Incident

Remembering the Philadelphia Gulf Refinery fire — 50 years on

Ewan Stewart
On behalf of the Queensland Joint Chemical Engineering Committee

Summary

The date of 17 August 1975 is remembered for the highest firefighter fatality count in Pennsylvania State's modern history. What started as a crude oil tank fire at the Girard Point refinery (then operated by Gulf Oil Corporation) was initially brought under control. However, containment issues and problems managing the spent firewater left a precarious situation — a layer of naphtha hidden beneath the firefighting foam suddenly ignited, with the resulting inferno rapidly advancing through the flooded refinery. A massive emergency response was eventually able to reclaim the facility, but at a cost of the lives of eight firefighters. Memorial plaques outside of the Fireman's Hall Museum in downtown Philadelphia honour each of the fallen.

Keywords: Tank fire, floating roof storage tank

Introduction

I initially learned of this incident some years ago. As a graduate engineer, I was encouraged to present a brief safety moment before team meetings, and so I had formed a habit of checking the index of "What Went Wrong" to find relevant safety topics. One of our projects at the time was the conversion of a fixed storage tank to a floating roof tank (spoiler alert: a similar modification had also been undertaken at the Gulf Refinery prior to this incident). By sharing the details of this incident before our HAZOP workshop, it really put the importance of our task into focus, and we were careful not to repeat the same mistakes. This incident has always resonated with me and has become one of my go-to safety shares.

Earlier this year, I made the decision to track down more information with a view to better understanding exactly what happened. The official reports do not exist on the internet. Historical newspaper archives were a useful first port of call. These provided context on the incident, documented the public reaction, and alluded to the investigation work as it unfolded. Soon I was able to identify interested parties, some of which are fortunately still around today. After months of reaching out I was finally able to track down one of the elusive reports through a prominent Hazmat consultant. A freedom of information request revealed that a further report had long since been destroyed.

After all my research, I have concluded that the memory of this tragic event has been kept alive by the firefighting community and has been largely forgotten within the process industries. This is a great shame as we are the ones responsible for designing and operating plant in a manner that does not put people in danger. I feel that there is much to be learned from this incident, even today. In this article I will explore some of the technical aspects of what caused the initial explosion, how the situation was able to escalate out of control, and the steps that were put in place to avoid similar incidents occurring.

Gas release from a floating roof tank

To understand the origin of this incident, we first must understand the operation of floating roof storage tanks (see Figure 1). This style of tank is used for the storage of products such as crude oil, diesel, jet fuel and gasoline which can emit large quantities of vapour at ambient conditions. The tank roof is supported by a number of buoyant pontoons, and floats on top of the liquid in the tank eliminating any vapour space that would be present in a fixed roof tank. Relevant to this incident, the floating roof is equipped with a pressure/vacuum valve which operates to expel air during the initial tank fill and to prevent vacuum formation when emptying the tank for maintenance.

This incident centres around Tank 231. Originally built as a fixed roof storage tank in 1929, this had been rehabilitated and converted to an internal floating roof tank before being placed back into service in the months prior to the incident. Crucially, a last-minute design alteration increased the height of the pontoon legs. This change was not indicated on the drawings

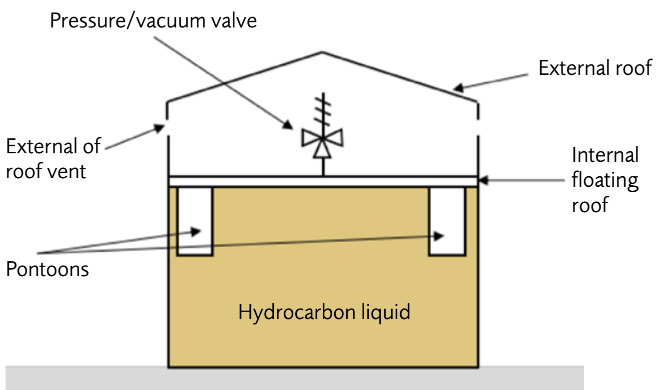


Figure 1 – Floating roof storage tank layout

given to the operators. As a result, the tank was inadvertently brought "off float" meaning that the level was brought low enough for the pontoon legs to rest on the base of the tank. As the liquid level decreased further, the pressure / vacuum valve opened, allowing air to enter the void under the roof space.

