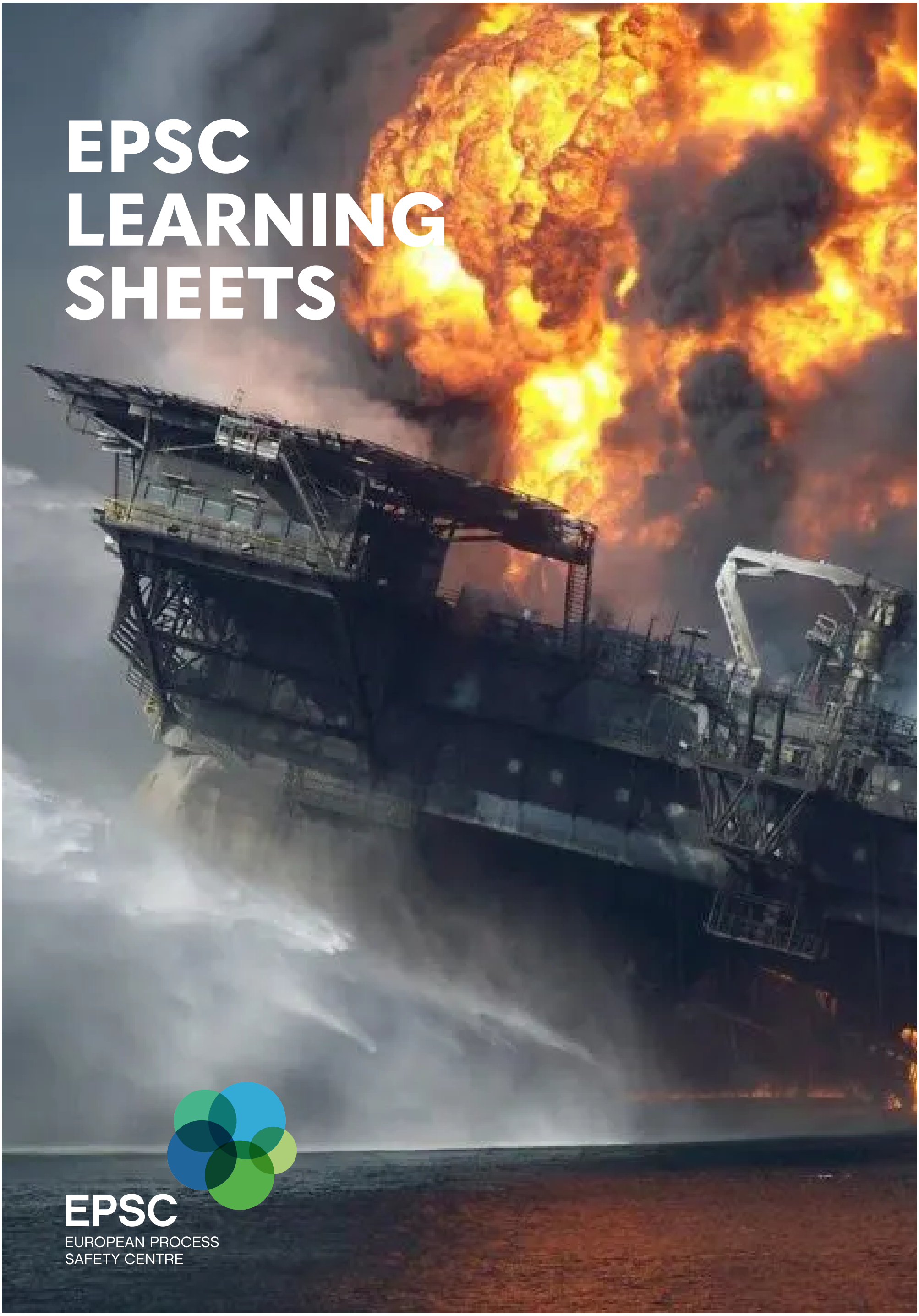


EPSC LEARNING SHEETS

EPSC
EUROPEAN PROCESS
SAFETY CENTRE

INTRO

Learning from incidents that involve hazardous chemicals is a difficult process, as similar incident occur multiple times. Raising awareness on the practical aspects that can help avoiding these incidents remains a key task for all involved.

Included in this booklet are EPSC Learning sheets that have been published in the period 2017-2023 and that are available in many languages on the EPSC website. They can provide input for a valuable discussion on safety of chemical processes.

DISCLAIMER

EPSC Learning sheets are meant to stimulate discussion and raise awareness on processes with hazardous chemicals. They are available free of charge. The user of the sheets remains fully responsible. EPSC can not be held liable for any consequence of the use of the Learning Sheets.

TABLE OF CONTENT

1. RUPTURED HOSE

WHAT HAPPENED

Phosgene was unloaded from 1-ton cylinders through a flexible hose (PTFE braided with stainless steel) to a chemical process. Under the label, the hose braiding corroded. The weak hose ruptured, spraying a nearby operator with Phosgene.

PROCESS SAFETY FUNDAMENTAL

Verify the condition of flexible hoses

ASPECTS

- Phosgene permeates through PTFE causing high HCl concen-trations under the label that fully corroded the stainless-steel braiding. Avoid permeating plastics and assure braiding material is resistant (SS-316 is incompatible with HCl).
- Inspect hoses according a PM schedule and replace in time.
- When deviations like corrosion are observed (see photo), take appropriate action on all similar hoses.
- Hoses full of liquid Phosgene could be blocked in, causing increased pressure during temperature rise. Discuss this hazard in PHA studies and explain this to operators.
- Use fixed piping (avoid hoses) for very toxic chemicals.

AVOID FLEXIBLE HOSES WITH VERY TOXIC CHEMICALS

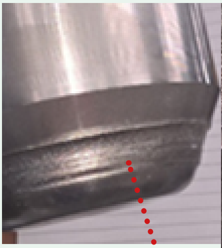
2. DAMAGED VALVE

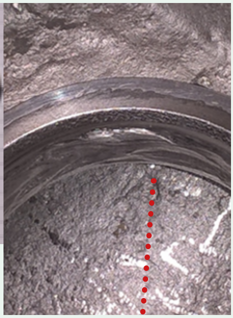
WHAT HAPPENED

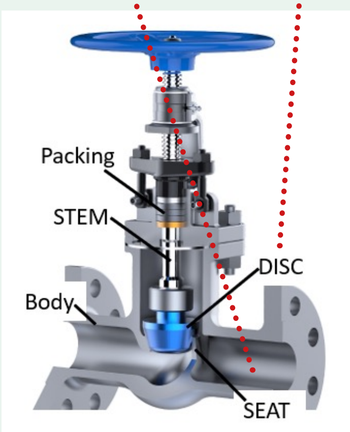
A ball valve was replaced by a globe valve to throttle an ethylene flow from 80 to 30 bar. The throttled valve caused heavy vibrations in the connected 3-inch pipeline that could have caused fatigue rupture. Vibrations were discovered betimes before leakage.

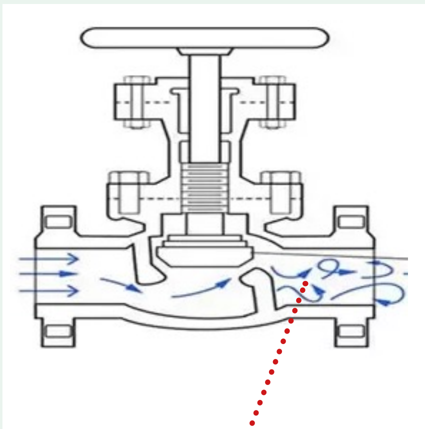
ASPECTS

- When a valve is partially closed to below 20% of its original opening, vortex induced vibrations can cause damage to valve seating, disc, packing and stem.
- Throttling a valve to reduce flow and pressure requires analysis, good valve design and operation (see API-615).
- Strong support and anchoring are required, to protect equipment and piping.
- Ethylene pressure reduction can result in brittle carbon steel due to low temperature; control is required.
- Assess vibration and erosion when choosing a valve that might be used in a partially closed position.









vortex

BE CAREFUL WHEN REDUCING PRESSURE BY THROTTLING VALVE

3. EXPLOSION IN A TANK

WHAT HAPPENED

A Sulfuric acid tank was emptied, aerated and prepared for inspection. During removal of rusted bolts of a cover on the tank roof using a grinder, an explosion occurred. Hydrogen had collected under the tank roof.

ASPECTS

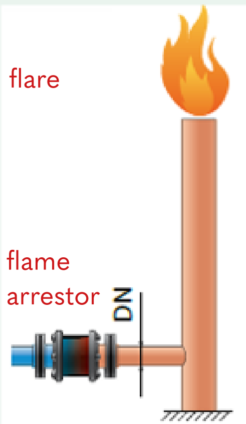
- Concentrated Sulfuric acid with some water becomes very corrosive for carbon steel and generates hydrogen:
  $H_2SO_4 + Fe \rightarrow H_2 + FeSO_4$
- Measuring the presence of flammable gas was done at the manhole (entry) at the bottom of the tank. The explosive mixture (hydrogen/air) however accumulated under the dome at the top of the tank.
- Hydrogen in air has a very wide explosive range, it has a very low ignition energy at stoichiometric concentration and leads easily to a violent deflagration or detonation upon ignition. Assure top venting of acid tanks that are prepared for maintenance and inspection.
- Avoid accumulation of hydrogen at high locations.

HYDROGEN CAN ACCUMULATE AT HIGH LOCATIONS FORMING AN UNEXPECTED EXPLOSIVE MIXTURE

4. BURST FLAME ARRESTOR

WHAT HAPPENED

High gas flow rate above design was sent by a compressor to a flare. This caused high pressure and the inline flame arrestor to burst releasing natural gas



ASPECTS

- The gas flow was too high to be measured by the flow meter! The flow was outside design. The operators were unaware of process limits and thought they could flare at any rate. Train operators well and provide clear procedures.
- It is good practice to have an alarm on high flow and on high pressure in a flare line to stay within safe operating limits.
- Flame arrestors are critical equipment, their reliability has to be ensured. Cleaning is important as they can foul and become a restriction.
- Flame arrestors pressure rating is often below the pipe spec.
- Avoid deflagration flame arrestors in flare systems. See ISO 16852 for design of flame arrestors on flare systems.

