

A CASE HISTORY - WHOSE RESPONSIBILITY?

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A case history of an incident is presented which occurred over 15 years ago in a solvent extraction oil refining Plant, whilst the author was working for a contractor. This occurred after the Plant had been handed over, and was in full production, but the hot oil heating system was not performing correctly. While sampling the hot oil, the oil sprayed out suddenly, burned the operator, and then ignited. Whilst it would be simple to blame the operator, there were consequences which had not been foreseen, and which resulted in the entire Plant being shut down for 12 weeks.

KEYWORDS: Hazard, Fire, Incident, Oil refining, Learning, Safety

INTRODUCTION

This incident occurred after the Plant was handed over to the Operating Company, following commissioning. This was about 16 years ago, prior to the Author joining ICI and the subsequent demerger to Zeneca and the sale as Avecia. The incident resulted in the entire Plant being shut down for a period of 12 weeks after a serious fire. This major shutdown was as a result of a series of small shortcomings in the design, construction, and operation of the Plant, all triggered by a single event of sampling the heat transfer fluid because of degradation of the performance of the heat exchangers in the Plant. Although an investigation was carried out, it concentrated on the immediate cause, but did not review the lessons that could be learned, nor the wider implications of the incident.

THE INCIDENT

The heat transfer hot oil system was not performing at its design rate, so it was decided that it was necessary to determine whether the oil had degraded. The operator had been asked to take a small 500ml sample so that an ASTM distillation[1] could be carried out to determine the fraction of light ends that had formed. There was no dedicated sample valve, so the Operator was instructed to use a 1/2" gate valve which was not intended for taking samples. This had been fitted to the 12" diameter overhead heat transfer hot oil mains to allow for draining the horizontal section after the isolation valves. This 1/2" gate valve was some 4 metres from the ground and was not intended to be used unless the system was cold and the section had to be drained. It was capped to prevent drips of oil which might leak past the gate valve falling onto the work area below. The operator had to stand on a ladder, as it was considered unnecessary to erect scaffolding.

When the cap was unscrewed, the oil sprayed out, and the operator received serious burns to the chest, but was able to climb down the ladder and report to the control room. The operator had checked that the valve was shut prior to unscrewing the cap, and thought that the oil leaking out as he unscrewed it was simply a small quantity of oil which had leaked past the gate. However, as the cap was unscrewed to the end of the thread, it flew off, and the oil sprayed out. It sprayed down onto the mineral wool acoustic insulation forming the stair-well wall, and covered the area beneath the valve, forming a large pool of hot oil, well above its flash point. The acoustic wall had been required as a condition of planning permission to screen neighbouring houses from the noise of the main pumps of the Plant. Shortly after the release the oil ignited as a classic "lagging fire", being hot and dispersed on the mineral wool of the acoustic insulation. The ensuing fire engulfed the north end of the Plant. The main power cables serving the entire Plant entered at the north-west corner and passed along the stair-well wall and then down the centre of the Plant. These cables were PVC covered, single wire armoured PVC insulated cables, so the fire destroyed the cables and shut the whole Plant down. It took 12 weeks of working 24 hours a day to replace the cables and re-commission the Plant. Fortunately, the fire did not spread to any of the major equipment and damage was limited to the stairs and the power and instrument cables.

The initial investigation showed that the 1/2" gate valve, which was on a short set-on branch, had a short stub of welding rod in it. It was not possible to determine when the stub of welding rod had lodged in the valve, but as the valve had been capped on installation, it would not have leaked when the system was commissioned. Therefore, even though the Operator had checked that the valve was closed, there was no way that it was known that there was an obstruction in the valve seat, and only when the screwed cap was removed would the oil come out. It was believed that it was safe to remove the cap even with the main under pressure, as the valve had been confirmed to be closed. In fact the Operator had only checked that he could not close it any more than it was already closed. He did not fully open the valve and then re-close it, counting the turns, so that he knew it was not obstructed. With hindsight, this should have been done, so that it would be known to be closed fully, and only small leakage past the gate would be likely to come out.

