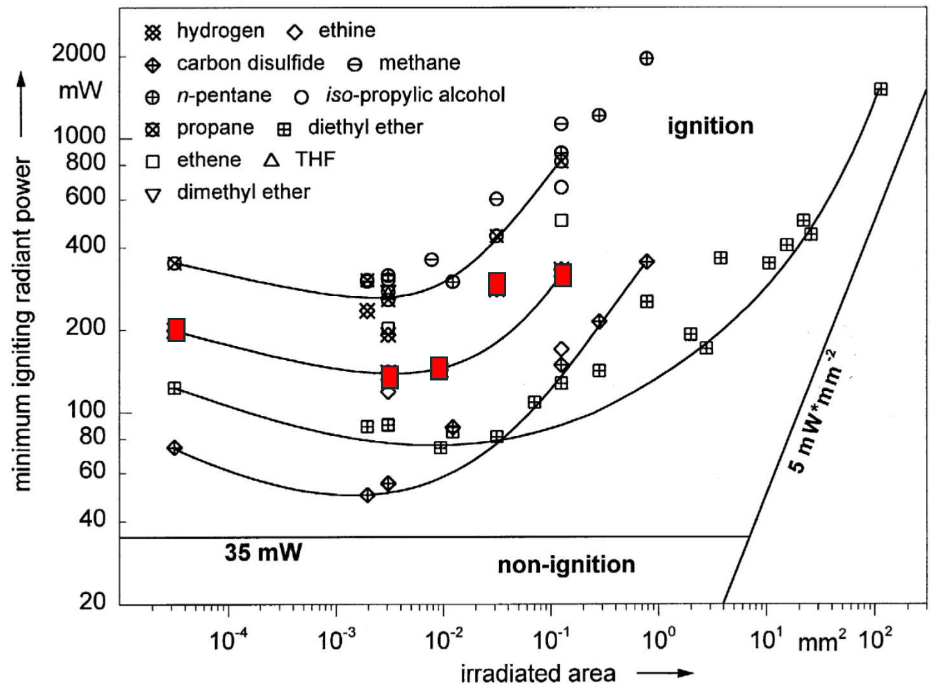
- Radio transmission sources cause circulating currents in structures including vessels, pipework, vent stacks and other equipment such as loading cranes
- May in this way cause ignition by spark discharge or hot surface due to ohmic losses

- Radar systems used for level measurements in tanks
- Heating of small objects by absorption of the electromagnetic waves

- Risk reduction possible by limitation of power and energy (especially in connection with HAC and instrumentation)
- PD-CLC/TR 50427 2004) presents guidance for what to do when power is above the safe levels

Electromagnetic waves from 3×10^{11} Hz to 3×10^{15} Hz

- Absorption of the radiation by a solid object causing it to be heated and becoming a hot surface ignition source
- Safe limits considering all gases and liquids are 35 mW and 5 mW/mm²
- For hydrogen one could operate with the limits of 100 mW for small areas and 500 mW/mm²



Welzel, 2000

Ionising radiation

- Ionising radiation caused by X-ray tubes and radioactive substances can ignite explosive atmosphere
- Mechanisms: energy absorption by the flammable gas mixture (especially in the presence of dust particles) and heating of the radioactive source itself
- The ionising radiation can cause highly reactive radicals or unstable chemical compounds resulting in ignition.
- A radiation intensity of 0.1 kGy/s (100 J/kg.s) would be sufficient to ignite a hydrogen-air mixture (Gerasimov 2002)

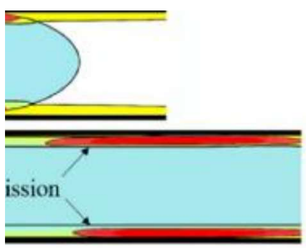
Ultrasound

- Indirect ignition is possible by the heating of solid materials with high acoustic absorption coefficients
- Ignition could be effected for sulphur dust, carbon disulfide and diethyl ether.
- Hydrogen-air or even hydrogen-oxygen mixtures could not be ignited.