OPERATE FLARE SYSTEMS WITHIN SAFE LIMITS

5. INSPECTOR FAINTED

WHAT HAPPENED

During a tank inspection an inspector put his head inside a tank and fainted as there was a nitrogen atmosphere. Co-workers saved him from asphyxiation.

ASPECTS

- Clarify the task and document the risk analysis. What will be done and how? What risks exist and must be excluded? The permit to work mentioned 'tank inspection through the manhole'. It was not recognized that this would require a tank entry.
- Prior to inspection the tank was cleaned with nitrogen gas and the manhole was opened. Operation did not consider the remaining Nitrogen as a hazard, did not place a sign 'Do not enter- or prohibited tank entry physically. The inspector did not use an oxygen sensor to test the atmosphere before putting his head in the vessel.
- Filling your lungs with Nitrogen gas makes you faint very quickly and kills many in industry.
- Never do a tank entry alone and assure a person at the manhole is available for emergency response.
- Tank entry is a hazardous operation that requires good preparation including testing of the atmosphere.

INERT GAS IN A CONFINED SPACE IS DEADLY

6. FAILING SAFETY SYSTEMS

WHAT HAPPENED

When a last line of defence is not working severe incidents happen.

1.Bhopal
Flare was not working
(this was known)

2. Chernobyl
Emergency stop did not work
(design flaws were known)

3. Ski-lift Italy
Emergency break was bypassed
(on purpose)

4. Macondo oil rig
Blow-out preventor failed

ASPECTS

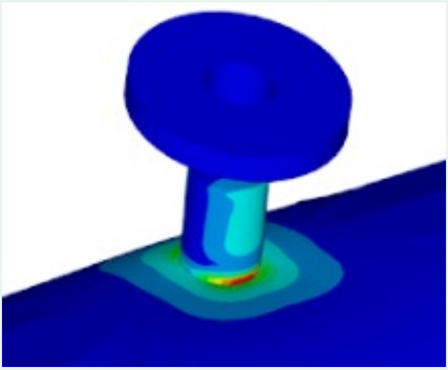
A solid last line of defence, like SIL rated interlocks, Pressure relieve devices and Passive barriers, are essential for scenario's that involve multiple fatalities. Assure high reliability by a good design, preventive maintenance and regular testing.

A LAST LINE OF DEFENCE, THAT PREVENTS MULTIPLE FATALITIES, HAS TO WORK

7. FATIGUE CRACK

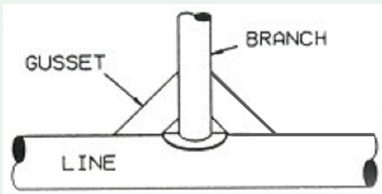
WHAT HAPPENED

A pressure indicator mounted on a pipeline after the compressor started to leak at the weld point of the branched pipe. Due to trembling a fatigue crack was formed.



ASPECTS

- Compressors (& mechanical equipment) introduce energy that can result in trembling of pipelines that eventually cause fatigue cracks.
- Small bore piping (<1 inch) is sensitive for fatigue as the connecting surface is small.
- Gussets can be used to strengthen the connection of branched pipes to minimize movement.
- Also a larger tie-in can be taken that is further reduced to the smaller required tubing size.
- Dampers can absorb energy and mitigate vibrations.
- Assure good fixation of piping to avoid movements that result in fatigue and repair fixation when applicable.
- Stress calculations (top image left) can indicate weak spots.



AVOID FATIGUE CRACKS AT SMALL BORE TUBING

8. VIS-BREAKER FIRE

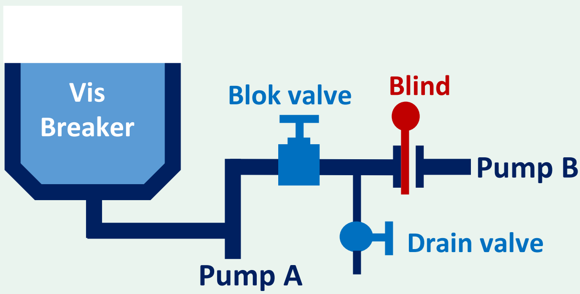
WHAT HAPPENED

Reconnecting the B bottom pump of a visbreaker distillation column, resulted in a hot hydrocarbon release and fire.

The work took place behind a single valve that was not fully closed and released a sludge plug when the blind to the pump was unbolted.

ASPECTS

- The single valve to the process was not well closed and blocked by heavy residual material. This is a typical hazard of valves in heavy hydrocarbon services.
- Before opening such systems clean them well and try to flush heavy residuals away with lighter solvents.
- Opening of the drain line (between suction valve and blind) did not reveal that the valve was not entirely closed. Validate that drain valves and lines are fully open and unplugged. Also tubing to pressure sensors can be blocked.
- The release could not be stopped by the emergency valve to the column as cables to the valve were already burned. A fail close valve or fire protection could have helped.



WORKING BEHIND A SINGLE VALVE IS A HAZARDOUS OPERATION THAT REQUIRES ADDITIONAL MEASURES

9. EXPLOSION AT HYDROGENATION UNIT

WHAT HAPPENED

A rupture of an 8″ pipe elbow in high pressure (280 bar) and high temperature (320 °C) service in a hydrogenation plant was followed by a release and ignition of hydrogen. The construction material of the elbow was carbon steel which is not a resistant alloy and prone to high temperature hydrogen attack (HTHA) at mentioned conditions.

ASPECTS

- Hydrogen under high pressure and high temperature will cause hydrogen attack resulting in micro fissuring and decarburization due to methane formation. Suitable material (Cr/Mo alloys) need to be used within their Nelson curves (API-941 ed 8th), checked regularly. Material selection need to be reviewed during revalidation of the hazard assessments.
- Make sure to check the correct material of construction sufficiently during assembly and posterior maintenance. Verify the equipment marks to avoid installing a non-suitable piece of equipment.
- A proper MOC process needs to ensure that all potential risks are checked including material aspects. When replacing components, a 'real in-kind replacement' needs to be guaranteed.
- A Pre-Start-up Safety Review with elaborated checklists can assist to unveil deviations in materials of construction.

USE CORRECT MATERIAL OF CONSTRUCTION IN HYDROGEN SERVICES

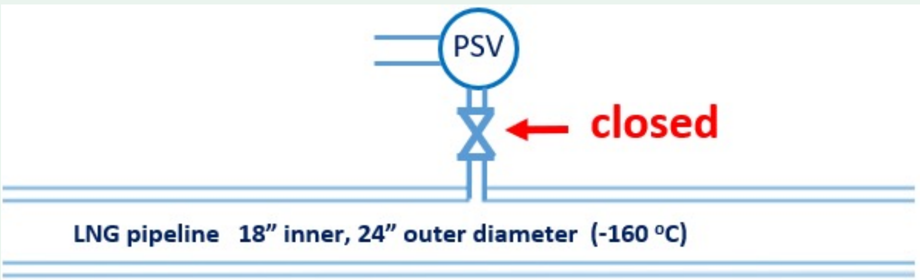
10. LNG EXPLOSION

WHAT HAPPENED

After an inspection of a Pressure Safety Valve (PSV) it remained blocked-in: separating an LNG pipeline from the PSV. During pressure build-up, the LNG pipeline started to leak creating a methane cloud that exploded.

ASPECTS

- A valve between a PSV and the equipment that needs pressure protection requires special attention.
- An isolation checklist helps to assure all valves are managed well, and end-up in the right position after maintenance.
- PSV maintenance requires individual permit to work.
- Pre Start-up Safety Review, after maintenance work, can validate the position of critical valves.
- Critical valves that must be open during production, can be locked with a car-seal or with a key-lock system that shows a green or red key in the control room.

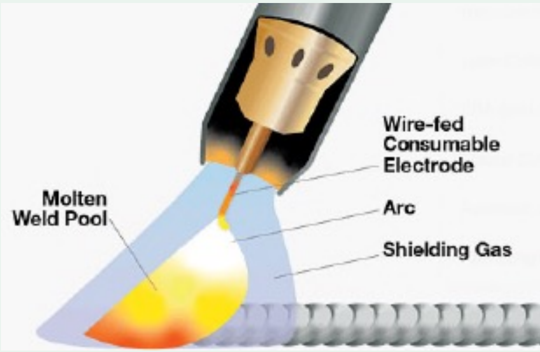


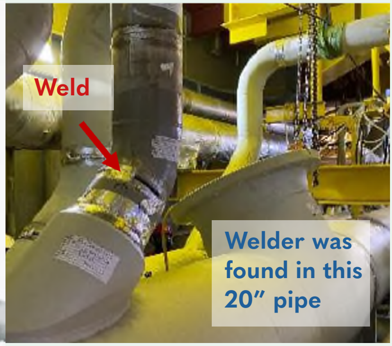
A PRESSURE SAFETY VALVE MUST BE CONNECTED TO THE SYSTEM IT PROTECTS

11. ARGON ASPHYXIATION

WHAT HAPPENED

During construction work at an LNG plant, Argon was used in Corrosion Resistant Alloy (CRA) welding, to remove oxygen from the molten weld. The Argon accumulated in the piping and when the welder checked the weld from inside, he fainted and died.





ASPECTS

- There is no early warning before fainting, that can occur after 20 seconds breathing Argon instead of air. Argon is slightly heavier than air and can accumulate at low points.
- Consider alternative welding technique like Flux-cored arc that does not require an inert gas.
- Assure welders are trained and aware of the Argon hazards.
- Assure welded pipes are capped and equipped with signs mentioning fatal hazard.
- Assure a welder enters a pipe only with an approved confined space permit and an oxygen detector.
- When finding an unconscious person in a confined space, first alert and equip yourself with breathing air before rescuing.