Not only had the tank been under-filled, but it was also now about to be over-filled. Sometime later, when a docked oil tanker commenced transfer of warm crude oil to Tank 231, the flammable air and hydrocarbon gas mixture trapped under the tank roof was expelled through the P/V valve into the external tank. The operators assigned to the task were not monitoring the tank levels and allowed it to be filled beyond its safe maximum level. As the tank continued to fill, the rising roof pushed the vapours to the height of the external overflow vents, from which they started to cascade out of the tank in increasing quantities.

Ignition

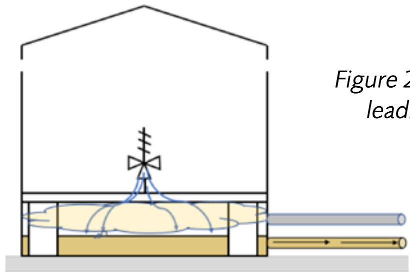
A familiar site to motorists traversing over the refinery on the Penrose Avenue bridge was the chimney stack of the no. 4 boiler house. Towering over the freeway, this bore the giant white letters "G U L F" vertically down the stack. Shortly before sunrise, the escaping vapours from Tank 231 had surrounded and entered the boiler house, where an uninsulated high temperature, high pressure steam line ignited the first explosion. The iconic chimney stack that had announced the refinery's owner, now bore a massive fracture down its facade. Worse was to come.

The flames flashed back to the vents of Tank 231 where a massive fireball erupted. As filling continued, flames were observed at the tank vents. The initial flash and explosion were seen and heard by the crew of the offloading oil tanker, who almost immediately shut-down their pumps. Without inflow to the tank, the space above the roof was no longer pressurised. This allowed the flames at the vent to enter the tank, where a further explosion occurred. This time, the floating roof was forced down like a piston. Displaced crude oil came up past the floating roof seal, and this flaming liquid was ejected from the tank vents. More importantly, the downward force on the internal roof created a hydraulic shock damaging the tank's fill lines at the manifold. This placed the fire in the street area where it was not contained by the dike walls.

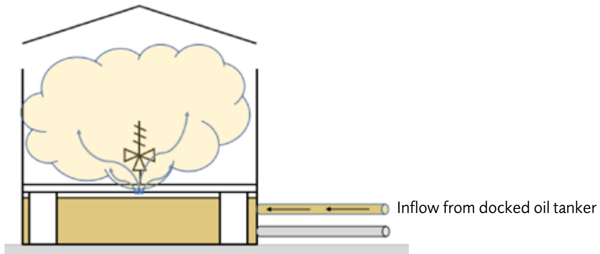
Burning crude oil which had been forced onto the floating roof transferred heat through the floating roof pan and to the liquid surface below where the crude began to vaporise and froth. As the frothing liquid boiled over through the tank vents, burning crude streamed down the outside wall of the tank causing additional gaskets to fail on the inlet and outlet lines. The compromised lines and sustained fire around the tank and manifold valves removed all possibility of shutting down reverse flow from the tank, which continued feeding the fire from its 73,000-barrel inventory and 12m static liquid head.

As the burning crude flowed into the dike, it caused the collapse of several other pipelines which passed through the Tank 231 dike area. These pipelines contained benzene, aviation gasoline and jet fuel, which contributed to the fire already burning within the dike. A smaller tank, Tank 1114, within the dike was overpressured due to the intense fire and ruptured at its roof-to-shell seam with its vapours continuing to burn.

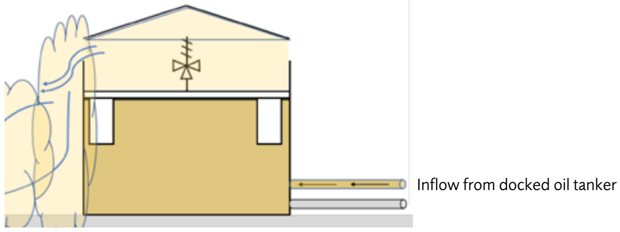
Figure 2 – Sequence of events leading up to the explosion



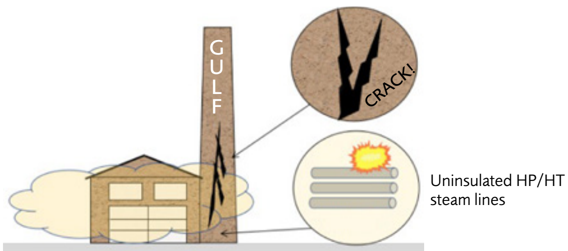
Tank emptied below minimum safe level, roof brought off-float, air enters tank



