REFINERY AND PETROCHEMICAL PLANT FIRE PROTECTION
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Introduction

In the mid-19th century oil was used primarily to produce kerosene for lamps. Later events, particularly the spectacular development of the automotive and aviation industries and the attendant demand for petroleum spirit, led to a tremendous increase in the number of products obtained from oil. The result has been dramatic growth of the petrochemical industry as well as, over the last half century or so, a blurring of the distinction between petroleum refining and derivative chemical manufacture; collectively termed 'hydrocarbon processing'.

Although the overall fire safety record is good, Vervalin (10) observed, 'it seems that no matter how hard the hydrocarbon processing industry tries, it will never eliminate fire, detonations and explosions. Too much volatile material is handled for a fail-safe operation. In spite of the best intentions and planning, people do make mistakes, equipment does fail, or something else totally unexpected may occur'. Lees (2) noted that, ‘the first of the major hazards in process plant is fire’. In Australia, fewer refineries implies greater need to safeguard the remaining production facilities.

Process outline

Typically, the refining process commences at marine terminals where crude oil enters (and finished products may leave). Storage tanks contain not only crude oil stocks, but also the whole range of refined products including bitumen, asphalt,
heavy fuel oil, lubricating oils, gas oil, auto-diesel, kerosene, petrol, turbo jet fuel, white spirit, propane, butane, chemical feedstocks (such as ethylene and butadiene) and refinery fuel gas.

The crude oil is initially treated in pipe stills (furnaces heated to about 400 degrees C) in which it is split into separate streams or fractions. Fractionating towers, up to 70 m high, condense vapours at different levels; yielding at the bottom products such as asphalt, heavy oils and lubricating oils and, at the top, gases, naphtha, methane, ethane, propane, etc. Catalytic cracking plant: In the language of the refiner, 'cracking' means breaking down the large molecules of heavy petroleum fractions, such as gas and fuel oil, into smaller molecules of gases and motor spirit. The 'cat cracker' as it is commonly known is a unit where heavy gas oil and a catalyst are mixed together in a reactor to produce a high quality motor spirit and gases.

Hydroformer: Operation of the hydroformer is similar to that of the 'cat cracker'. The cat cracker converts heavy gas oil into high quality motor spirit, but the hydroformer converts or 'reforms' low octane heavy naphtha from the primary distillation process into a motor spirit of higher quality. This is carried out in an atmosphere of hydrogen at high pressure. The hydroformer is typically about 70 m high.

Downstream chemical plants consist of a number of units concerned mainly with the production of ethylene which is used for the manufacture of plastics and butadiene which is used in the synthetic rubber industry. Ethylene is produced from raw naphtha which has been steam cracked, and butadiene is obtained by a catalytic process which recovers butene from the steam cracker and 'cat cracker'. There are many other processes such as sulphur plants, bitumen plants, lubricating oil plants and so on; all of which involve extensive pipe mazes on racks or in trenches. Refrigeration machinery and cooling towers are typically part of hydrocarbon processing facilities.

Pyrophoric materials may be involved, particularly during shutdown procedures. Pyrophoric iron sulphide may accumulate at various places in equipment handling sulphur-bearing oil. Exposed to air, it will ignite spontaneously even at low temperatures. The simple burning of this material may do considerable damage. If hydrocarbon vapours and air are also present, an explosion and fire may follow ignition of iron sulphide. Aluminium alkyls, now often used in the chemical industry, include triethylaluminium, triisobutylaluminium and diethylaluminium chloride. Significant quantities are used in Ziegler catalyst systems for polyethylene, polypropylene and synthetic rubber. Most of these metal-organic
compounds are pyrophoric liquids which ignite on contact with air and react violently with water. Any leak or spill during manufacturing processes is followed immediately by fire. Sodium bicarbonate-based dry chemical in large amounts can control small shallow spill fires. MET-L-KYL, a dry powder with a sodium bicarbonate base and an activated adsorbent, is a satisfactory extinguishing agent when applied in sufficient quantity to absorb and blanket a spill.

As Lees (2) points out, fires in process plant normally occur as a result of leakage or spillage of fluid from the plant. Larger leaks may occur due to failure of a vessel, pipe or pump, and smaller ones from flanges, sample and drain points and other small bore connections. Combustion of material which has leaked from a plant may take a number of forms. A leak of a gas or liquid may be ignited at the point of issue so that it behaves like a flame on a burner. In some circumstances this flame may be directed like a blow torch at another part of the plant.

Should the leak give rise to a gas or vapour cloud which grows for a period before it is ignited, the resultant effect may be either an unconfined vapour cloud explosion or a flash fire. In a flash fire the gas cloud burns but does not explode. A typical flash fire may cause quite extensive damage, particularly to vulnerable items such as electrical cabling, but may leave the main plant relatively unharmed. If a leak forms a liquid pool on the ground this may ignite and burn. The flame may be substantial and may do damage by direct impingement or by radiation.