ARGON CAN CAUSE ASPHYXIATION

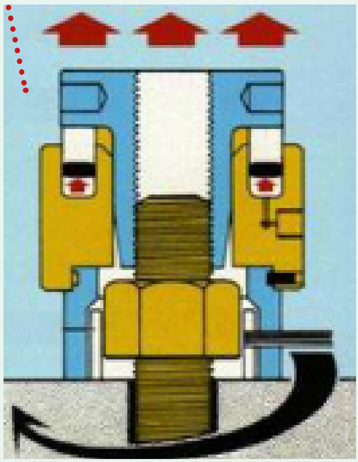
12. LEAKING FLANGE

WHAT HAPPENED

In a refinery desulfurization unit a flange leaked hot hydrogen, that took fire. The flames impinged on a reactor that got leak and a large fire started.

ASPECTS

- Hydrogen flames are difficult to see in day time.
- Bolt tension can change overtime especially at equipment with temperature cycles.
- Document the Packing and ideal BoltTension for critical flanges.
- Use a Torque Wrench, attention for friction!
- Rotabolts™ can measure and adjust bolt tension during use.
- Also available Pre-Clamping Cylinders to assure bolt tension on large flanges.



- Consider to not insulate critical hot flanges, so leakages can be detected.
- Consider a PM or monitor plan.

TAKE CARE OF CRITICAL FLANGES

13. CONDENSATE EXPLOSION

WHAT HAPPENED

On the roof of a water / natural gas condensate tank at a gas production site, welding work was done. A handle of a valve was moved out of the way, that opened it. LPG flowed through the valve to the hot spot and exploded. Two workers died.

Handle

ASPECTS

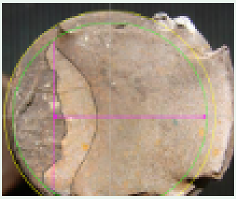
- ‘Condensate’ is not water: in Oil & Gas exploration it refers to LPG that can ignite and explode when mixed with air. The contractors doing the work were unaware of this.
- The hot work was not well isolated from the gases in the tank (e.g. by LOTO or a spade): a valve could be opened that allowed LPG from the tank to flow to the hot pipe and ignite.
- The welding was added later to an existing permit to work, that was not recognized as high risk work afterwards.
- No good discussion took place on the work hazards between permit issuer and contractor.
- The tank was not made free from the hazardous LPG.
- The workers felt safe as as safety was important on the site.

ASSURE ABSENCE OF FLAMMABLE MATERIALS BEFORE STARTING HOT WORK

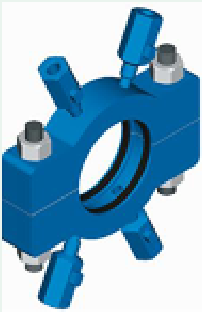
14. STEAM EXPLOSION

WHAT HAPPENED

During reinjection of a clamp on a flange of 70 barg 290 °C water line, the 20 bolts failed and steam was violently released. Two contractors died.



Broken bolt



Clamp

Re-injection on a clamp on leaking flange.

ASPECTS

- High pressure steam release is dangerous: besides the high pressure and heat, steam also eliminates visibility and oxygen.
- Stress Corrosion Cracking phenomenon in bolts or studs should always be considered even when bolt material has been selected as SCC resistant (e.g. threaded rolled ASTM A193 Grade B7 bolts and studs).
- During injection of a clamp the tension on the studs can be increased with 10 to 20% (from experiment).
- Caustic is used for pH control in steam systems. High caustic can weaken the carbon steal piping and bolts after leakage: attention for white deposit.

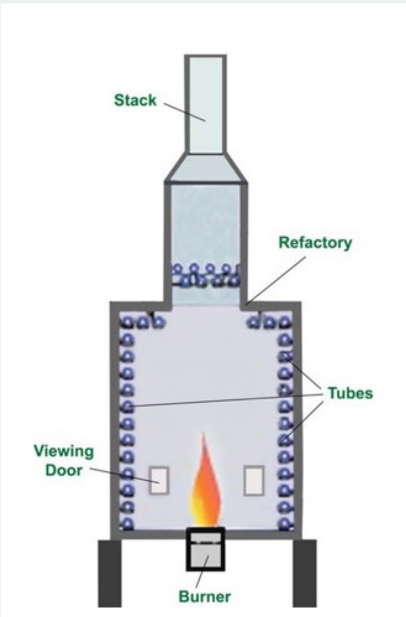
- A Clamp is a temporary solution, plan removal at installation.

CLAMP REINJECTION IS HAZARDOUS AND NEEDS SPECIAL ATTENTION

15. FURNACE FIRE

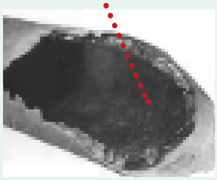
WHAT HAPPENED

At refineries large furnaces are used to heat-up hydrocarbons for refining. A red hot spot was identified on a furnace tube that later ruptured. The hydrocar-bons entered the furnace and created a large fire in which an operator died.



ASPECTS

- The temperature in the furnace is above the design of the carbon steel tubes. Only because of the liquid flow in the tubes, the steel is cooled to acceptable temperature.
- Respect the temperature window and check for red hot spots on the tubes, visually or using IR detection When a hot spot is detected, take the pre-defined actions.
- Good burner pattern can avoid flame impingement on tubes.
- Carbon deposit in the tubes can be a cause for red spots.



Furnace Tubes

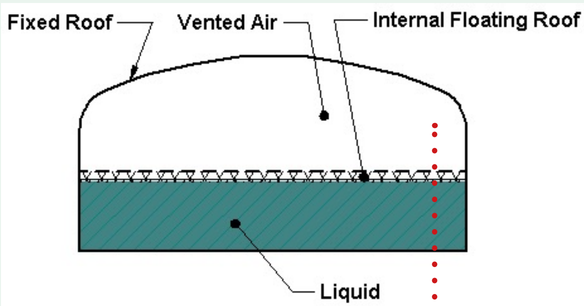
- Temperature difference between the different tubes exiting the furnace can be a good indicator to shut down the furnace.

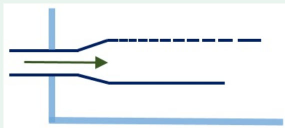
FURNACE TUBE RUPTURE SCENARIO MUST BE WELL STUDIED AND PROTECTED

16. STORAGE TANK ON FIRE

WHAT HAPPENED

A storage tank with an inner floating roof got on fire while being loaded from a tanker with gasoline.





ASPECTS

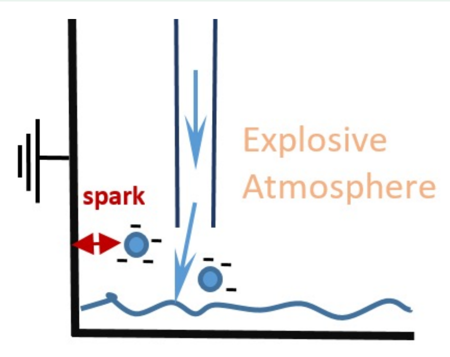
- Floating roof of flammable liquid storage tanks are zone 0, that require elimination of all ignition sources.
- Hydrocarbons can accumulate here.
- In this incident, it seems that a spark generated around the floating roof seal started the fire.
- Check seal performance with e.g. an explosion meter or FLIR.
- Assure that the internal floating roof is well bonded.
- Minimise trembling & static charging due to gas bubbles from filling, by inlet pipe design.
- Automatic extinguishment of rim fires is good practice.
- Good design and fire protection needs to avoid domino effects from heat radiation, use QRA and apply safe distances.

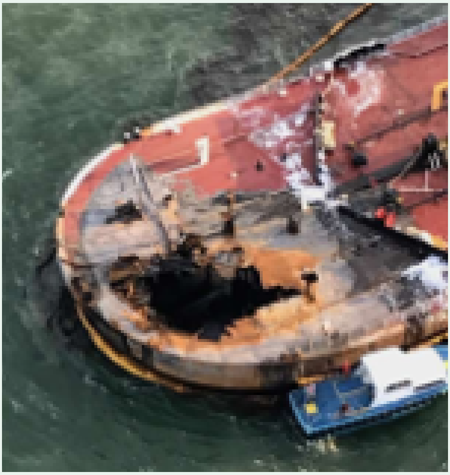
AVOID FIRES ON FLOATING ROOF TANKS

17. BARGE HOLD EXPLOSION

WHAT HAPPENED

While loading kerosene from a refinery into a barge an explosion in the hold took place. Charged droplets after splash loading was the most likely ignition source.

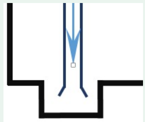




Example photo for illustration

ASPECTS

- Substances with low electrical conductivity and flash points below 20 °C are hazardous, and form explosive atmospheres.
- When filling an empty vessel initial loadings speed must be below 1 m/s to avoid charged droplets! The initial pump speed must be part of the signed loading agreement.
- Filling pipe design can reduce droplet formation by splash loading.



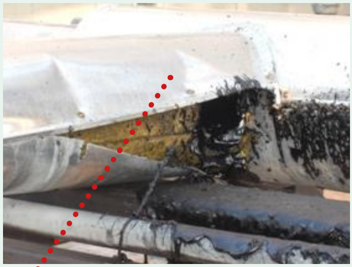
- The incident happened after low ambient temperature resulting in dry air, that only slowly dissipates electricity.
- A connected barge is a process part to be reviewed in a PHA.
- While crude tankers are made inert by exhaust gases, the holds in barges contain air and potential explosive mixtures.
- Grounding is important but does not avoid the creation of charged droplets that can generate a spark.

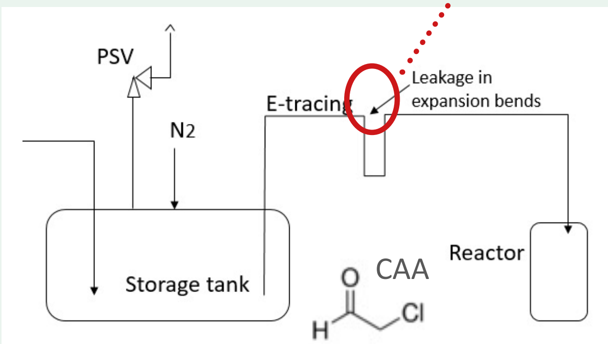
AVOID SPLASH LOADING OF HYDROCARBONS

18. RUN AWAY IN A STORAGE TANK

WHAT HAPPENED

At a pharma production location a storage tank with 45% chloro-acetaldehyde (CAA) released an HCl cloud after the CAA polymerised in an exothermic reaction. The pressure increase ruptured piping.





