– All the tanks looked at in detail were of a welded construction, but some of the older cone roof tanks at refinery B were riveted. Generally, all welded tanks are better for minimising sparking at joints etc, when carrying large lightning currents, but a gas-tight or oil-tight riveted construction is considered satisfactory. No cone roof or LPG tanks were looked at, but it was communicated that many of the cone roof tanks had 'floaters' in them (i.e. a floating roof directly on top of the liquid). These are not considered to be subject to the same lightning hazards as open top FRTs, because there is no equivalent of the rim seal sparking problem in tanks with welded construction conducting roofs. However there may be other issues, especially with geodesic roofs.

  One geodesic roof tank was viewed at some distance (see Photograph 2), the roof of which was said to be of bolted construction, but the skin thickness of the aluminium panels is not known at the present. The steel cone roof tanks have steel at least 5 mm thick so they are able to carry the high current safely. There remains the possibility that an incendiary hot-spot could form on the back surface of an arc attachment point. This is discussed in EI-TN1-03 *Review of burn-through and hot-spot effects on metallic tank skins from lightning strikes*.

– All the tanks examined were equipped with flexible bonding cables from the shell to the roof. One tank had the usual type of yellow/green insulation covered cable, lying loosely on the floating roof deck, (which might have been a temporary cable), another tank had two bonding cables, both fitted to automatic tensioning spools on the top of the floating roof. These are expected to play a secondary role in lightning protection because of their relatively large inductance, although they might be of sufficiently low resistance to prevent sparking associated with the continuing current, which is only a few hundred amps at most, and has a very low di/dt. They are much too inductive to affect current flow appreciably for the fast high di/dt return stroke and restrikes.

– It appears to be industry practice that shunts are made from steel, but stainless steel not carbon steel. It was noted that the shunts used on the tanks at refinery B were grade 312 stainless steel, which is a non-magnetic austenitic type of steel. This means that one of the metals involved in the shell to shunt contacts is uncorroded, and in fact polished smooth by the rubbing on the shell wall as the roof moves up and down. However it appears that the shunts do not rub the oxide layer off the shell to any extent so that one electrode of the contact (the shell) is always corroded and/or covered in a layer of wax etc.

  It would appear that no other materials are in general use as shunts. Scrap samples of the stainless steel shunts were provided, to be used in later tests.

– On cone roof atmospheric tanks at refinery B, the pressure-vacuum breather vents do not have flame traps owing to problems with them getting blocked up and so allowing the tank to have an over or under pressure in it which can lead to collapse. Although the vents are located high up on the roof of the tank, they do not protrude upwards very far. Therefore the probability of them being hit directly is very low. Also, the probability of one of the vents being open at the time of the strike is viewed as small. Overall there is likely to be a low probability of a lightning induced ignition in such cone roof tanks, and experience supports this.

– Painting of tanks. Electrically, from the standpoint of lightning safety, the only concerns with painting are where paint is on a surface upon which the floating roof tank shunts slide, that is, the inside surface of shells of either open FRT tanks, or nonconducting geodesic roofed tanks. Mostly tanks are unpainted, being in effect bare metal, which for crude oil is protected to some extent by the wax. Motor spirit, Avtur and Avgas tanks are usually unpainted on their shell inner surface.

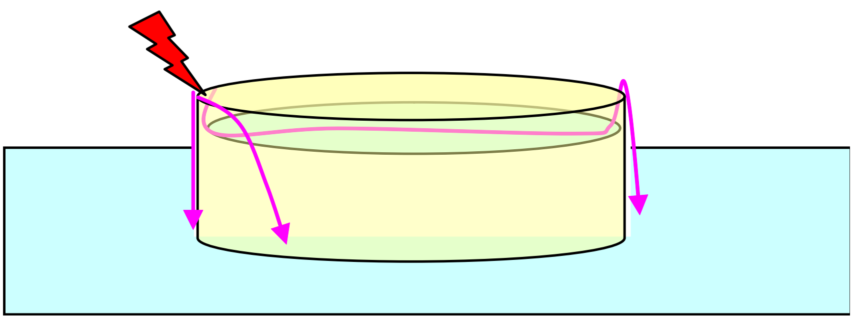
Tanks are sometimes painted with an epoxy paint. Where epoxy paints are used, it should be noted that they are very tough electrically (i.e. very good insulators) so they will inhibit electrical contact between shunt and shell. Voltage breakdown accompanied by arcing and sparking is inevitable. (Iron rust is essentially a non-conductor too, so whether the surface is rusty or painted it makes for high resistance contacts for the shunts.)