Flare stacks

Flare stacks are a familiar sight at hydrocarbon processing installations and many major chemical plants. They are designed to permit convenient and safe disposal of unwanted material (eg, excess light hydrocarbon gases) by burning, usually at an elevated location. Dependent upon position, proximity to other equipment and amount of gas discharged, flare stacks may range in height to well over 60 m; the feeder system being a complex arrangement of pipework to which flammable liquids are admitted via emergency blowdown facilities, relief valves and a host of other connections. A pilot flame at the top of the stack serves as a continuous ignition source, and it is common practice to admit a continuous stream of bleed (purge) gas for the purpose of air exclusion.

The majority of accidents involving flare systems have one common denominator; namely, the entry of materials that the system was not built to accommodate. These may be in the form of air, steam, heavy oil, corrosive materials, low-boiling hydrocarbons or perhaps an excessive amount of liquid. . . serious hazards may
result when material which it was not built to handle is allowed to enter a flare line.

Fire protection for flare stacks (as for most special hazards) involves proper design, installation, operating and maintenance practices. It is obvious that flare stacks must be located with proper clearances from exposed plant; at least 30 m and up to 150 m from the nearest process units, with due attention to topography and prevailing winds. Proper design will include structural support and careful attention to sizing of knockout vessels and headers, together with provision of appropriate flame failure devices. Then too, automatic explosion suppression systems are being increasingly specified for major flare stack installations.

Truck and rail tank loading racks

As truck loading racks increase in size, in number and in pumping rates, the problem of providing effective fire protection becomes more difficult. Aside from the normal loading rack provisions for static earthing, explosion-proof electrical wiring, portable extinguishers and good personnel discipline, remote control valves should be provided as well as automatic fire extinguishing systems that protect both the rack and the vehicle. Two general fire possibilities exist; 1, when the tank truck does not overflow and 2, when it does overflow. In the first case, a hatch fire results and portable dry chemical or carbon dioxide extinguishers can do an effective job. Overflows can occur from several causes; chiefly due to human error. In such cases, liquid runs down both sides of the tank truck forming a pool around and under it. Considering the high pumping rates at modern loading racks, spill fires can grow to major proportions almost in a matter of seconds. Fixed water spray or foam protection should cover over, under and sides of tank trucks.

Escaping flammable vapour may serve as fuel for diesel engines and cause malfunction in such a way as to ignite a surrounding flammable atmosphere. In these circumstances, it is only possible to stop engines by choking the intake or discharging a combustion inhibitor (‘engine strangler’) into the intake.

Some notable fires

The industry has accumulated many years of safe operating experience and much information is available concerning the safe design and operation of hydrocarbon processing plant. This is contained in well-documented safety regulations and guides to safe practice. Because of these careful precautions, the oil industry can boast a generally good fire record. But, despite the precautions, large fires still occur. This was the case when fire struck an oil refinery in Whiting, Indiana, in 1955:
Plant explosions

The overnight shift at the Standard Oil Refinery neared quitting time with one big chore left - restart of the 84 m tall Hydroformer Unit 700 (reportedly the largest in the world). Without warning, several explosions tore it apart. Debris weighing many tonnes rained down across a half-kilometre radius of the plant. Moments later, flames began to spread and consume the refinery's tank farm hectare by hectare for the next two days. With 67 storage tanks destroyed, the fire took eight days to finally extinguish. Standard Oil became Amoco in the late 1950s, which merged with BP in 2000. Today, as in 1955, the Whiting refinery, near the shores of Lake Michigan, remains the largest inland refinery in the USA, covering more than 640 ha.

In 1959, a fractionating column (dephlegmator) exploded at Cities Service Oil Company refinery, Ponca City, Oklahoma. This was attributed to a detonation within the dephlegmator caused by spontaneous ignition of a volatile oil in a closed, heated system containing air at an elevated temperature and pressure.

Pump and heat exchanger seals

In Carthage, Texas, failure of pump packing released oil that ignited at exposed parts of a steam regulator in an absorption petrol plant. Heat caused the head of an oil-to-oil heat exchanger to leak around the seals, adding more fuel to the fire. The unprotected steel supports on a 600-barrel rich oil storage tank collapsed. When the tank fell, piping from the tank to a 25 m high reabsorber tower pulled the tower over. It fell across the ends of a 600-barrel distillate tank and the rich oil tank, squeezing the end and causing it to rocket about 50 m. This released fuel and led to more pipeline and equipment failures.