ASPECTS

- A failing tank tracing caused an initial temperature rise.
- 45% CAA in water can polymerise exothermic as of 60°C.
- The reaction plugged the line and continued in the tank.
- The PSV was not sized for this scenario, high pressure damaged gaskets and caused a hole in the piping (picture).
- It is essential to understand the chemistry under normal and all foreseeable abnormal conditions (quote from CSB).
- Contaminants sometimes act as catalyst and start a reaction.
- The SDS did not mention the exothermic polymerisation specifically. Indicated storage conditions can be important.
- Determine thermal stability and safe storage conditions using lab tests, DTA (Thermal Analysis) and modelling.

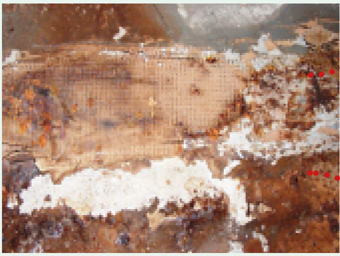
AVOID REACTIONS IN STORED CHEMICALS

19. CHLORIDE STRESS CORROSION

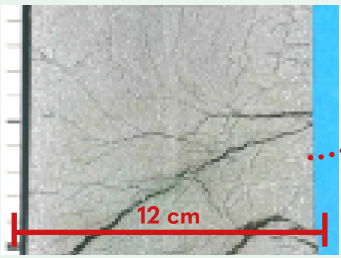
WHAT HAPPENED

A leak was discovered on a stainless steel pressure vessel, that showed large cracks that started underneath adhesive tape. The cracks grew undetected behind thermal insulation.

Crack in vessel wall (visible with red die)



Corrosion developed under adhesive tape



Cracks through wall

ASPECTS

- Chloride Stress Corrosion Cracking occurs as of ca 50 °C on Stainless Steel (like 304 & 316) in the presence of Cl.
- Adhesive tape was found to be the source of the chlorides: 4% Chlorine was detected in the remains of it.
- Local repair can be possible, never easy.
- Avoid chlorides on stainless steel.
- Be aware that glue (e.g. tape), inks (e.g. marker pens) and sometimes insulation can contain chlorides.

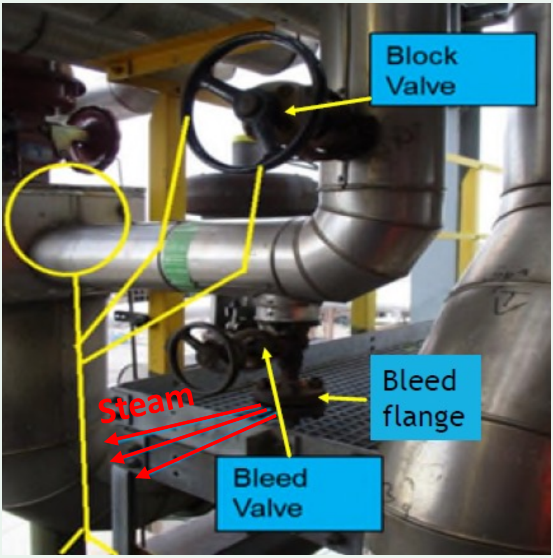
Next crack location?

AVOID CORROSION OF STAINLESS STEEL BY CHLORIDES, HERE FROM AN UNEXPECTED SOURCE

20. STEAM EXPLOSION

WHAT HAPPENED

Condensate was drained from a steam line by opening the bleed valve and flange (for maintenance). When an operator opened the block valve, he was hit by steam that came out of the bleed flange (see image).



ASPECTS

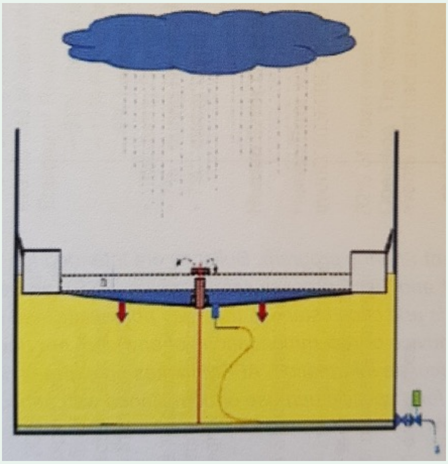
- The special line-up (draining) was not secured by a locked block valve. LOTO can help to secure the block valve.
- The special situation was described in the logbook, but insufficiently addressed in the shift handover.
- Identifying the special situation in the field by a label can help warning the operator of this special line-up.
- Utilities might have a lower level of attention, but steam and nitrogen are hazardous and require full attention.
- The hazards of special line-up need to be understood.
- Heat and fire resistant clothing can help to mitigate injury.

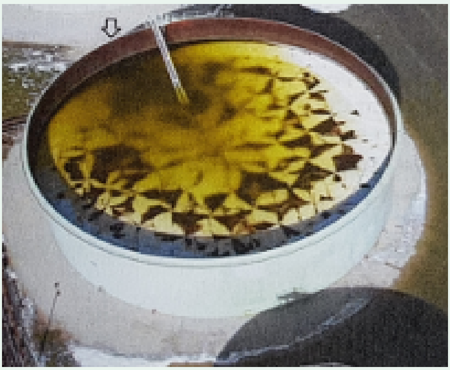
SECURE THE HAZARDS OF SPECIAL LINE-UPS

21. SUNKEN ROOF IN STORAGE TANK

WHAT HAPPENED

Insufficient draining of rainwater on floating roofs of storage tanks has resulted in many sunken roofs. Good draining is not easy.





ASPECTS

- Water on floating roof is hazardous as the roof deforms and eventually sinks.
- Water on the floating roof can push the roof legs to the tank bottom and subsequently pressing hydrocarbons through the vacuum breaker on the roof.
- Procedures often require water drains from floating roofs to be normally closed, to avoid hydrocarbon releases from the internal flexibles that can start to leak.
- Typical causes for insufficient drainage of roof water are: closed drain valve, frozen drain, debris/ fouling in the drain.
- Roof drains that are not well indicated have been mixed with the tank water drain resulting in hydrocarbon spills.
- Validate that rainwater drain capacity is sufficient.
- Hydrocarbon recognising block valves (after the drain valve) can help to stop the drainage of hydrocarbons.

REMOVE WATER ON STORAGE TANK FLOATING ROOF

22. FLASHING OF HYDROCARBONS

WHAT HAPPENED

A carbon steel heat-exchanger reached -40 °C due to flashing of propylene. It was depressurized after a trip, and restarted (pressurized). It ruptured open and an explosion and a serious fire took place.

ASPECTS

- Depressurising (flashing) of C_2, C_3 hydrocarbons can result in low temperatures, where plain carbon steel becomes brittle.
- Never pressurise equipment when being below its design temperature: due to the stress of the brittle steel at low temperature it can break catastrophically (see picture).
- Include flashing scenarios in the PHA and define measures.
- Measure impact strength at low temperature of the specific steel batch used (in design phase), in case the equipment can auto-refrigerate by flashing.
- Validate the mechanical integrity by an inspection expert when equipment has gone below its design temperature, before using it again.
- Train auto-refrigeration scenarios with operators.

AVOID COLD BRITTLE STEEL
DUE TO FLASHING OF HYDROCARBONS

23. COLLAPSED RAILWAY CAR

WHAT HAPPENED

A railway car collapsed during unloading. A new railcar was purchased that did not have the low pressure specification that operation was used to.

ASPECTS

- Emptying without a vapour line results in under-pressure. Railcars (and trucks) often do not have vacuum relief devices. Tanks that are not designed for vacuum will collapse.
- When purchasing new equipment, the specifications (like pressure rating) need to be carefully checked.
- A connected railcar is part of the process that has to be reviewed in a PHA: include this in the HAZOP.
- Use gas displacement procedure, e.g. a vapour line for pressure equalization, when a railcar is unloaded, to avoid low pressure.
- Blocked lines (freezing / fouling) may prevent addition of air, nitrogen or vapours and generate unexpected vacuum.
- Upon arrival of new equipment, validate specifications before putting it in use, or connecting it to the plant.

ASSURE GOOD SPECIFICATIONS FOR NEW EQUIPMENT

24. TANK BOIL OVER

WHAT HAPPENED

During a full surface tank fire, a boil-over occurred when water below the flammable liquid was heated above its boiling point and suddenly vaporized.

1955 series of boil overs

Nigeria 2016

ASPECTS

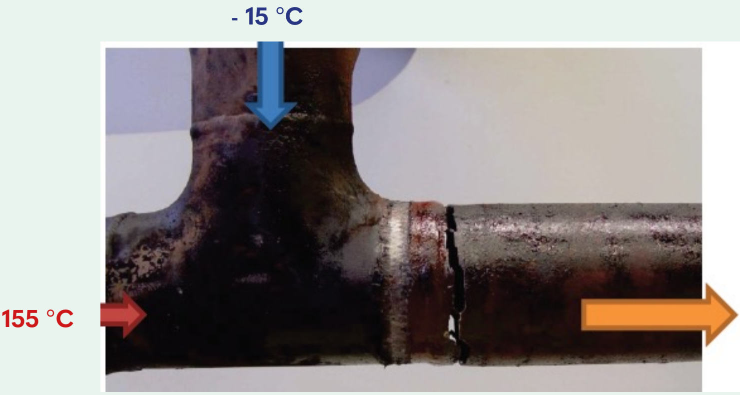
- During a full surface tank fire the liquid heats-up, that will heat the water layer in the tank in time. This water can be super-heated and turn into steam suddenly with great force.
- Water turning into steam multiplies 1500 – 1700 its volume.
- Minimise water in storage tank, by regular draining and by minimising water addition from the fire extinguishment.
- Flammables will typically stay within the bund during a boil-over. A single tank in a bund is therefore preferred.
- Fire people must be aware of this scenario and be prepared for it, extinguish the fire fast, and stay out of the bund.
- IR temperature guns can help to predict the boil-over.
- The best way to avoid Tank boil over is to avoid a full surface tank fire. Install sufficient measures for that.