Adiabatic compression and shock waves

- Adiabatic compression as an ignition source is only possible within closed volumes, i.e. geometries where a hydrogen-air mixture is compressed causing the mixture to exceed its AIT
- Shock waves are unlikely ignition sources if the source of the flammable cloud and the source of shock waves are not coupled
- Diffusion ignition: shock wave resulting from failure of high-pressure reservoir containing hydrogen. Shock wave causes mixing of hydrogen and air and sufficiently high temperature to cause ignition
- Has especially been seen in thin vent stacks

Diffusion ignition: mechanism



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Exothermic reactions

- Exothermic reactions are a known source of hydrogen gas.
- There are several incident reports where an unwanted chemical reaction resulted in the generation of hydrogen gas which also ignited (Wen 2022)
- No reports on the reaction itself being an ignition source

Summary results experiments performed: Gexcon, electrostatic charging of non-earthed object

- Electrostatic charging due to particles and gravel outside of high-pressure reservoir and drawn along by the jet release is possible
- No electrostatic sparks
- Future tests: reduction of capacitance of charged object will lead to higher voltages and potentially sparks (Q=C*V)

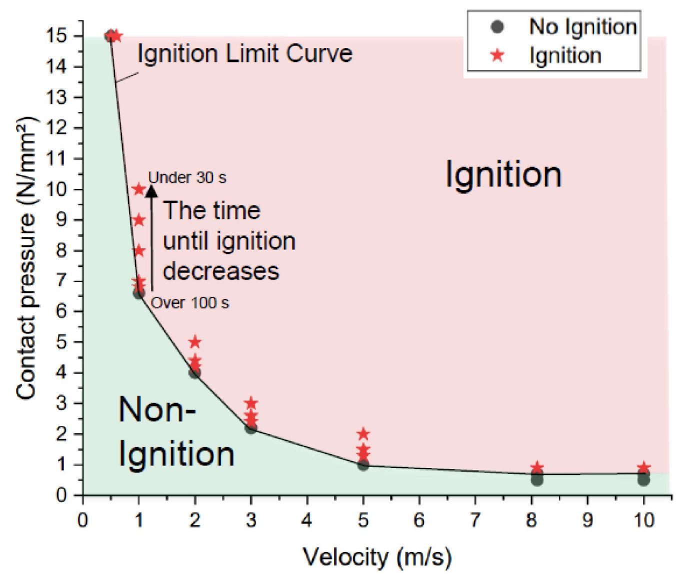
BAM: Single mechanical impact

- Several new material combinations tested
- High incendivity combinations include:
  - Quartz - quartz
  - Quartz - concrete
  - Quartz - stainless steel
  - Stainless steel - stainless steel contaminated by oil
  - Stainless steel - sand-blasted stainless steel

- Low incendivity combination:
  - Bassalt - concrete
  - Bassalt – stainless steel

PTB: mechanical friction

- Lower conductivity: higher incendivity due to hot surfaces
- Material combinations:
  - Stainless steel – concrete
  - Aluminium bronze – concrete
  - Mild steel - concrete



Stainless steel - concrete

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DNV: diffusion ignition flange configuration

- Work still ongoing

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Ignition modelling concept

- Based on MISOF framework for ignition modelling (Lloyd's Register Consulting, 2018)
- Physical properties of hydrogen released (pressure, temperature) and ignition properties
- Contribution of each ignition sources/mechanisms as described in EN1127-1 considering the defined "ignition cases"
  - Ignition sources generated by the release itself
  - Ignition sources not caused by the release itself
  - Ignition sources not included in the model
- Immediate and delayed ignition