LPG storage vessels

1966: At a refinery in Feyzin, France, butane and propane were stored in eight 1200 cubic metre spherical pressure vessels. Employees cracked open a water draw-off valve to drain water from the bottom of a sphere containing propane. There was an obstruction in the valve, so they opened it fully. The obstruction suddenly cleared, discharging a full stream of propane so that the operators were unable to close the valve. The propane vapour cloud was ignited by a passing car on a motorway 60 m away. About an hour later the leaking sphere BLEVEed*. The erupting fireball killed and injured firefighters and hurled a 70-tonne fragment 300 m. Half an hour later, a second sphere BLEVEed, and three
spheres toppled when their unprotected support legs collapsed. 17 people were killed and 84 injured during this incident.

* BLEVE: Boiling liquid expanding vapour explosion.

Unconfined vapour cloud explosion

In 1968, a serious explosion occurred in the Shell Nederland Raffinaderij NV in Pernis (a 500 ha site with a labyrinth of pipelines, storage tanks, distilling units, cracking units, chemical plants and treating units). The explosion was followed by fire in several installations. Two people were killed and 85 injured. At Hoogvliet, a town close to the refinery, thousands of windows in houses, flats and shops were shattered by the blast. All installations at Shell Raffinaderij NV and Shell Nederland Chemie NV had to be shut down. About 10 hours after the initial explosion, a slops tank began overflowing. Within minutes a hydrocarbon cloud erupted. Ignition occurred and, after one or two smaller explosions, a heavy detonation caused extensive shock wave damage and a large fire. It was estimated that the blast had the force of about 20 tonnes of TNT.

Piping failure

29 people died in the 1974 fire and explosion in the Nypro Ltd chemical plant, Flixborough, UK. Ninety per cent of the plant and associated buildings covering 25 ha was severely damaged. Some 1,800 tonnes of flammable liquids, including cyclohexane, cyclohexanone, phenol, naphtha, benzene, toluene and fuel oils were destroyed, together with several hundred tonnes of acids. Caused by a fracture in piping between reactor vessels, explosion damage affected the whole site and the subsequent fire involved some 81,000 square metres. The Nypro plant, a specialty facility, was the only one of a kind in Britain producing caprolactum, a basic material used in the manufacture of nylon.

Crude oil tank boilover

In 1980, a huge explosion and fire ripped through a Shell refinery in a Western Sydney suburb, killing one person and injuring six others. The blast tore out the side of a boiler, bringing down a 39-tonne catalytic tower. This was followed in 1983 by a major storage tank fire in Milford Haven UK. An 85 m diameter floating roof tank contained more than 250 million barrels of light North Sea crude. The single-skin roof floated at 5 m below its 22 m high maximum. Crude oil seeped through cracks in the floating roof skin (perhaps due to constant flexing in high winds). Ignition was probably caused by incandescent particles released by a nearby flare stack. A boilover occurred. Flames reached 1000 m high and covered 1.5 ha of the 98 m by 196 m dike.
Tank truck loading rack fire

A loading rack fire was believed responsible for a major 1984 fire in Mexico City (San Juan Ixhuatepec district). Fire broke out as a tank truck was being filled. The truck’s tank BLEVEd. The rocketing truck tank struck a group of giant LPG spheres; four ruptured dumping some 50 million litres simultaneously. A tremendous fireball ensued, levelling the facility and engulfing homes on either side of the surrounding valley. South and east of the spheres lay a network of LPG horizontal cylindrical vessels arranged at close intervals. 36 of these 48 vessels BLEVEd. Officially, the final death toll was 490. Taking into account those who died later from severe burns, the death toll was probably closer to 2000.

Storm-caused tank fire

In 1988, fire in the 150,000 barrel-a-day Orion Oil Refinery in Norco, Louisiana, caused $400 million property damage. Tropical storm Allison dumped heavy rain on the same facility in 2001 (1000 mm over 3 days), partly sinking the floating roof on storage tank 325-4 (90 m diameter) containing about 300,000 barrels of petrol. Orion maintains a storage terminal with a 10 million–barrel capacity, including four tanks even bigger than tank 325-4. Lightning struck the tank. It ignited and fire immediately spread over the entire surface. This huge blaze was finally extinguished with determined foam application - at time of writing the largest successful tank fire extinguishment on record.

Unconfined vapour cloud explosion

Finally, mention should be made of two major incidents in 2005: In March, a large flammable vapour cloud was ignited by the backfire of an idling diesel truck, resulting in a massive explosion and fire in the isomerisation unit at the BP Refinery in Texas City, Texas. Fifteen workers were killed and 180 others were injured. The blast caused an estimated $1.5 billion in economic loss, including splintering nearby work trailers, buckling giant petrol storage tanks and shattering windows in homes and businesses up to 2 km away. The vapour cloud formed in a little over 90 seconds due primarily to evaporation of falling hydrocarbon liquid that had erupted from a 36 m-tall atmospheric stack of an overfilled blowdown drum.