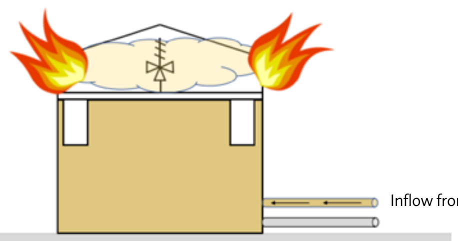
Tank filled, air/hydrocarbon mixture expelled from P/V valve into outer tank



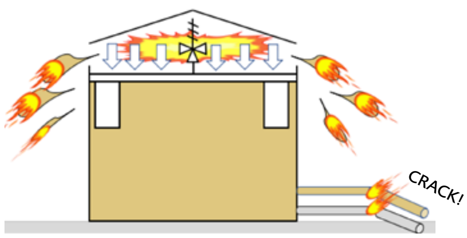
Tank further filled, Air/HC mixture expelled from outer tank vents



Vapour cloud surrounds boiler house, is ignited by high temperature steam line. Explosion damages chimney stack brick facade



Tank filling continues. Flame flashes back to tank and is observed at vents



Tank filling stopped. Flame front enters external tank. Resulting explosion pushes roof like a piston creating a hydraulic shock which damages manifold lines. Burning crude ejected from tank vents

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Initial response

Refinery employees began to fight the fire whilst the Philadelphia Fire Department was notified. Six alarms were transmitted bringing 201 city firefighters and over 50 items of fire-fighting equipment. Cooling lines were quickly brought into play on all exposures. The fire in Tank 1114 was promptly extinguished. Burning crude oil frothing out of Tank 231 was blanketed with foam, and foam lines were placed into service on the burning manifold lines. Tank 231 was being cooled down to prevent a boil-over and the fire commissioner declared the fire "under control". This did not mean that the fire had been extinguished. Rather, it meant that barring any unforeseen circumstances, no further alarms were expected, and some apparatus would begin to return to the stations.

Rising water

As the firefighting efforts continued throughout the day, increasing volumes of run-off water were observed. Whilst this should have been contained within Tank 231's diked area, unfortunately the dike drain valve had been left in the open position. Further, the dike wall had been damaged, further allowing spent firewater to flow into the street in the vicinity of the manifold fire. The compromised dike meant that the sewer water pumps could no longer keep up with the volume of water being applied to the fires.

Concern at the rising water levels was raised by the fire department. Pumper trucks were deployed to draft water from the sewer pumps inlet and transfer this into the diked area of another tank. However, the drainage valve on this dike had also been left in the open position, and another location had to be found.

Little did the Philadelphia Fire Department know, the sewer pumps were about to stop completely. Earlier that day, a Gulf fire department employee had been shocked when an overhead power line had fallen in the fire response area. Although the fire department were applying fog-lines on the wires to keep them cool, refinery staff became re-concerned that further power lines would burn and drop onto the street below where several personnel were working in the water and foam. A decision was made to de-energise the electrical substation feeding the sewer pumps. The fire department were not informed and only became aware of this as the streets became inundated with water and foam.

Hidden danger

Communication between the refinery staff and the fire department had been a major contributor as events unfolded. The Gulf fire chief had forgotten to bring his radio which had been specially equipped for use on the city fire department channel. Whilst this was later remedied, it was characteristic of the strained communication throughout the day. The city department had not been made aware of the nature of the tank fire they were fighting, specifically the presence of 5% naphtha within Tank 231 which gave the crude the ignition characteristics more akin to a volatile well-head fluid. They were also given false information on the inventory within Tank 231; only after the fact was it learned that the tank levels had been completely fabricated by the operator.

Throughout the day, the fire commissioner ordered that all

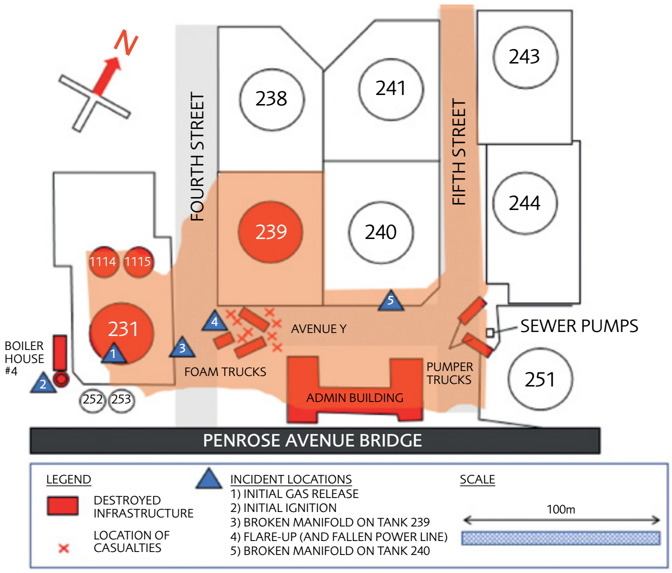

Figure 3 – Site map of the incident

pipelines running through the fire area be shutdown, however this did not reduce the fire's intensity. A further order was issued that all tank valves be closed, however only the manifold valves of two large naphtha tanks, 239 and 240 were closed. The valves at the tanks were left in the open position and this was to have a significant effect later.