PIPE DEBRIS

The stub of welding rod that had been left inside the pipe was there simply because the procedure for cleaning the pipe had not been followed. The 12" pipes had been cut, set up, and welded in a Fabrication Shop on the site, and the 1/2" valve had been screwed onto the set-in branch and seal welded. To prevent potential damage of the valve seat during welding, the piping specification stipulated that the valve should not be tightly closed during seal welding, but left partially open. Thus the procedure had been followed at this point in that the valve had been opened prior to the welding. Once welded, the valve should have then been closed and capped with a screw cap. The entire pipe section was then subject to the regular inspection laid down in the piping specification. The inspection consisted of a visual inspection for cleanliness and freedom from debris, radiography of 10% of the butt-welds, and finally a hydraulic test. As the pipework was to be used on hot oil service, it was also to be drained thoroughly and dried out before installation.

As the weld debris had clearly been left inside the pipe, there was either a failure to apply the appropriate inspection of ensuring that the pipe was free of foreign matter, or contamination after inspection had occurred. In this case, it was not possible to determine whether the welding stub had been in at the start and had not been seen when the pipe was inspected, or whether it had entered during the erection phase whilst the pipe section was being moved from the on-site Fabrication Shop and lifted into the Plant structure.

Whilst such a breach of inspection is rarely so catastrophic, it does underline the need for procedures to be implemented correctly. As the entire construction phase of the project was behind time, it is easy to see that apparently trivial details can be ignored to save time. Hence if it is apparent that procedures are not being followed, then it is necessary to determine whether the reason is that the procedure is unworkable or simply the reason is unknown to those who should follow it. Appropriate corrective action is then required. In this case it is not possible to determine where the fault lay, but the inspection requirement of confirming that pipework is free from foreign matter is a generally accepted good practice, but is often ignored or simply undertaken in a cursory fashion.

THE HOT OIL SYSTEM

After a short period of normal production, it was apparent that the hot oil system was not performing correctly, since the main circulation pump was cavitating, and the heat transfer was not being achieved at the correct operating bulk temperature. The oil temperature had been increased marginally, but this had not improved the Plant performance. It was also apparent that there was some cavitation at the control valve on the largest heat exchanger. This was thought to be due to degradation of the hot oil by producing light ends which were flashing off in the pump and after the control valve. This was the reason for the requirement to sample the oil. The risk of poor performance was not entirely unexpected as the design of the heater had been significantly altered to a non-standard design with an unusually low pressure drop to minimise pumping power. The design for the hot oil system had been altered during the design phase because of the layout of the plant in the existing buildings, in order to save capital costs. The main plant location was constrained by a number of reasons, but the position of the Services Building, electricity Substation and the Control Room were fixed as these were existing buildings, served by existing cables. The Site plan is shown in Figure 1 below.

The existing cable supplying the Services Building from the substation was of a small capacity, and was buried along its entire length and passed under the main access road for the Plant. The installation of a new steam boiler, the hot-oil heater and circulating pumps, and a new air-compressor gave an electrical loading which exceeded the capacity of the existing cable. As all the loads were continuous, there was no possibility of applying diversity, so either the cable had to be replaced or the loads reduced.

The cost of replacing the cable was high, as the existing cable was buried rather than being in a service trench. Hence there was no simple way of running another cable either as a total replacement or as a separate cable running in parallel with the existing cable. Since the total load was only marginally above the continuous capacity of the cable, all the loads were critically examined to see if a reduction was possible. The largest single load was the hot oil main circulating pump rated at 45kW, and was the only load where some reduction might be possible.

The original design flow for the thermal load for the Plant fell between two sizes of pump frame, so the larger pump frame was selected. The standard motor for this pump frame fitted with its largest impeller was 45kW which not only exceeded both the flow and head requirements for the hot oil system, but also overloaded the electric cable supplying the building. Therefore the pump characteristic curves were examined, and it was found that by using a turned down impeller and accepting a lower head, the flow could be maintained and the required motor power could be reduced to only 30kW as the pump would be operating much closer to the best efficiency point. The 30kW motor current was within the capacity of the existing cable, but the available head on the pump was now below that required by the manufacturer of the hot oil heater. Thus there was a possible way of avoiding replacing the cable if the heater could be designed for a lower pressure drop. This was thought to be a distinct possibility, as one of the Contractor's senior staff had previously worked for the heater manufacturer, and was confident that such a design was possible.