– Halon fire extinguishing systems were not fitted to tanks at refinery B, but as is common, several outlets of foam pipes were located around the tops of the tanks.

– From observations on the tank floors (see 3.2), it is interesting to make a comment about overall current flow on tank shells. These comments are expanded in Cul/LT-0234 *Review of lightning phenomena and the interaction with above ground storage tanks* and Cul/LT-0235 *Review of tank base earthing and test current recommendations.*

– The tank floor is generally 8 mm thick and welded to the tank shell walls. The significance of this is that the skin effect will cause the fast pulses of lightning current to flow exclusively as a thin outside layer. So for a strike to the top of the shell of an open FRT, much of the current will flow as a surface layer down the outside surface of the shell. Some will also flow down the inside surface of the shell to the level of the floating roof, cross via the shunts to the floating roof, flow across the top surface of the floating roof and then to the shunts on the opposite side of the tank, up the inside surface of the shell to the top, and then down the outside surface to ground. Current will enter the ground by flowing on the underside surface of the tank floor steel plates. This current flow is shown in Figure 1.

Figure 1 Current flow



Thus no fast current will flow in structures or surfaces adjacent to the tank liquid.

3 DETAILED OBSERVATIONS ON THE TANKS THAT WERE INSPECTED

3.1 TANK A

This was an open top FRT for crude oil, and was equipped with primary and secondary rim seals. The primary seals could not be observed, because the secondary seals were in good condition, and were pressing firmly against the shell over the length of seal that was inspected. The secondary seals were fitted with shunts similar to the ones found on tanks at refinery A, about 18 cm wide, and pressed against the shell at about 15 cm above the bolt line where the shunt was fixed to the top of the secondary seal. The spacing was about 3 m (but this was not actually measured), and the build-up of wax under the shunts appeared to be less severe than found on tanks at refinery A.

As is common on FRTs, tank A had a foam dam immediately next to the secondary seals, the top of the foam dam being higher than the top of the secondary seals. The shunt contact point may have been at about the foam dam height or just below. Thus it would be possible for sparks from a shunt to drop into the region between the foam dam and the secondary seal, even though the shunt contact point was much higher than the dam. This is because the thermal sparks (small pieces of incandescent material) can travel large distances and still be very bright. However, on this particular tank, the secondary seal made good contact against the shell so that it looked to be very unlikely that thermal sparks could drop into the volume between the primary and secondary seals, a region where there would be a relatively high probability of a flammable vapour/air mixture being present.

3.2 TANK B

This open top FRT was undergoing maintenance and the roof was supported on its legs. The primary and secondary seals had been removed for the maintenance programme, so they could not be inspected. The region below the floating roof had been completely cleaned out as part of the maintenance and refurbishment programme, so the condition of the shell could not be assessed. The floor of this tank was suffering corrosion and was being replaced with 8 mm thick steel sheets that will be welded into place to be oil tight. The significance of this observation is discussed in Section 2.

3.3 TANK C

This was an FRT for motor spirit, (petrol) also in its maintenance programme, and so allowed detailed inspection both below and above the floating roof. As with tank B, the seals had been removed so the construction details could not be seen. During discussion on this tank, EEMUA 159 *User's guide to the inspection, maintenance and repair of above ground vertical cylindrical steel storage tanks* was referred to.

Photograph 1 Showing the corrosion inside a motor spirit tank. Although the picture is slightly blurred, it shows the flaking away of the rust on part of the surface

Photograph 2 Geodesic tank roof at refinery B

Photograph 3 Geodesic tank roof at an overseas refinery

EI-TN1-03

REVIEW OF BURN-THROUGH AND HOT-SPOT EFFECTS ON METALLIC TANK SKINS FROM LIGHTNING STRIKES

CONTENTS

SUMMARY

This report describes the threat from puncture and hot-spots in igniting vapour/air mixtures in storage tanks. A review of data from different sources suggests that puncture of steel skins >4 mm thick is not a threat. Hot-spot effects may be a hazard at this thickness and possibly greater, but that is not so clear.