The firefighters were now tackling the fire whilst standing in a mixture of water and foam which was up to 24 inches on their boots. It appears that the presence of hydrocarbon in this mixture was known and that the thick layer of foam was expected to have excluded air from the fire triangle. However, few would have been aware of the presence and quantity of naphtha. The flow of this volatile material into the street is thought to have been masked by the foam blanket. As the water level continued to rise, it encountered an ignition source, thought to be the exhaust pipe on one of the foam trucks.

A sudden flare-up engulfed several of the firefighters with others coming to their aid. The men became trapped with no way out as the fire advanced along the refinery streets in all directions. Under the intense flames, the manifold of naphtha Tank 240 ruptured. As the isolation valve at the tank had not been closed, the contents of this 80,000-barrel tank were spilling freely from the manifold and igniting in mid-air. This additional inventory greatly increased the intensity of the fire as it continued to devastate the surrounding area.

Aftermath and investigation

A massive firefighting operation was undertaken throughout the night. By the following morning the fire was confined to the area of Tank 231. Six firefighters had died in the inferno and a further two would later die of their injuries. Four storage tanks appeared crumpled and melted and the administration building was destroyed, whilst the burnt-out carcasses of five fire trucks lay next to the mangled manifolds. In total, the damage was more than $10 million. The decision was made to let the fire

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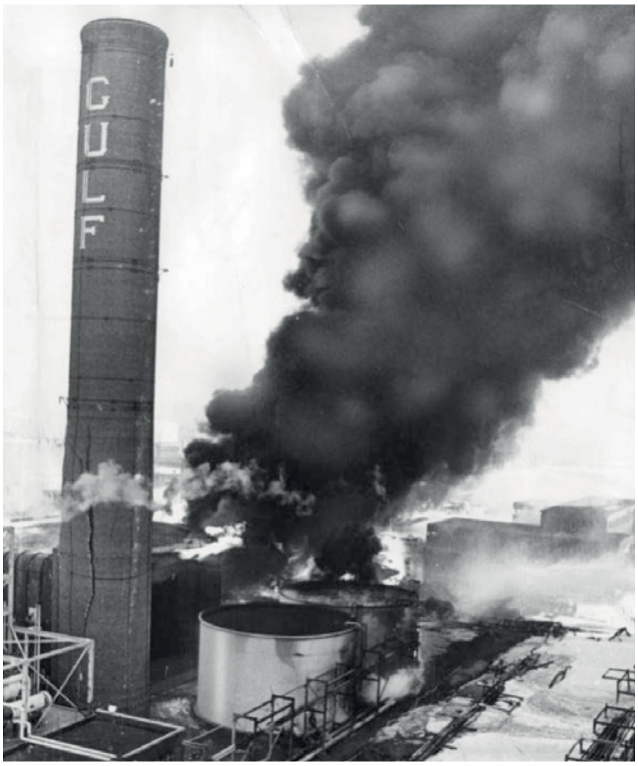

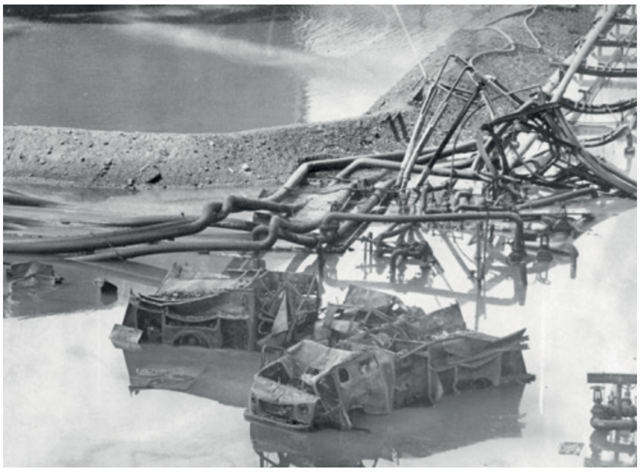

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burn itself out, and the fire was finally completely extinguished on 26 August, nine days after it had started.