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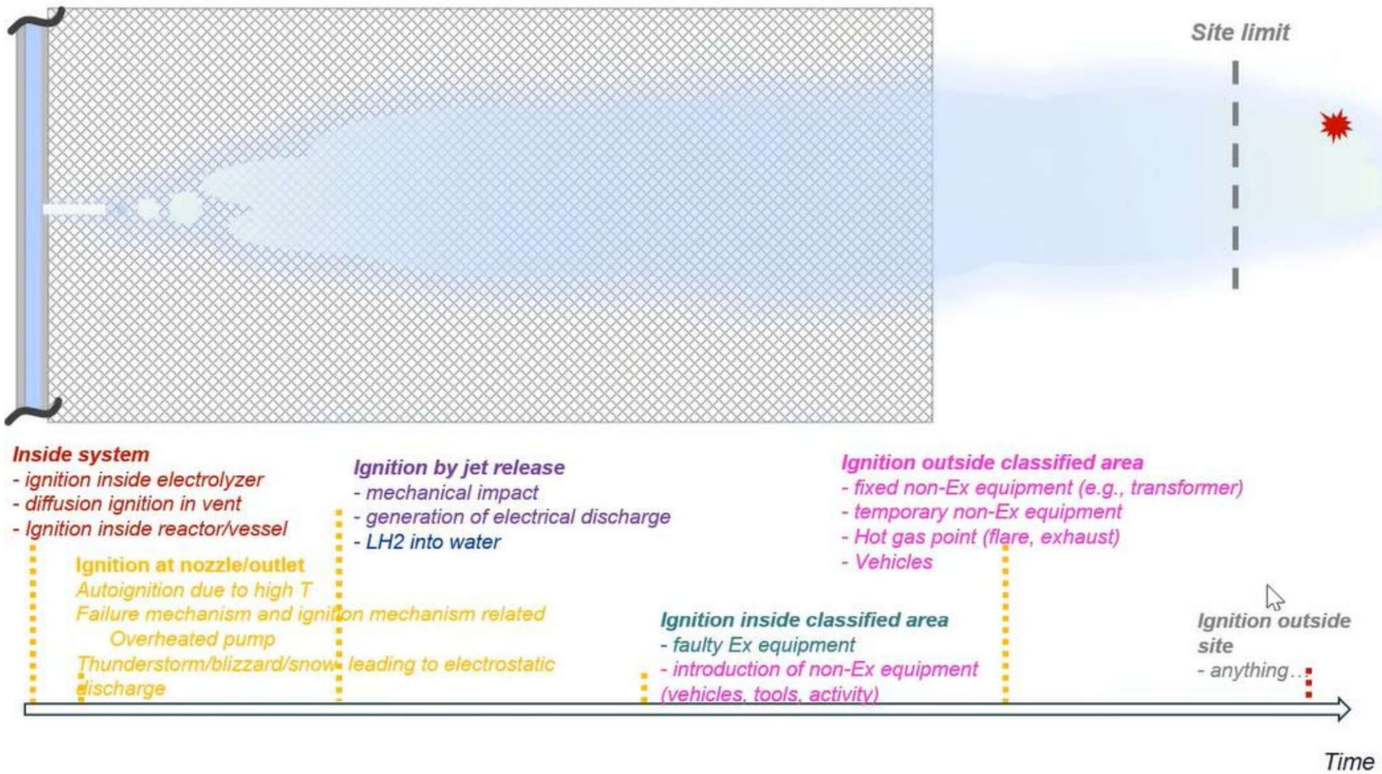
Ignition cases



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Ignition cases

- IC1001 Internal ignition
- IC1002 Internal ignition in vent system
- IC2001 Ignition of cold vent
- IC2002 Ignition due to high process fluid temperature
- IC2003 Event ignition of LoC Failure cases
- IC2004 Ignition of LH2 leaked onto/in water
- IC3001 Ignition by jet release
- IC3002 Ignition in classified area – fixed equipment
- IC3003 Ignition in classified area - temporary Non-Ex equipment
- IC4001 Ignition outside classified area - fixed Non-Ex equipment
- IC4002 Ignition outside classified area - hot gas point sources
- IC4003 Ignition outside classified area – activity
- IC5001 Ignition outside facility premises

Immediate ignition and delayed ignition

- By definition immediate ignition results in a jet fire whereas a delayed ignition results in an explosion
- Considering jet releases: the turbulence combined with the high reactivity of hydrogen makes that strong explosions can be expected already within a fraction of a second
- In this light only two types of releases are considered to result in immediate ignition:
  - Diffusion ignition
  - Release of hydrogen at temperatures exceeding its auto-ignition temperature

Ignition cases

IC1001: internal ignition (hydrogen-oxygen mixtures, e.g. after membrane failure)

- Electrostatics
- Stray currents
- Will not be included in ignition probability model

IC1002: internal ignition in vent system

- Diffusion ignition (immediate ignition dependent on internal pressure and)
- Electrostatics