1 INTRODUCTION

For some types of petroleum product storage tanks there is a possible threat from lightning puncturing the roof of the tank. If the vapours in the head-space within the tank are within the flammable range then such a puncture would be expected to result in an ignition. An ignition of enclosed vapours will result in large overpressure and severe structural damage.

Similarly the effect of the arc would be to heat the roof skin locally, and it is possible that, even if puncture does not occur, the local hot-spot could itself present an ignition hazard.

This report reviews available data on lightning effects on metal skins. It assesses whether there is such an ignition hazard from these sources. There is a scarcity of relevant data, but it is clear that steel skins in excess of 4 mm thick do not have risk of puncture.

There is similarly a lack of relevant data on hot-spot effects, and although there does not appear to be a significant risk, it is proposed that some supplementary testing be carried out to confirm this.

2 INSTALLATIONS VULNERABLE TO IGNITION

Types of tank for which this could be a threat are discussed briefly in this section. Types of tank are also covered in Cul/LT-0234 *Review of lightning phenomena and the interaction with above ground storage tanks.*

2.1 FLAMMABLE RANGE

Both ignition by hot-spots and by a puncture are not particularly sensitive to the vapour concentration. That is, the parameters of the hot-spot required to cause ignition, in terms of temperature/time/size, do not vary much across the flammable range[11]. On the other hand ignition by spark sources is strongly dependent on vapour concentration, so that low energy sparks of perhaps 0,5 mJ can cause an ignition, but only if the mixture is in the flammable range. Higher energy sparks will be required to ignite mixtures away from the optimum proportions.

Table 1 Some examples of the volume percentage of various vapours which define the flammable range.

Product	Min % vol	Max % vol
Propane	2,2	9,5
Ethylene	2,75	34
Gasoline	1,5	7,5
Avtur	1,3	8

The conditions which lead to these concentrations occurring will vary widely.

For the aviation industry this limited range of flammability has helped prevent fuel ignitions and explosions. Older fuel types were very volatile and under most flight/lightning strike conditions the tank vapour space was too rich to burn. Modern jet turbine fuels are low volatility and usually too lean to burn.

Where catastrophic incidents from lightning have occurred it has been when these fuel types were unwittingly mixed, leading to a fuel within the tank of dangerous volatility. In the case of the TWA800 explosion in 1996, Avtur was brought into a hazardous state primarily because the centre fuel tank was adjacent to air conditioning equipment and became unintentionally heated[12].

2.2 TANK TYPES AND FUEL/AIR HEADSPACES

It follows then that the installations potentially at risk are only those where flammable vapour/air mixtures could be present. These could include:

– fixed roof tanks;
– geodesic tank covers, or
– pontoons on floating roof tanks (if fuel has leaked into one of the pontoon cells).

For fixed roof tanks, complete equilibrium is likely to have formed between the fuel and the vapour space. This is because of the large surface area interface between the liquid and vapour, and also because there would be little or no air flow other than through the vent. Tanks potentially at risk would be those holding the less volatile fluids, such as some alcohols, which form a flammable equilibrium mixture at normal temperatures. Motor spirits would become dangerous typically at temperatures below 0 °C.

For geodesic tanks, or tanks where there may be limited visibility of the vapour surface, as well as some ventilation, then the more volatile liquids would be those likely to be more dangerous. This is because the equilibrium vapour air mixture (which would be too rich to ignite) is less likely to have formed, and there will be a tendency to have more air present than would be the case at equilibrium.

It is believed that many fresh crude oils have flashpoints below 10 °C, which would make crude oils relatively hazardous in an enclosed environment. That is, it may well form an equilibrium vapour ratio which is in the flammable range.

It would be interesting to source any data on monitoring of vapour space flammabilities in fixed roof and geodesic tanks, and near to floating tank seals.