The official investigation on this incident was carried out by the Joint Fire Investigation Committee, comprising members from the fire department, police department, and Gulf. The resulting 14-page report describing how the events unfolded is the basis for much of this article. A further report was released by the Occupational Health & Safety Administration (OSHA), which made several recommendations for the facility in light of the incident. Whilst this report was unavailable at the time of writing, we know from newspaper reports that the recommendations were in the following areas:

Equipment spacing: A major factor in the design of oil and gas facilities is the placement of equipment to keep potential hydrocarbon releases separate from ignition sources. It was unanimously agreed that Tank 231 had no place being where it was, immediately adjacent to the boiler house. In fact, the industry recommended spacing at the time was 250ft (76m). Gulf learned their lesson, and when the boiler house and stack were rebuilt the next year, the destroyed tanks were not replaced.

Tank level alarm system: Reliance on strapping charts and filling rates to estimate tank levels left a lot of room for human error. OSHA recommended the use of level alarms to inform operator action prior to dangerous levels being reached. The widespread implementation of such alarms was cited as one of the accomplishments of the fire safety advisory committee, which was formed in the wake of this incident.

Actuated shut-off valves: An iconic photograph from this incident shows three Gulf employees, clinging to a rowboat, wading out into a flooded tank dike. This operation was necessary to close off the valve at Tank 240 after the manifold had become compromised in the fire. Had an actuator been installed on this valve, then it could have been closed from a safe distance without putting further lives at risk. Newer plants at the time had automated systems to shutdown plant based on elevated levels, temperatures, and pressures, however these were not yet fitted at legacy plants where all valve operations were performed manually.

Auxiliary dike: The open drainage valves rendered the tank dikes ineffective in containing the tank contents, which resulted in spent firewater and hydrocarbon flowing freely through the refinery. OSHA recommended the construction of an auxiliary dike to divert released fluid away from streets and process areas. In any case, there should always be a clear plan on how to manage firewater in an emergency. A further improvement campaign was undertaken to replace earthen dikes with steel ones after dike damage had been sustained in the firefighting operations.

It is unclear whether the OSHA report referred to the impact of the design changes to Tank 231 prior to the incident. This factor emphasises the importance of managing change, and in particular keeping drawings up to date. Floating roof tanks should never be brought off-float, except for in a controlled scenario where they are being emptied for repair.

The events of 17 August 1975 marked a watershed in Pennsylvania state government attitude to refinery safety. Historical accident had placed the refinery close to civilian infrastructure, putting bridges, highways, and people's lives at risk. These trends were representative of other refineries throughout the USA. As the last of the flames were being extinguished, the state attorney general was assembling a task force on refinery fires. Almost a year later, the recommendations were made — among these were mandated adoption of the NFPA standards, hot-work permits, routine testing of fire equipment, safety inspections, safety information signs, fire drills, and compulsory tank-fire training of firefighters.

The last chapter

Unfortunately, the story doesn't end there. The Girard Point refinery, during the course of multiple mergers and acquisitions, was combined with the adjoining Point Breeze refinery to form a single complex — the largest on the US eastern seaboard. Eventually this came under the ownership of Philadelphia Energy Solutions (PES). In 2019, poor maintenance led to the rupture of a heavily eroded pipe elbow. This was followed by a disastrous series of explosions which destroyed the HF alkylation unit, hurled multi-tonne vessel fragments across the complex, and released thousands of pounds of hydrofluoric acid to atmosphere.

Just as 44 years prior a courageous effort was able to reclaim the facility from the flames, tank by tank, block by block; this time things were different. The refinery operator had been struggling to emerge from bankruptcy proceedings 18 months prior, citing difficult economic conditions, weak gasoline margins, and high debt costs. Whilst fortunately there were no fatalities this time, there was one major casualty — the refinery complex itself. The site, which had been a bustling hub of engineering activity for over a century was forced to shut down permanently with the loss of more than 1,000 jobs.

A lot had occurred in the intervening years between 1975 fire and the refinery's eventual demise in 2019. Times had changed. Young men had grown old. Many involved had passed on. Process safety has come a long way, but evidently not far enough. In hindsight, perhaps the facility had not been so much as saved all those years ago. Maybe it had just been bought more time. Time for the next generations to learn the lessons of the past.

This article is dedicated to the families of those that lost their lives in Philadelphia Gulf Refinery Fire of 17 August 1975; John Andrews (49), Joseph Wiley (33), Roger Parker (28), Hugh McIntyre (53), Robert Fisher (43), Ralph Campana (41), James Pouliot (35), Carroll Brenek (33).

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