Explosion and Fire in Gas-Oil Fixed Roof Storage Tank

(A non inherently safer design)

Yigal Riezel
Process Safety Management, consultant
Ashdod, ISRAEL 77409
Email : yriezel@trendline.co.il

Abstract

On November 2nd, 1997 an explosion of fixed roof gas-oil tank located in the tank farm of Ashdod Oil Refinery caused loss of life of One Sample Man, Fire in two adjacent tanks located in the same dike. During the fire, which lasted less than 3 hours, there was a big public concern about necessity for emergency evacuation from 2 neighborhood settlements.

Emergency operations of the refinery and external forces were very effective and within 3 hours fires in both tanks and the dike were put down without any additional damage to other tanks or equipment in the tank farm. The source fire was a heavy top phase pool fire.

The investigation pointed out that the source of explosive mixture in the tank was hydrogen that penetrated with the gas-oil to the tank as a result of non-complete gas-oil stripping with hydrogen at the exit of gas-oil hydrotreating unit.

The source of ignition was electrostatic spark initiated by synthetic rope (instead of cotton one) used with the sampling device in order to get samples out of the tank.

After the accident, unfortunately too late, it was found that similar scenario was reported about 15 years before but was not digested widely enough through accident databases.

1. INTRODUCTION

There is no doubt that storage tanks of an oil refinery belong to a category of inherent risk systems. Their only purpose is to store hazardous materials. But would it be safe enough to store gas-oil or diesel-oil in an atmospheric fixed roof tank even if the temperature of the stored hydrocarbons is lower than its flash point?

In the morning of 2nd November 1997 a gas-oil tank containing 15000 cu m of gas-oil exploded and initiated a big fire starting on top layer as pool fire. The fire was contained within the dike of two adjacent tanks. A very tall smoke cloud dispersed towards north east (the center of the country) and without harming any settlement wandered under very low wind velocity about 40 km until it vanished.

Investigation started immediately but almost same time came in first question from an experienced safety adviser of a famous refining corporate abroad, asking for information in order to digest the lesson learnt. The main question was: " In Platt's Oilgram News of November 1997 it was indicated that a diesel tank exploded in the Ashdod refinery. Under normal circumstances it is **virtual impossible** to have an explosion in a diesel tank. ".

The reality showed that the possibility for such explosion is there. The thorough investigation aiming to identify mainly the root causes focused on hydrogen contamination in the gas-oil. Some weaknesses in the system contributed to the accident and illuminated few basics that should always be kept in mind and applied.

- ✓ It is better to brainstorm ahead than investigate later.
- ✓ Inherently safer alternatives should always be sought.
- ✓ Wide distribution of accident data and lessons learnt can serve more than mutual aid between members of the society dealing with hazardous materials.
- ✓ Comprehensive schemes of Process Safety Management systems applications are recommended for use even not yet required by regulators or authorities.

An equally important lesson was expressed by a famous international safety consultancy services company: " Oil Refineries Ltd.s' emergency response to the explosion appears to have been extremely good and followed ' textbook procedure ' on how to deal with such a situation ".

2. THE GAS-OIL PRODUCTION SYSTEM IN ASHDOD REFINERY.

The Ashdod Crude Oil Refinery is a simple type plant and its gas-oil course of production from the distillation in the main crude tower till the finished products storage tanks is via units of fairly low complexity factor.

In the main crude oil distillation tower several types of crude oils or mixtures of some, are separated to the main raw products like: gas, naphtha, kerosene, light atmospheric gas-oil (LAGO), heavy atmospheric gas-oil(HAGO) and atmospheric bottoms (fuel-oil). The LAGO is stripped (as well as the kerosene) in a steam stripping tower in the crude unit in order to reduce content of light materials and increase its flash point.

The LAGO, HAGO and another vacuum gas-oil are routed to Hydrogen Catalytic Desulfurising units or to direct blending in the products gas-oil tanks in the tank farm. The activity is dependent on the sulfur content in the crude oil and the level of sulfur required in the different gas-oil products for marketing. There is also an option to run the kerosene HDS (hydrogen desulfurising unit) with gas-oil either in parallel or as spare to the gas-oil HDS.