CONSIDER AND BE PREPARED FOR A TANK BOIL OVER SCENARIO

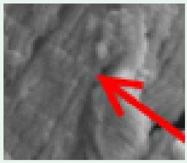
25. FATIGUE STRESS CRACKING

WHAT HAPPENED

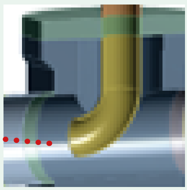
Just after the point where two liquids with different temperature met in a 80 mm stainless steel line, the tube fully ruptured, after only 6 weeks in use, causing a release and an explosion.



ASPECTS



- The large temperature fluctuations in the tube led to high tensions, cracks, and full rupture of the pipe.
- The mechanism can be confirmed by Scanning Electron Microscopy of the ruptured surface.
- CFD modelling estimated temperature swings to be above 120 K, that induced the rapid formation and growth of cracks from inside, that ruptured the tube.
- The pipe was made out of austenitic SS 316, other alloys would probably not have helped.
- Good mixing design with central tube inlet can reduce temperature fluctuation.
- Be cautious when mixing liquids with different temperatures. Inspection can not really help, only good design.

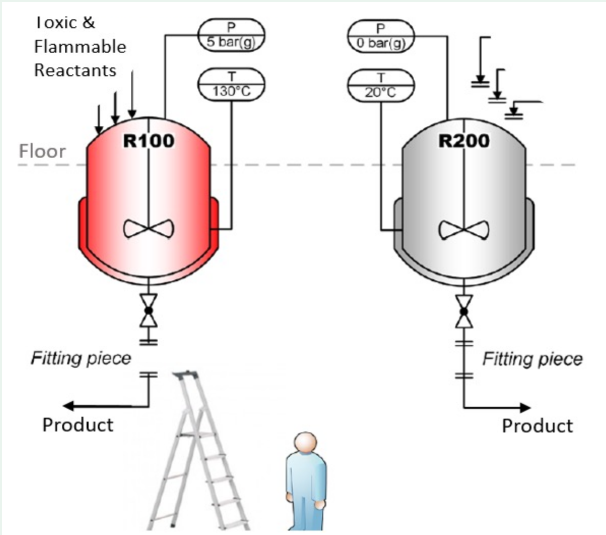


LARGE TEMPERATURE FLUCTUATIONS CAN INDUCE FATIGUE CORROSION

26. WORK AT WRONG LOCATION

WHAT HAPPENED

A mechanic was requested to remove the spool piece below a reactor that was well isolated for maintenance work. Unfortunately he went to the wrong reactor that was in use with hazardous chemicals.



ASPECTS

- Mechanics & contractors are not as familiar with the plant as operators and can easily end-up at a wrong location.
- It is the responsibility from operations that maintenance people and contractors work at the right equipment.
- It is essential to instruct the mechanic at the work location in the field and assure the task is fully understood.
- Make sure that critical flanges to be opened in the field are well indicated, e.g. by a label. In this case the reactors were not identified at the lower floor where the work was done.
- Just a permit to work, without instruction at the work site, is not a good barrier for this typical mistake.

**VALIDATE THE RIGHT LOCATION IN THE FIELD
BEFORE STARTING THE WORK**

27. CHATTERING PSV

WHAT HAPPENED

In 1985 in Priolo (Italy) an explosion occurred on a refinery, after a pressure safety valve opened. The vigorous opening and closing of the safety valve caused trembling that damaged the piping and caused an LPG release; the vapour cloud ignited.

ASPECTS

- Chattering is the rapid opening and closing of a pressure relief valve.
- The resulting vibration can cause misalignment, valve seat damage and sometimes even mechanical failure of valve internals and associated piping.
- Chattering is influenced by: high inlet pressure drop, high backpressure, oversized relief valve e.g. above 140% (See API 521 Part II, section 7) and is difficult to fully avoid.
- Avoid multiple PSV's with the same pressure setting.
- The PSV surrounding piping needs to be strong & well fixed.
- Inspect also for potential damage of the PSV fixture and surrounding piping, after a release.

**PSV CAN VIOLENTLY CHATTER AND CAUSE RUPTURES
THIS REQUIRES DESIGN CONSIDERATION**

28. BLOCKED PIPING

WHAT HAPPENED

A 4-inch pipeline from a distillation column to the PSV was plugged with polymer. High pressure events deformed the piping, as the pressure valve was blocked.

Popcorn Polymer

ASPECTS

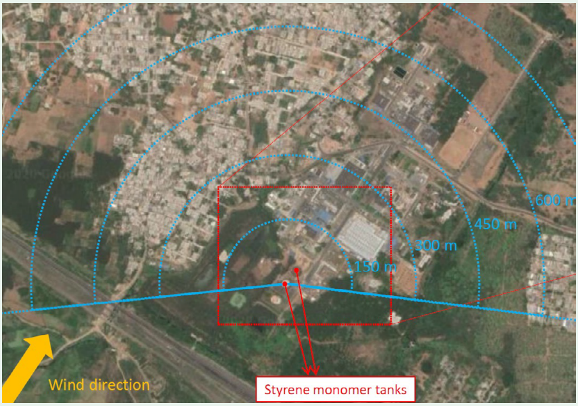
- The incident happened at a debutaniser distillation column in a refinery that separates C3 and C4 products.
- Double bonds can undergo radical polymerisation. Butadiene is known to do this well, even at reduced concentration (as of 30%, depending on temp. & pressure).
- Oxygen is an initiator: keep oxygen concentration low, add O_2 scavengers and passivate. equipment before start-up.
- Concentrations can build-up in dead end piping, like piping to a PSV, continuously flushing these lines can prevent issues.
- Learn to recognise deformed piping, as you can see that from the deformed paint (see the red circle). Report this.
- Include polymerization in pipelines in Hazard Analysis.

UNDERSTAND WHERE UNWANTED POLYMERIZATION CAN BE EXPECTED AND CAUSE PROBLEMS

29. TOXIC GAS CLOUD

WHAT HAPPENED

Styrene Monomer (SM) polymerised exothermally in two storage tanks, evaporating SM that was released from the tank. The toxic gas cloud killed 12 and injured ca 1000 in the area.



ASPECTS

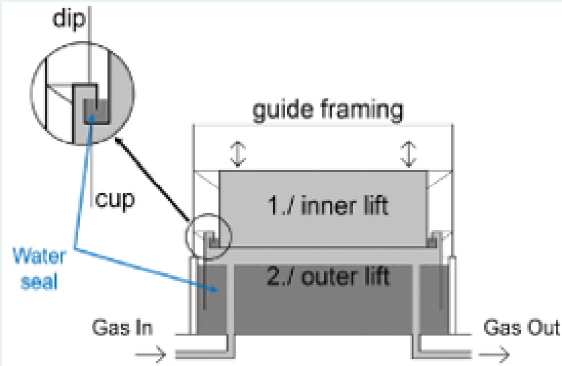
- SM evaporation created a lethal concentration of 5000 ppm at 200 m distance, killing and injuring nearby civilians.
- SM polymerisation must be avoided by keeping the temperature below 20 °C and adding an inhibitor (TBC).
- Control tank temperature with a SIL rated cooling system.
- Understand inhibitor (TBC) depletion characteristics, measure it and add it in time to stop a runaway reaction.
- Keep O_2 concentration 15-20 ppm in the liquid (that equals about 5% in the gas phase) to help inhibiting polymerisation.
- Keep circulation over the tank to avoid stratification.
- Storage siting: take off-site exposure into account.

STYRENE MONOMER STORAGE NEEDS ATTENTION

30. GASHOLDER RELEASE

WHAT HAPPENED

Vinyl Chloride Monomer (VCM) leaked from a gas-holder of 5000 m^3. The gas cloud ignited, resulting in 24 fatalities.



ASPECTS

- Gasholders can store large quantities of hazardous gases at low pressure.
- VCM is toxic and can form an explosive cloud.
- The inner (top) lift was tilted and got stuck. When it fell down 2000 m^3 of VCM gas was released through the water-seal. The cloud was ignited 130 meter away from the gas holder.
- Lubrication, so the top-lift does not get stuck, is essential. A lack of maintenance resulted here in the malfunctioning.
- Validate the horizontal position of the top-lift with e.g. radar or laser measurement as early warning for tilting.
- Pressure deviations initiate critical alarms, that need operational action.
- Eventually an inert gas can be added automatically at low pressures to avoid such an incident.
- Evaluate gas release consequences (e.g. with QRA or OBRA), and minimise presence in the identified hazardous area. In this case many truck drivers died sleeping in their cabins.

MAINTAIN GASHOLDERS WELL

31. AMMONIUM NITRATE

WHAT HAPPENED

Stored Ammonium Nitrate (AN) has exploded violently.

Beirut 2020
2700 t

Tianjin 2015
800 t

Texas 2013
200 t

Toulouse 2001
300 t

Texas 1947
3200 t

Oppau 1921
4500 t

ASPECTS

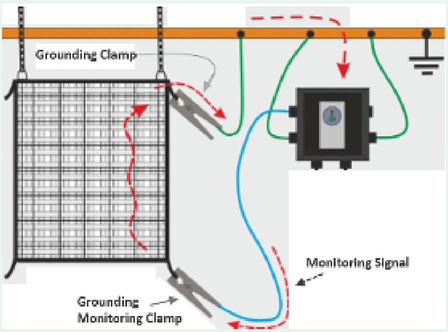
- AN is used as fertilizer and sometimes stored in large quantities close to populated areas.
- Under a number of conditions, certain grades of AN can undergo a violent decomposition resulting in a devastating detonation. Fire and shock wave can cause ignition. $NH_4NO_3 \rightarrow N_2 + 2\ H_2O + 0.5\ O_2$ releases ca 118 kJ/mol.
- Safe handling and storage of AN requires the application of basic rules understood by all involved.
- See public guidance from EFMA European Fertilizers Manufacturers Association.
- Contaminants (e.g. chlorinated products and metals) might enhance reactivity. Ensure accidental mixing is not possible.
- Limit at all times the maximum quantity and define layout with safe distances based on risk calculations.