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Ignition cases

IC 2001: Ignition of cold vent

- Electrostatics: corona discharge (probability related to occurrence of “electric weather”)

IC 2002: ignition due to high fluid process temperature

- Hydrogen temperature higher than AIT upon release

IC 2003: event ignition of LoC due to failure cases

- Diffusion ignition at flange
- Electrostatics
- Overheated pump
- Hot surfaces due to mechanical rupture

Ignition cases

IC 2004: ignition of LH2 leaked onto/in water

- Unknown ignition source: during bunkering operations (inherent ignition source)

IC 2005: ignition by jet release

- Electrostatic charging unearthed and non-conductive objects (related to release rate)
- Single impact (related to release rate)
- Corona discharges at sharp objects due to ice/snow from LH2 container

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Ignition cases

IC 3002: ignition in classified area –fixed equipment

- Probability of Ex-equipment failing, radio waves
- Dependent on hydrogen cloud size and position

IC 3003: ignition in classified area – temporary non-Ex equipment

- Probability of presence of temporary non-Ex equipment
- Activities (hot work, electrostatic sparks from workers, stray currents)
- Dependent on hydrogen cloud size and position

Ignition cases

IC 4001: ignition outside classified area – fixed non-Ex equipment

- Dependent on gas tightness, rotating equipment, radio waves
- Dependent on hydrogen cloud size and position

IC 4002: ignition outside classified area – hot gases point sources

- Flares, car exhausts
- Dependent on hydrogen cloud size and position

IC 4003: ignition outside classified area – activity

- Hot work, forklifts, electrostatic sparks from workers
- Dependent on hydrogen cloud size and position

Ignition cases

IC 5001: ignition outside facility premises

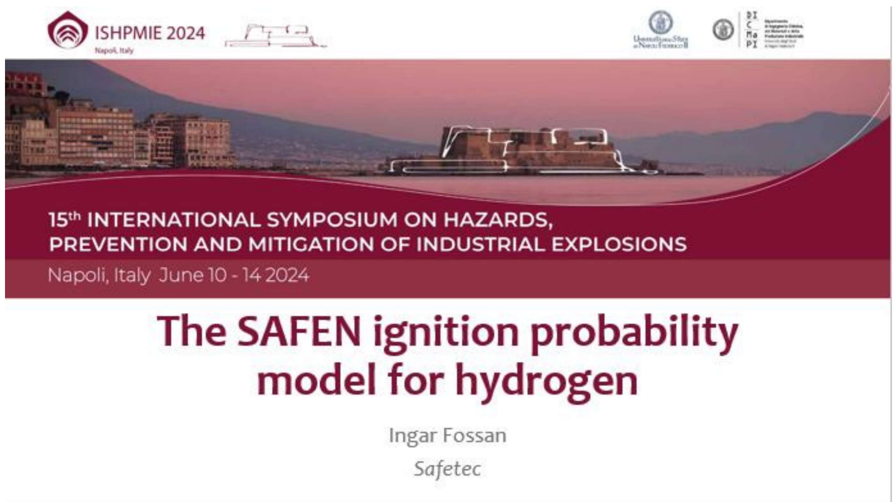
- Anything

Possibilities of ignition probability reduction by design and maintenance

- Model allows for inclusion ignition probability reduction by design and maintenance
  - Use of basalt instead of quartz containing gravel as a substrate
  - Cleaning of concrete floors to avoid material that can be drawn along by a release
  - Clean inside of pressurized-hydrogen equipment
  - Earthing of all metal parts of an installation including bolts, avoid non-conducting parts
  - Using of slow opening bursting discs or other sufficiently slow opening devices to protect against overpressurisation
  - Avoidance of sharp edges at equipment, toroid ring on top of vent stack
  - Lightning protection, stray current protection
  - Use of Ex-equipment throughout entire installation (i.e. beyond that what hazardous area classification demands)
  - Wear ESD-safe (electrostatic discharge) shoes and fire-resistant clothing that does not generate static
  - Limitation of power and energy of radio transmission waves. Follow guidance for what to do if power is above safe levels

Hydrogen ignition probability model

- The presented status of knowledge and concept is used to improve the hydrogen ignition probability model suggested in phase 1 of SAFEN



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Thank you for your attention

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