The two HDS units include a stripping section in each of them. These sections were started as Reboiling Heaters Strippers and in order to save energy adapted to steam injection stripping. As a consequence of turbidity problem in the stripped gas-oil it was decided about 20 years ago to replace the steam with hydrogen as the stripping material only in the Gas-Oil HDS unit. The hydrogen was there and cheap, the turbidity problem disappeared and there were already few examples for applying this process in some other industries. In the Kerosene HDS unit the stripping remained with steam and only after about 15 years of experience with hydrogen in the Gas-Oil HDS and when there was a higher need to operate this unit also on gas-oil the change was made and hydrogen replaced steam as stripping material in the Kerosene unit.

The gas-oil products from the two HDS units and those streams bypassing the HDS units are routed and blended to on spec. products in the tank farm which is part of the refinery. The tanks are regular atmospheric fixed cone roof tanks with open vent to the air.

On Friday 02:30 operation department started filling tank 401. The program indicated filling To 15000 cu m gas-oil of -6°C Pour Point. The filling was completed on Saturday 21:30 when the level in the tank was 16.49 meter and the temperature 48°C. During the filling the blend got streams from various origins:

- ✓ High Sulfur G.O. from the tank farm.
- ✓ Low Sulfur G.O. from tank farm.
- ✓ Light Atmospheric Gas-Oil from Crude Unit.
- ✓ Heavy Atmospheric Gas-Oil from Crude Unit.
- ✓ Light Vacuum Gas Oil from Crude Unit.
- ✓ Hydrotreated Gas Oils from the two treatment units working parallel on Gas-Oils.

On Sunday 7 a.m. the tank was full without any movement in the preceding 10 hours and ready for final sampling before dispatching.

3. THE ACCIDENT.

On Sunday 7.30 a.m. the Sample Man went on the tank in order to bring the samples needed for final testing. Few moments later a big explosion was heard in the refinery and its neighborhood and fire and smoke were observed immediately from far away.

The first close picture identified that tank 401 exploded, its fixed cone roof ruptured and thrown into the dike. A fire was also in the dike and engulfed great part of the perimeter of the neighboring gas oil tank No. 402 with 20000 cu m capacity. At the very beginning it was difficult to identify which tank is the origin of the fire because of the very heavy smoke spread over the bound.

In a very short time the refinery emergency system started to operate trying mainly to cool few naphtha storage tanks that are located immediately west to the burning dike. The main fire was observed as full diameter (30 m) pool fire on top of tank 401, a ground fire in the dike between tank 401 and tank 402 and ground fire around the walls of tank 402 up to the top. Municipal fire fighting units arrived in a very short time and also other units from distances within an hour drive, were directed to arrive to the fire area. The efforts were concentrated on putting down the fire in the dike including the fire near the 402 tank. The fire on the top of tank 401 was very heavy with a heavy dense smoke which didn't enable visibility and efficient access with foam.

After about two hours of fire fighting majority of the ground fire and the 402 fire was put down leaving ground fire near 401 and mainly the fire on top of 401. It took another half an hour to fight the ground fire and than was received the decision to try to put down the top pool fire with foam. After a very concentrated effort this fire was knocked down within minutes.

The immediate damage that could be identified was the loss of life of the Sample Man who was thrown with the roof in the explosion. Tank 401 lost about 3000 cu m gas-oil blown to the ground and burnt in the dike. The tank was totally damaged. The roof which had a weak seam weld connection disintegrated without tearing the walls plates. The beams inside the tank twisted and couldn't be used again. The remaining gas-oil was pumped to other storage and sent as product later. Tank 402 suffered damage on the top plates while few pipes crossing the dike on the ground bent heavily but didn’t rupture. Flow was kept all the time in the pipes.

About 12000 cu m fire water out of more than 30000 available were used during the operation and 22000 Liter of foam concentrate out of 80000 available.

The sampling device used by the Sample Man was split in the explosion. One meter of **Nylon** rope connected to the container (all parts from brass) were found on the bottom of tank 401 on the First entrance after it was evacuated. The other part of the rope was thrown during the explosion and found inside the dike area

4. FINDINGS.

“It is impossible to reduce all hazards in an hazardous chemicals system, but all the risks in the system should be identified”.