STORE AMMONIUM NITRATE WITH GREAT CARE

32. UNLOADING POWDERS

WHAT HAPPENED

While unloading combus-tible powder from a FIBC type C Big Bag, a dust explosion occurred.



Big Bag FIBC type C Woven plastic with conductors

ASPECTS

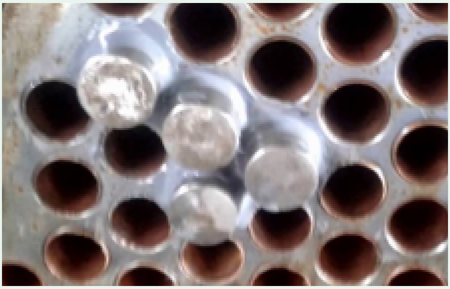
- If a type-C FIBC is not properly grounded it turns into a potential electrostatic ignition source (isolated conductor).
- Flowing of non-conductive powders will generate static charges that can accumulate and result in spark discharges.
- Flammable volatiles (>0.5 w%) do increase ignition risk.
- Validate that the grounding & bonding work well. The drawing shows how instruments can be used to assure this.
- Assure that bags including the inner-liner dissipate electricity well: the specs are defined in IEC 61340-4-4.
- Avoid that operators get charged (shoes, clothing, earthing).
- Keep the unloading area dust free.

AVOID SPARKS WHEN UNLOADING POWDERS

33. HEAT EXCHANGER TUBES

WHAT HAPPENED

A technician was checking a plug on a heat exchanger tube, while the equipment was heating up. Due to pressure build-up in the tube the plug was released from the tube bundle with great force, killing the technician.

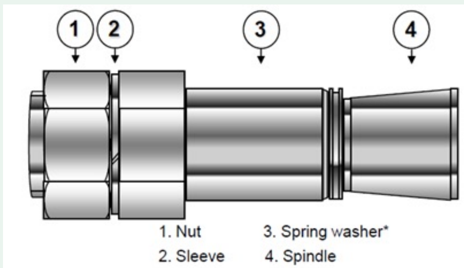


Tapered plug

Hydraulic activated plug

ASPECTS

- Heat exchanger tubes are regularly plugged when the tube is leaking or has thin wall areas.
- Tubes to be plugged should be first fully opened (cut), to avoid pressure build-up in the tube when heating-up!
- Define the right plug related to pressure and temperature.
- Validate that the bore of the tube is in good condition and that the plug is compatible with the fluids/gases used as well as with the tube sheet material.
- Be careful with welding that can cause tube-sheet cracking.
- Validate leak tightness of the plug and when inspecting a plug at a heat exchanger, stay out of the line of fire.



Compression fit plug

PLUG A HEAT EXCHANGER TUBE WITH CARE

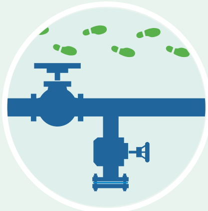
34. PIPELINE TRENCH FIRE

WHAT HAPPENED

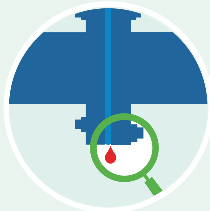
To start-up a new isomerisation unit at a refinery, an existing pipeline was cleaned and drained. When Naphtha was pumped through that line, the drain plate was still open and over 1000 m3 spilled into a pipe trench. This started a fire with serious damages.

Drain plate

PROCESS SAFETY FUNDAMENTAL



Walk the Line



Validate Leak Tightness

ASPECTS

- Good checklists ‘isolation plans’ should indicate all flanges and valves to be involved in a special operation.
- After opening an installation, a leak proof test is required before putting hazardous chemicals in that system.
- Before starting a transfer-pump apply ‘walk the line’ principles, to validate the line-up. Also check that changes in level and transfer-flow do match well.
- Pipeline trench design can reduce consequences of a spill: compartment of the trench, gas detection, fire resistance of critical pipelines and good access to fire hydrants.

VALIDATE THE LINE-UP BEFORE STARTING A TRANSFER

35. METHANOL TANK OVERFILL

WHAT HAPPENED

During a methanol transfer to a tank the high level switch tripped the pump. The level transmitter indicated that the tank was only half full. The interlock was bypassed and the pump was restarted, resulting in overfilling the tank and a serious methanol spill.

PROCESS SAFETY FUNDAMENTAL

Interlock Bypass

ASPECTS

- The bad level transmitter was trusted while the good Level Switch was concluded to give a false signal. The shift there-fore incorrectly bypassed the automatic overfill protection.
- Bypassing a Safety Interlock should not be possible by shift personnel but could involve e.g. an electrical engineer.
- Authorization from at least a day supervisor is required, based on an appropriate analysis and temporary measures.
- Define the SIL rating of safety interlocks using IEC 61511.
- Make sure bypasses are well documented and communicated from shift to shift.
- With two level transmitters, failure modes are easy to detect.

MANAGE OVERRIDES OF SAFETY INTERLOCKS!

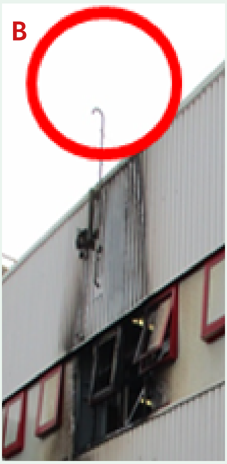
36. HYDROGEN VENT FIRE

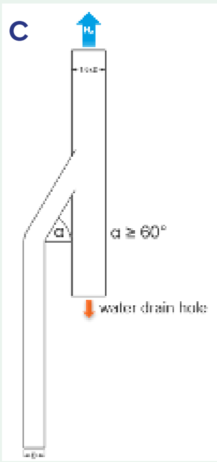
WHAT HAPPENED

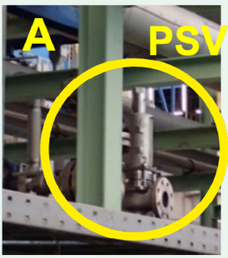
Hydrogen was released by a PSV and ignited, causing damages. The initially installed vent line was dismantled after being folded by high reaction forces during a former release. It was decided to wait until the next turnaround to repair the vent line.

Downward bent discharge tube

Vent Design







PROCESS SAFETY FUNDAMENTAL

Report deficiencies of safety critical equipment

ASPECTS

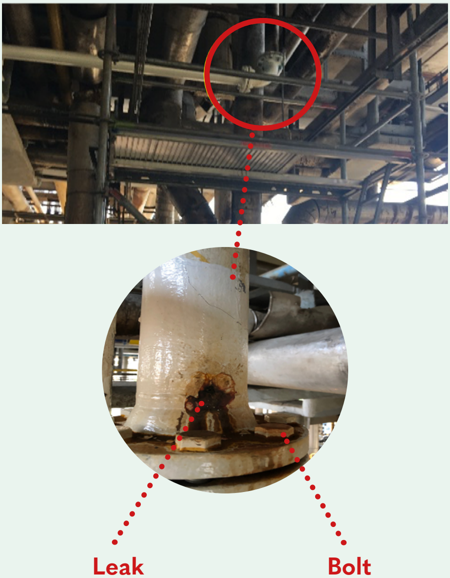
- Expect hydrogen to ignite during process vents due to atmospheric electrical effects or charged dust particles.
- Avoid flow-diverting by weather protection hoods or bent line ends. Use upwards outlet designs as shown in picture C.
- Design aspects: H_2 release points should be above roof top. Assure vent piping has a flame arrestor to avoid back fire and is well fixed to handle release forces.
- Flush hydrogen vents with inert gas after the discharge process to prevent explosive mixtures in the vent line.
- Use dispersion modeling to estimate the consequence:
- Hydrogen cloud size & heat effect upon ignition.

MANAGE HYDROGEN VENTS WELL

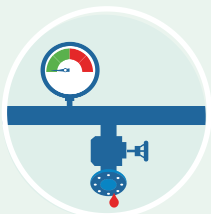
37. PROPANE FLASH FIRE

WHAT HAPPENED

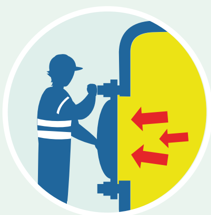
The discharge pipeline of a propane compressor had a leak. During the complex repair using cutting tools to open a corroded flange, propane was released and a flash fire injured the mechanic.



PROCESS SAFETY FUNDAMENTAL



First Line Break



Stay out of the line of fire

ASPECTS

- Apply first line break principles: assure that equipment is isolated, de-energized and free of chemicals, before opening.
- Opening equipment that contained hydrocarbons using cutting equipment, requires intense preparation.
- Validate that isolation plans are complete: leaking valves can reintroduce hazardous materials, as happened here.
- Mechanics are advised to first cut or open the bolts on the other side of the pipe to stay out of the line of fire (chemical spray).
- If remaining chemicals can form a hazard, PPE like face shield and fire-resistant clothing, as well as easy escape routes to emergency shower are essential to protect workers.

ASSURE PROCESS EQUIPMENT IS ISOLATED, EMPTIED AND DE-ENERGIZED, BEFORE OPENING

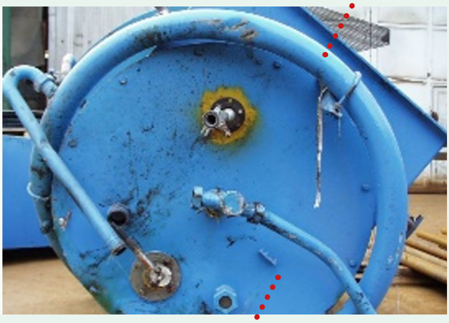
38. FURNACE EXPLOSION

WHAT HAPPENED

Operators tried to restart the tripped hot oil furnace of an FCC unit using a torch. At the third attempt the fire box exploded causing two fatalities.

The gas feed valve did shut very slow at the furnace trip, resulting in gas accumulation in the fire-box exceeding the LEL value.