In December, an overfilled petrol storage tank in a Buncefield, UK, oil storage depot caused the worst blaze in Europe since World War II. The overfill created an immense vapour cloud which flowed offsite. The initial explosion, cause unknown, reached 2.4 on the Richter scale and was heard 320 km away in France and the Netherlands. All of the foam liquid on site was destroyed in the explosion. Foam and equipment supply represented a formidable logistics problem.
Active fire protection

Water supplies

The American Petroleum Institute (API) recommends that a refinery fire water system be designed such that fire main sizing meets fire flow requirements throughout the facility. The water demand should be based on hydraulic calculations for current and future needs, with a minimum fire main size calculated to deliver a minimum of 500 to 950 kPa hydrant pressure at full-rated demand. Vervalin (1) considers that a fire water system capable of delivering approximately 12,000 L/min at 950 kPa (allowing 12 hose streams) should be adequate for most modern process units.

A well laid-out water supply is essential for good fire protection. A ring or loop main system is best, and should surround the entire facility with connections passing beside units or structures to be protected. Valves on the loop should be spaced so that any section can be isolated in case of breakage. This also permits water to flow from several directions to the point of fire, reducing line friction losses. Water storage tank or reservoir capacity should be adequate to meet peak demand for at least four to six hours. It is becoming more common to retain fire water run-off as a pollution control measure. This water may be run through a solids/liquids separator and then be recycled into the fire water supply, thereby extending the duration for fire-fighting.

Fire hydrants

Hydrants are usually spaced about 90 m apart and so located that any one fire may be covered by at least two hydrants. Fire hydrants typically have a capacity of 1900 L/min and are furnished with two hose connections rated at 950 L/min. Pumper or booster connections are provided at appropriate points on the loop.

Monitor nozzles

Portable monitor nozzles are designed to stand on the ground or on a trailer. They can be left, if necessary, unattended where a large jet may be required in a position of danger. Fixed monitor nozzles may be permanently secured to mobile appliances or fireboats or in strategic positions such as towers. The jet can be traversed or elevated by controls which may be remotely operated. Because plant layout dictates fixed monitor nozzle positioning, there are no standards governing monitor system layout. Unless arranged for remote control, monitors need to be positioned close enough to hazards to permit effective operation but not so close
as to endanger operators. ‘Fire shields’ for operator protection may be necessary in some cases.

Water monitors may have nozzles up to 65 mm diameter for portable types and 90 mm diameter for fixed types. Foam monitors may have nozzles up to 100 mm diameter with a height of reach of 23 m, a range of 60 m and a foam output in excess of 18,500 L/min.

Water spray systems

Water spray systems are widely applied in refinery and petrochemical plant fire protection. British Standard CP 3013 notes that fixed water spray systems may be manually operated or automatically operated with over-riding manual control. It suggests that a generally accepted figure to give protection is a water application rate of 10 mm/min on surfaces exposed to heat input. Heat exposed surfaces may include accumulators, wash drums, gas separators, cylindrical and spherical gas storage vessels, high pressure columns, heaters and critical process piping concentrations.

The Institute of Petroleum code of practice similarly recommends a water spray application rate of 10 mm/min for uninsulated vessels, equipment, structural steel, pipe racks, fin-fan coolers, compressors handling flammable gases, electrical and instrument cable trays and pumps handling flammable liquids adjacent to cable runs. Protection in depth also requires that water spray systems be designed to function adequately after an explosion. Such relatively fragile devices as cast iron deluge valves must be shielded and major pipe runs must be welded and supported only from major beams and columns.

In some cases it may also be feasible to arrange upwardly spraying water curtains to assist in interception/dilution/dispersion of flammable vapour clouds. Such curtains should be located between fired heaters and the rest of the process plant.

Dry chemical

It is acknowledged that fires involving gas escaping under pressure should not be extinguished unless it is certain that the gas supply can be shut off immediately following extinguishment. With this proviso, a major (trailer or truck mounted) dry chemical unit can greatly facilitate extinguishment of both high- and low-level fires in process plant. Dry chemical is the preferred agent for such fires; however, flow rates and range of stream are critically important factors.
Operator training

A final point: It goes without saying that plant operators must be well trained. The proper activation of instruments must be emphasised so that reliable control and indications of operating conditions can be maintained at all times . . . operators should be aware of their dependence upon instruments, and should recognise, investigate and seek cause for any discrepancies or abnormalities.

Fire-fighting and accident training is important. Major fire-fighter training facilities are available in both the USA and the UK. In the late-1980s, the French also converted part of a former British Petroleum refinery at Vernon, near Paris, into a one-of-a-kind training centre. The $12 million investment was financed by the French insurance industry. Various refinery units were retained for setting on fire during training. These included a gas scrubber with 35 m high columns; leaking flanges on distillation platforms, pumps, heat exchangers, elevated pipe racks, fans, bundle coolers and loading racks with tank trucks.

References