The main gas-oil streams flowing from the bottoms of the two HDS strippers operated many years under hydrogen stripping. The entrance to the storage tanks was never HAZOPED while the stripping tower in the HDS unit was HAZOPED during a course given to train people for being group leaders in HAZOP. This exercise was a kind of tutorial one, and the special question: " Is there any possibility of hydrogen sweeping or solution with the product gas-oil ” was never asked. On this special case the situation was that two hydrogen stripped streams were directed to the finished product tank and two other gas-oils from the crude unit with some lower boiling points and flash points were added to the stream. Would it be hydrogen in one of these streams it would not appear in a flash test as it evaporates before the sample is tested meaning that standard flash tests couldn’t identify positively presence of hydrogen.

From the 3 constituents for flammability: Flammable material, Air, and ignition origin the air was getting to the tank via the vent while the hydrogen was most probable the flammable component in the explosive mixture with air. The ignition source found during the investigation to be the most probable one was the Nylon rope in the sampling device that was introduced into the tank by the Sample Man.

Hydrogen that served as stripping material and injected to the tower in a low level, replacing the steam injected before, was thought as a very light material which would dissipate upward towards the top of the tower and was not even suspected to remain as part of the bottom stream. Preceding the accident the filling of the tank was based on two parallel hydrogen stripped streams and few bypass streams with individual flash points, some of them lower than the standard 66°C Flash Point. Filling the tank to its maximum operating level left volume of 880 cu m as vapor space under the roof of tank 401.

Some simulations done with Simsci Pro-I I model showed that hydrogen saturated gas-oil in the pressure and temperature in the stripping column would dissipate 90% of the dissolved hydrogen while transferred to the atmospheric pressure and temperature in the storage tank. In addition, there could be some more hydrogen which entrained with the gas-oil as bubbles.

Short time after the explosion the tank filled following 401, under same filling conditions and same blending, was tested and found containing hydrogen mixture above the gas-oil.

Air is always to be considered as present in a vented atmospheric fixed roof tank. On top of the roof, a 12 in diameter, “Goose Neck”, air vent is installed and breaths air. Air is sucked to the tank while it is lowering and surplus is vented out when level is rising.

Explosive mixture of air and light hydrocarbons, mainly hydrogen, formed during the filling of the tank and contained about 880 cu m. During the night hours of Saturday between end of filling and sampling, conditions were not sufficient to release all the hydrogen to atmosphere leaving in the morning an explosive volume above the product gas-oil.

One of the fundamentals that should always be emphasized when identifying risks of Hydrogen is its explosive limits in the mixture with air**:** 4.0%Vol.-75.6%Vol**.**

The presence of hydrogen makes the formation of flammable atmosphere particularly likely. Furthermore, hydrogen mixed with air at normal pressure and temperature has a very low ignition energy:

- ✓ Hydrogen 0.017 – 0.018 mJ
- ✓ Acetylene 0.017 – 0.018 mJ
- ✓ n-Pentane 0.49 mJ

Together with the wide flammable limits in air and high flame velocity, a hydrogen rich flammable atmosphere ignition is very susceptible to ignition even by weak sources. Flame propagation will be very rapid and the explosion is unsurprising.

Ignition source**.** “Possible sources of ignition are so numerous that we can never be certain that we have eliminated them completely, even though we try to remove all known sources” Kletz T. 1994.

The investigation identified several possibilities as ignition source. Almost all off them were eliminated. The Sample Man wore anti-static dress and put on safety anti-static shoes. Almost 10 hours passed from end of liquid movement during filling till sampling which eliminates the possibility of liquid charging with electrostatic charge. Another low probability Ignition source eliminated was the possibility of pyrophoric materials presence, although some remnant quantities of sulfur and iron were present on the internal walls.
Yet, the probability of self ignition of these materials exactly when the sampling was operated is very low but should be considered.

The investigation committee came to conclusion that the most probable ignition source was electrostatic charge charged on the sampling device rope which was synthetic rope and not a cotton as should be. The rope was charged probably by rubbing with rag or PVC gloves before lowering the sampling device to the liquid while air on that hour was dry. A rope charged like this might unload its charge while approaching the liquid in the tank or the walls of the tank.

During the work of the investigation committee, it found an 1995 important standard where in the special precautions of tank sampling included the following remark: “In order to reduce the potential for static charge, nylon or polyester rope, cords or clothing should be used”. The committee immediately sent the finding to the originators of the standard and got a fast reaction apologizing for a typing mistake by missing the word NOT before “be used”.