The torn-off Burner **Gas feed line**



Furnace Fire box **Position of the operator igniting the burners**

PROCESS SAFETY FUNDAMENTAL

Igniting burners

ASPECTS

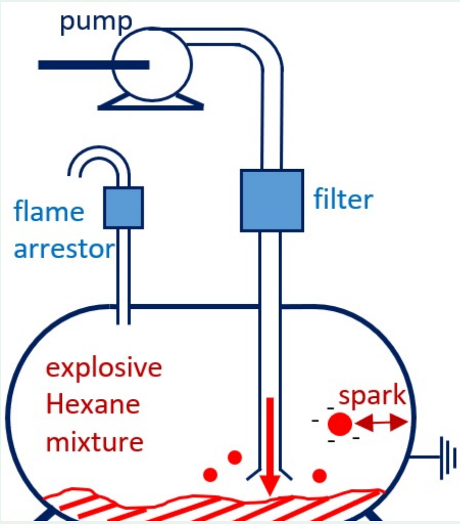
- Cold furnace start-up requires flushing before ignition! Here the Burning Management System (that assures flushing) was bypassed by local operation of the gas feed valves.
- Furnace start-up requires a validated practical procedure that describes actions at all possible scenario's.
- Before ignition with a torch validate that LEL is below 1%.
- Ignition from a distance using pilots is preferred.
- Limit the number of restarts (e.g. never more than 3).
- Validate that the gas feed valves closes fast and completely.

THE FURNACE BOX MUST BE GAS FREE BEFORE IGNITION

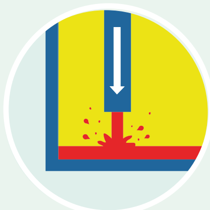
39. TANK EXPLOSION

WHAT HAPPENED

While filling an empty storage tank with hexane, an explosion occurred with a subsequent fire.



PROCESS SAFETY FUNDAMENTAL



Avoid Splash Loading

ASPECTS

- Pumping a nonconductive flammable liquid into a tank is hazardous as it forms an explosive mixture with air and has the tendency to be charged and generate sparks.
- Friction between materials (flow or gas bubbles) will cause charged liquids and droplets that potentially can spark.
- Keep the initial filling flow rate below 1 m/s to avoid sparking droplets, until the dip-tube is submerged!
- Grounding is important to dissipate electrical charges.
- Allow relaxation time after filters and valves that increase friction, to allow charge dissipation.
- Additives can increase conductivity of liquids.
- N_2 blanketing can be used to avoid explosive mixtures.

AVOID SPLASH LOADING NON-CONDUCTIVE LIQUIDS

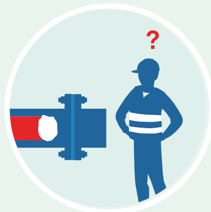
40. UNPLUGGING EXPLOSION

WHAT HAPPENED

In 1989 the Philips Pasadena disaster started after an ethylene release that ignited.

High pressure ethylene might have been used to blow out residual PE polymer from a reactor settling leg. A LOTO locked ball valve was opened to do so.

PROCESS SAFETY FUNDAMENTAL



Unplugging of Equipment

ASPECTS

- Polymers have the tendency to plug lines that can restrict flows or block instrument lines.
- Plants generally have no good procedures to remove plugs and operators tend to become creative to avoid shut down.
- The hazards of removing plugs need to be well understood and opening of equipment to reach the plug need to be avoided or controlled by senior management.
- Do not use pressure of hazardous chemicals to de-plug pipe lines or process equipment.
- Before opening an installation to remove polymer or plugs, remove hazardous chemicals, pressure and energy.

UNPLUGGING OF EQUIPMENT NEEDS AN APPROVED PLAN

41. EXPLOSION OF A REACTOR

WHAT HAPPENED

In Tarragona (2020) an Alkoxylation reactor exploded, due to the decomposition of the alkoxylation products and / or the reactant Ethylene Oxide (EO). Two operators died at the site. Debris killed a citizen at 2.5 km.

PROCESS SAFETY FUNDAMENTAL

Avoid Run-away reactions

ASPECTS

- Alkoxylation products and EO can decompose violently when the temperature gets too high. With alkaline catalysis this can start below 200 °C. This can result in an explosion.
- Understand the chemicals and decomposition energy & kinetics, also under abnormal conditions.
- Determine the safe distance between reactor and buildings and explosion pressure resistance of the buildings.
- The accumulation of free EO in the reactor must be limited, to disable an uncontrollable runaway reaction. Amount of free EO is indicated by the pressure in the reactor.
- Ensure sufficient Reactor cooling and temperature control.
- SIL rated interlocks should avoid critical scenario's such as EO accumulation, cooling loss and backflow into the EO line.
- Involve a safety expert on Alkoxylation and EO.

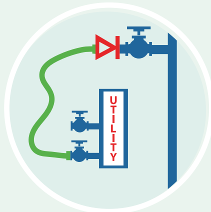
UNDERSTAND YOUR CHEMICALS AND ALL POSSIBLE REACTIONS

42. ROCKETED TANK

WHAT HAPPENED

A new vessel was rocketed into the plant due to pressure building up in the tank through a Nitrogen utility that was connected and leaking.

PROCESS SAFETY FUNDAMENTAL



Manage Utility Connections

ASPECTS

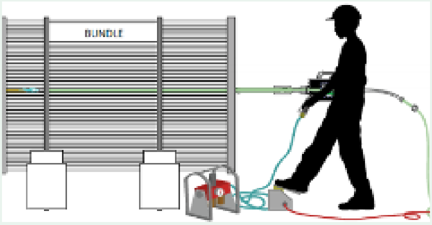
- Connecting a utility (water, steam, nitrogen, air, etc.) to a process is a newline-up with potential new hazards.
- Enforce by procedure, that all critical utilities are disconnected when vessels are prepared for inspection.
- Keep critical instrumentation, like pressure alarms, active during testing and inspections.
- Backflow from the process can contaminate utilities, Prevent backflow with at least one check valve.
- Disconnect utility hoses from the process directly after use.
- Ensure the utility pressure cannot exceed design conditions of the receiving system.

MANAGE UTILITIES CONNECTED TO A PROCESS

43. HIGH PRESSURE WATER

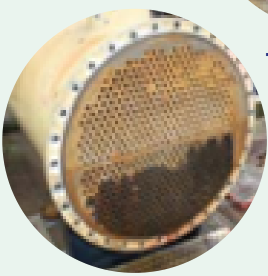
WHAT HAPPENED

Heat exchanger bundles are cleaned in turnarounds using high pressure water of 1000 bar. A cleaner died after hit by a water beam.



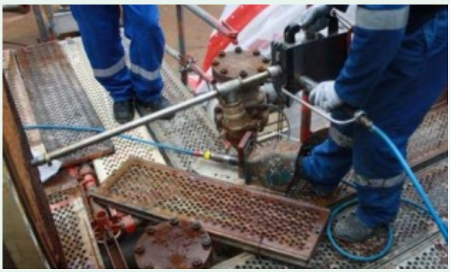
Dead man switch

The Cleaner



ASPECTS

- The lower tubes could not be cleaned with the foot on the dead man switch. The Cleaner disabled the switch to be able to do the work. When losing his balance the nozzle came out of the bundle and hit the cleaner, that died from the injuries.
- Consider ergonomic and tripping hazards of critical work in Job Safety Analyses and at work floor inspection (LMRA).
- A second person needs to observe the work permanently, and activate an emergency stop. He missed the incident; in practice it is hard to be in time in such a rare event.
- Automated HPW cleaning of heat exchangers is safer.
- A culture to 'get the job done' can result in an increased acceptance level to bypass safety systems.

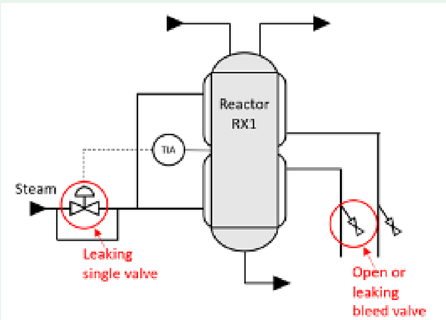


DO NOT BYPASS A SAFETY SYSTEM

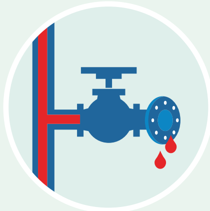
44. HIGH REACTOR PRESSURE

WHAT HAPPENED

A reactor was bypassed for a longer period without draining the isocyanate solution. Steam leaked through a closed control valve to the reactor jacket. The reactor temperature raised, and the remaining material started to polymerize resulting in high pressure and plugs.



PROCESS SAFETY FUNDAMENTAL



Apply double isolation

ASPECTS

- Do not rely on a single valve to isolate equipment.
- Steam flows are erosive and steam valves can leak. Inspect critical steam valves on leakages.
- Steam leakage kept running because of an open discharge valve to the ground floor, this was not noticed. Ask questions at steam releases.
- Empty a reactor when bypassed for a longer period.
- Know the reactivity of remaining chemicals.
- Keep monitoring temperature and pressure of process systems that remain connected and contain chemicals.

DO NOT RELY ON A SINGLE VALVE FOR ISOLATION

45. STORAGE OF CHEMICALS

WHAT HAPPENED

After 6 years of storage a drum was rocketed through the roof of a storage facility. Nitric Acid had leaked through the liner forming hydrogen at the iron wall. On a warm day the hydrogen pressure ruptured the metal, launching the 200 litre drum through the roof.

ASPECTS

- Critical chemicals can decompose or react with the packaging materials.
- Well known are: peroxides, acids, stabilized chemicals, oxidisers, certain compressed gases.
- Chemicals can permeate through plastic bottles and liners.
- Storage conditions like temperature and time are relevant and need to be inline with suppliers advise.
- Hazards of stored chemicals are not always part of a HAZOP, but reactive hazards must be well identified & understood.
- Storage time and expiration date need to be monitored and controlled by a system and trained people.
- Inspect packaging of stored chemicals and check for deformed vessels, that might indicate pressure or corrosion.

CHECK EXPIRATION DATE OF STORED CHEMICALS

46. IMPLODED STORAGE TANK

WHAT HAPPENED

After cleaning with steam a tank was quenched with cold water to shorten the cooling time (not normal practice). The tank vent was not calculated for the vacuum resulting from this rapid quenching operation, resulting in a collapsed tank (without liquid release).