Procedures. At the time of introducing hydrogen instead of steam the procedure of management of change was not yet in formal use thus no records left from any brainstorm analyzing the risks.

Audit procedures of the sampling operation, including the equipment used, were deficient and enabled the mistake of replacing the usual cotton rope with nylon one.

Emergency preparedness (internal and external) were good and efficient while the tactic decision of the timing to operate the foam on the roof concluded with short time, comparatively, to put down completely such a massive 30M roof pool fire inside a dike fire. The surface cooling systems enabled protection of number of naphtha and other products tanks in the near neighborhood.

Lessons from History. No accident of hydrogen in fixed roof Gas Oil tank was known to the refinery people before their own experience. During the investigation some data bases were searched and few cases found. Mainly there was one case reported by Searson A.H. 1983 when operator was killed in explosion of gas oil fixed roof tank while sampling the tank through a gauging hatch. The tank contained gas oil from hydrofined gas oil product rundown service and the explosion was believed as a result from ignition of flammable mixture of hydrogen rich treat gas and air.

Learning from accidents**.** T.Kletz 1991 details five main reasons why accidents reports should be reported nevertheless it does not reflect credit on the companies concerned. Immediately after the company and Government investigation teams, completed their reports, less than 3 months after the accident an open conference was called by the refinery people. The conference, directed mainly to industry members, included a detailed reports and lessons to be learnt and roundtable discussion with members of both investigation teams. Part of the conference program was a detailed analysis of accidents like this by international well known adviser- R. Taylor from Denmark. The participation of 250 stakeholders indicated the great potential of learning from accidents if they, unfortunately, did happen.

Mechanical (dis)integrity**.** While it is better not to experience such an accident, still when it happens unfortunately, the damage should be much lower if the roof was weak seam connected to the walls. Otherwise all the capacity of the tank might spread and burn.

Community and Media**.** This was the biggest of its kind fire watched in the country at last years and from the first moment it caused great anxiety. It was much in contrast to the work done in the Refinery which ended up with damage only in the dike which included the two gas oil tanks. The Media did its work but although they got some special pictures from the air it was risky to shoot them from helicopters from above the fire area.

Investigation. T.Kletz 1994: “Accident investigation….beneath one layer of causes and recommendations there are other, less superficial layers. The outer layers deal with the immediate technical causes while the inner layers are concerned with ways of avoiding the hazards and with the underlying causes…”.

5. CONCLUSIONS.

The safety system was managed in a traditional reactive safety behavior and not under proactive PSM kind of regime. Lessons learnt in Piper Alpha and Philips 66 Company Houston by interweaving comprehensive safety management systems were discussed but not applied as a whole.

The root cause for the accident was the presence of hydrogen in the vapor space of the gas oil tank. Kletz T. “Flammable mixtures should never be tolerated except in a few special cases when the risk of ignition is accepted.”.

A recommendation made by the committee after it started its investigation, to shut the hydrogen to both strippers was executed immediately. The heater reboiler stripping system replaced the hydrogen injection.

It was recommended to install the designed HAGO stripper in the Crude Oil unit in order to prevent Gas Oil blending with lower flash point. This tower is already operating few month by now.

Electrostatic charge accumulated on the nylon rope was the most probable source for the spark discharge when the sampling device approached the level liquid or was dragged upward from the Gas Oil. Instructions were reviewed and audits put in place in order to assure correct use of sampling equipment, Cotton ropes and rags.

An Electrostatic risk analysis for the refinery was recommended and implemented by an expert in the area.

Instructions were given to check for explosive atmosphere in fixed roof tanks before sampling implementation.

There is no doubt that HAZOP can identify all risks in a system but the key to it is still the attention to details pronounced by the participants in the brainstorm. In this case, dealing with all those flows of hydrocarbons, the forgotten question about possible contamination with hydrogen turned the HAZOP to be ineffective and enabled the miss.

Dwg.1 – Gas Oil Flow in the Refinery

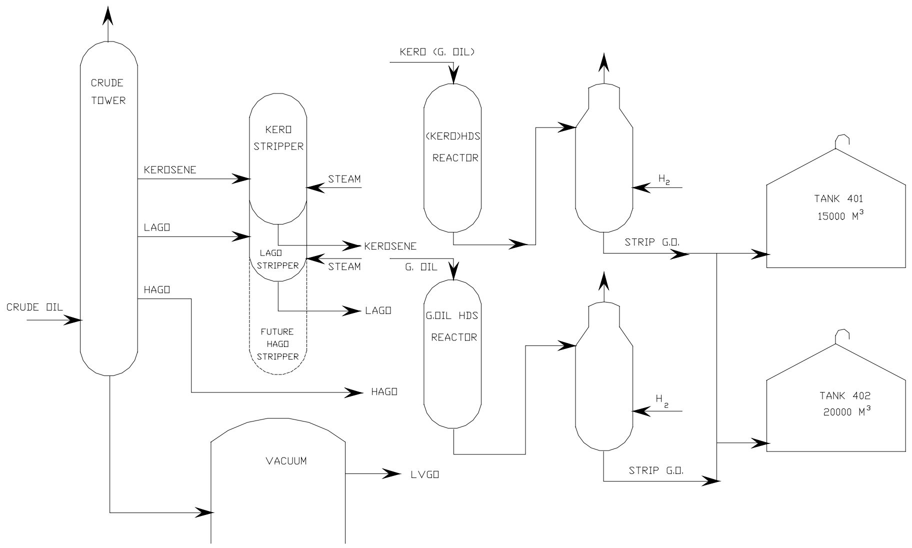

Fig. 1

Fig. 2 – The Roof in the Dike

Fig. 3 - Heavy Top Phase Pool Fire

References

Searson A. H., (1983) “Explosion in Cone-Roof Gas Oil Tank, Description of Incident” Proceedings of 4th International Symposium on Loss Prevention and Safety Promotion in the Process Industries, IChemE, Harrogate, England, Symp. Ser. No. 80.

Kletz T., (1994), “Learning from Accidents” 2nd edition. Butterworth Heinemann Page 53.

Kletz T., (1991), “Why should we publish accident reports?”, Loss Prevention Bulletin issue 100, August 1991, IchemE.

U.S. Department of Labor, (1990), “The Philips 66 Company Houston Chemical Complex Explosion and Fire”.

Kletz T., Andow P., (1986), “Risk Identification and Assessment”, A Seninar in Haifa Technology Institute.

CCPS, (1996), “Inherently Safer Chemical Processes, A Life Cycle Approach”, AIChE.

Kletz T., (1994), “Learning from Accidents”, 2nd edition, Butterworth Heinemann p. xiii.

The Hon, Lord Cullen, (1990), “The Public Inquiry into the Piper Alpha Disaster”, Department of Energy, England.

D. A. Moore, (1999), “Incorporating Inherently Safer Design Practices into Process Hazard Analysis”, Mary Kay O’Connor Process Safety Center, October 1999 Symposium.

M. Neowhouse, D. H. Napier , (1995), “ Hazardous Aspects of Fixed-Roof Storage Tanks “ SLP Second International Conference, Singapore December 1995.

Special Personal 50 years Anniversary

I have very special feelings standing on this stage in India and first time describing my personal experience with a big accident in Israel exactly 50 years ago (29.7.54).

I was 14 years old far from thinking about safety management and know nothing on Inherently safer design. I was taken with my family and some other 2000 people to a special memorial ceremony on the shore of sea of Gallile. It was held to honor the memorial and still living of parachutists penetrated from sky to the back of German forces in World war 2. There was a big gathering including leaders of the then young country and some were survivors from those very dangerous activities in the back of the defense lines.

All of a sudden appeared a small pilot (piper) whose pilot had a mission because of the nature of the ceremony to throw a parachute containing a special presentation from the prime minister. The parachute was stuck in the wing of the plane and while the pilot tried to make his mission and took his body out to free the parachute the plan lost control and went down to the crowd killing 20 people (among the 4 who survived the activities at the war) and wounded some 10th of audience.
At that time there was not deep investigation and I doubt that even there would have a real one if it would just give the root cause of the kind of inherent safety that why do planes have to fly over people in such occasions.

I believe that that event in my boyhood where I and my family were among the wounded audience was my first trigger to be busy in the business of safety management.

I never succeeded to meet later with the pilot,civilian pilot and sport star before the accident

I had few years ago a special guest I took to the area and detailed to him all the event. It was prof. Trevor Kletz and after we discussed the benefits of using Inherently Safer design he gave me his book "What went wrong ? " signed specially by him on the event area with his call for no more accidents which of course was very special for me.