ASPECTS

- Atmospheric storage tanks are not designed to withstand external pressure on the tank wall. A pressure as low as 20 mbar below atmospheric pressure can cause tank damage.
- The force on the wall can be high even at low pressure as the tank wall surface area is very large: Force = Area x delta P.
- Consider all scenarios resulting in pressures below atmospheric and make sure vent sizes are adequately designed for these, including abnormal operations.
- Make sure vents and safety devices remain operable: fouling bird nests, plastic bags, have all caused tank implosions.

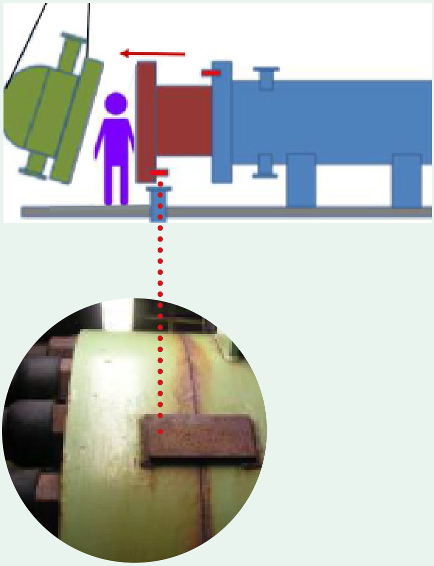
A larger vent size was installed after the incident

ATMOSPHERIC TANKS ARE USUALLY NOT DESIGNED FOR UNDER PRESSURES AND CAN BE DAMAGED EASILY

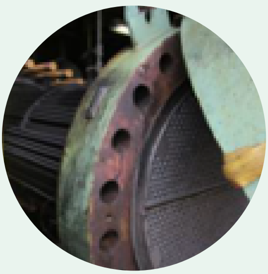
47. PRESSURE LEAK TEST

WHAT HAPPENED

In a turn around the head of a leaking heat exchanger was removed. 8 barg gas was placed on the body to find the leak. The tube bundle was pressed out of its house, killing two mechanics.



Clamp



ASPECTS

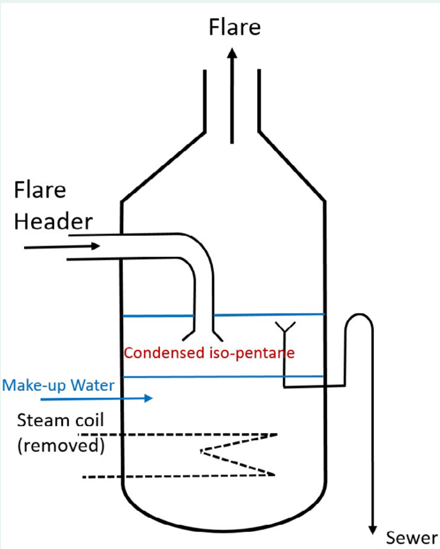
- When pressurizing the space between shell and tube-bundle for the leak test, it was not realized that with removed head, the bundle could come loose from the tube sheet.
- The failed clamp, was only designed to keep the seal in place.
- The approved permit to work, did not discover the hazards of reintroducing pressure during the production stop.
- In the test protocol there was no remark to stop when a certain pressure was detected in the body (blue part in fig.).
- A gas was used in this pressured leak test; a liquid would have most likely avoided fatalities.
- The mechanics were positioned in the line of fire.

VALIDATE EQUIPMENT INTEGRITY AT LEAK TESTING AND ASSURE A SAFE TEST PROTOCOL

48. RELEASE FROM FLARE

WHAT HAPPENED

During the start-up of a refinery, high amounts of iso-pentane did leak through an off-gas vent of a distillation column, to the flare. This condensed in the cold water seal of the flare and was able to overflow into the oily water sewer, where it evaporated and triggered gas alarms. The large gas cloud was not ignited.



ASPECTS

- Operators were unaware of the mechanical failed open vent control valve, indicated as closed on DCS.
- Iso-pentane has a boiling point of 26 °C, when released as a gas it passed the KO drum, condensed in the cold water seal vessel and flow-over into the sewer as a liquid, as its swims on top of the water. In the closed sewer it was mixed with condensate, evaporated and lifted several pit covers.
- In the past the steam coil in the water seal drum was taken out of service after it corroded, as its function was unclear. Warm water in the seal could have limited the release.
- If water is removed at a lower point in the seal drums, condensed hydrocarbons get more time to re-vaporate.
- This rare scenario was not described in the hazard analysis.

PLANT START-UP REQUIRES ADDITIONAL ATTENTION

49. HYDROGEN SULPHIDE EXPLOSION

WHAT HAPPENED

The vacuum breaker on a tank for molten sulphur was plugged blocking the air sweep gas flow, resulting in elevated H_2S concentration. An ignition source created an explosion. H_2S dissolves from the molten Sulphur.

Ruptured sulphur tank

Photos from AFPM safety bulletin

ASPECTS

- Vacuum breakers can foul on the inside when products condens or solidify at a lower temperature on the top of the tank.
- Ventilation systems in sulphur tanks are safety critical and their function must be validated e.g. by a low flow alarm.
- H_2S Lower Explosion Limit drops to about 3.3% at the elevated temperature applied to keep the Sulphur molten.
- In this case the ignition source might be from a spark related to flowing molten sulphur, that is an accumulator for electrostatic charges (here during a truck loading).
- Grounding and bonding of sulphur tanks is critical, as well as follow-up of the EX zone inside the tank.

SULPHUR TANKS NEED SPECIFIC ATTENTION TO AVOID AN H_2S EXPLOSION

50. CARBON DIOXIDE INTOXICATION

WHAT HAPPENED

In a laboratory environment residual solid CO_2 (dry ice) was stored in a bin in a cooled storage room. When entering this room, a person felt ill due to the CO_2 gas.

ASPECTS

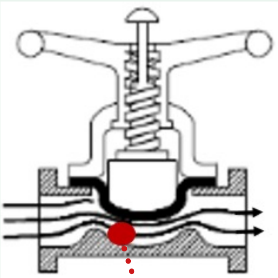
- Solid CO_2 or dry ice is often used in laboratories for the cooling of substrates. Solid CO_2 will evaporate over time (sublimation at ca -78 °C) and will release hazardous CO_2 that will also displace oxygen.
- Proper ventilation is essential when working with dry ice to keep CO_2 gas concentration low. CO_2 will result in hyper-ventilation (1%) and becomes a direct threat to life (10%).
- Closed boxes or storage rooms containing chemicals that can evaporate are "Restricted Areas" and need access control. Gas detection (O_2 or CO_2) on the inside with warning on the outside and inside. Access by trained personnel only.
- Make sure all such area's, locations where chemical gases can accumulate, are well identified and well controlled.

DRY ICE CAN CREATE A HAZARDOUS ATMOSPHERE

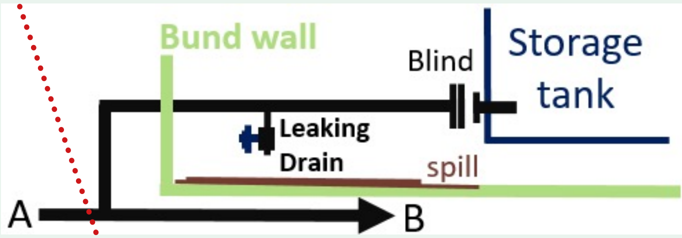
51. CRUDE SPILL IN A TANK PIT

WHAT HAPPENED

At a refinery a crude line was drained to place a blind before a tank that was in maintenance. During a next transfer ca 100 ton crude leaked through the drain valve into the tank pit. The crude was not ignited.



Leaking drain valve



ASPECTS

- Crude contains sludge that can compromise the closing of hand valves, as was here the cause of the leak.
- The drain valve was not secured with a blind or end cap.
  The transfer system had not undergone a leak pressure test, after being opened and closed (a blind-flange was placed).
- It is good practice to walk the line before, or just after starting, a transfer.
- Notice missing end-caps after a drain!
- The detection of the large crude leak only coincidentally happened by an operator smelling the crude during the night.
- ATEX compliance in the tank pit did help to avoid ignition.
- Checking the tank level versus the pump or flow speed can help to detect leaks or wrong line-up in an early stage.

VALIDATE THE FULL LINE-UP BEFORE STARTING A TRANSFER

52. FURNACE EXPLOSION

WHAT HAPPENED

During the restart of a furnace, that was tripped, an explosion occurred when igniting the burn ers. Furnace start-up incidents have happened all around the world with too many fatalities.

Dubai 2010

ASPECTS

- Purging a furnace with sufficient air, before igniting the burners is essential to remove explosive atmospheres.
- Depending on furnace volume and heat capacity, automated ignition is preferred above manual ignition.
- Before start, perform a leak test of valves in gas pipes to pilot and main burners and confirm gas conc. is below 10% LEL.
- Close burner valve after 5 sec of opening if ignition is not successful & wait at least 1 min between two attempts.
- Most operators have little training and actual experience in furnace start-ups, not knowing how to deal with problems.
- Furnace start is a time critical part of the total start-up, resulting in pressure on the people performing the task.
- Limit the number of restarts!
- Remove personnel from the area during a furnace start-up.

START-UP OF A FURNACE IS A HAZARDOUS OPERATION

53. CHERNOBYL

WHAT HAPPENED

During a test, before shutting down a nuclear reactor, the graphite rods were lifted to regain activity. When activity got too high, the emergency stop was activated, but it did not work and an explosion took place: worlds largest nuclear disaster.

ASPECTS

- The test was not well prepared or authorised.
- Due to a personal error the activity dropped below the point of the test.
- Regaining activity in the Xe poisoned reactor was difficult and dangerous.
- The test should have been aborted.
- The test leader had personal interest to get the test executed, and forced it into a dangerous area.
- The emergency stop, was slow and initially increased nuclear activity. These flaws were known but not addressed. The explosion happened after starting the emergency shutdown.
- Due to the heat of the nuclear run away the graphite rods got stuck and could not be re-entered in the reactor.
- The incident was badly communicated, limiting adequate emergency response.

PLANT TESTS CAN BE HAZARDOUS AND NEED GOOD PREPARATION AND AUTHORIZATION

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