The heater manufacturer was consulted about the possibility of designing a special hot-oil heater with a lower pressure drop. The standard heater at that thermal rating and oil flow rate used a three-start coil operating in parallel for the heater elements. This gave too high a pressure drop for the system, so the possibility of using more coils in parallel was investigated. This would result in a slightly larger heat transfer area, but as the velocity would be lower through each coil, the overall heat transfer coefficient would be reduced. Eventually, the heater manufacturer agreed to design a five-start coil heater, which would have a guaranteed low pressure drop at the required flow, thus allowing the smaller pump motor to be fitted, along with a turned-down impeller.

However, as the velocity would be lower, the heater manufacturer would not guarantee the performance of the heater other than the low pressure drop. The manufacturer also warned that as the velocity was much lower in the proposed five-start coil, there was a distinct possibility that the high film temperatures could occur, leading to thermal cracking of the oil. Hence the manufacturer suggested reducing the maximum film temperature from 315°C to 305°C, and a bulk temperature from 285°C to 280°C. The cracking of the oil could lead to deposits of carbon in the inside of the tubes, which would foul the heat transfer surface, leading to higher wall temperatures. As the pressure drop was so low, the risk of flow imbalance was much higher than would be the case for the normal three start coil, so the manufacturer suggested the incorporation of individual thermocouples at the outlet of each coil, so that any imbalance could be detected. In view of the cost of this, it was decided that the option of monitoring would not be purchased. However, it was decided that the oil would be changed on a regular basis to minimise the risk of degradation.

RISK MANAGEMENT

The decision to go ahead and purchase an unknown and unproven design of heater rather than accept the known cost of replacing the cable was taken on the basis that whilst there was a risk of the heater not performing, it was assumed to be manageable. To provide some finance for solving any technical problems which may arise during the commissioning, a sum of money was allocated as an ill-defined contingency, but there was no plan as to exactly what it would cover, or whether it would be adequate. It was decided that the heater manufacturers were being overly pessimistic in their warnings, so the unknown and un-quantified risk was accepted. No proper risk analysis was undertaken to determine the financial, technical and safety implications of the failure of the heater to perform at its required design temperature, despite the reservations of the manufacturer. Methods of risk management in capital projects is discussed elsewhere[2].

However, as there was an known potential for degradation of the hot oil, there was a recognition that complete replacement of the oil would be required, and a suitable 2" connection was provided to allow for emptying and refilling the system. No consideration was given to the provision of a sample point. Clearly the management of the technical risk was ignored. Once it became apparent that the decision had been taken to save capital by not replacing the cable, no follow up was undertaken for contingency plans. From the known potential for degradation of the oil into light ends and carbon deposits in the heater, it was apparent that a sample point should have been provided and a sampling schedule drawn up to monitor the quality of the oil. This omission was one of the root causes of the incident.

The choice of PVC cable for wiring the power into the Plant was made on the grounds of economy, as the risk of loss of the cables due to fire was considered remote. As there were existing pipe-bridges, it was decided to route all the cables along the existing pipe bridges, and provide short new spans to connect to the tank farm and the main Plant. This was seen as being economical as it used already available structures for support. As the Plant was a continuous plant, every pump on the Plant had an installed spare, so that in the event of loss of a pump for any reason, the installed spare would be available to avoid interruption of production. However, the supplies to the duty pumps and the supplies to the standby pumps were not segregated and brought in at opposite ends of the Plant, but were on the same cable run. The use of the single cable run introduced a potential common-mode failure that severance of the cable run for any reason would shut down both duty and standby pumps. Had the standby pump cables been brought in at the opposite end to the duty pumps, a failure at one end of the Plant may have stopped all the duty pumps, but would have allowed continued operation of the standby pumps. The potential for a failure of all the cables entering the Plant at a single point was considered too unlikely to warrant the use of mineral insulated copper clad cable, which is fire resistant. Consequently, the use of the lower cost cable, but using a common cable run, did not achieve the standby availability that had been intended.

LESSONS TO BE LEARNED

- Where procedures are available and required, then it is a management responsibility to ensure that they are followed. Where procedures are not followed, then the reason behind this should be determined, and appropriate corrective action should be taken.
- Project costs should be realistic, and pressure to reduce costs by cutting the scope should be either resisted, or the consequences of the reduced scope should be understood and accepted.
- The use of an ill-defined “contingency” for capital projects should be avoided, and the financial risks should be defined properly.
- Where information or warnings are given, then suitable action should be taken to ensure that the implications are fully considered, and are not simply ignored.
- The need to recognise the implications of operating outside the design parameters of equipment is essential.

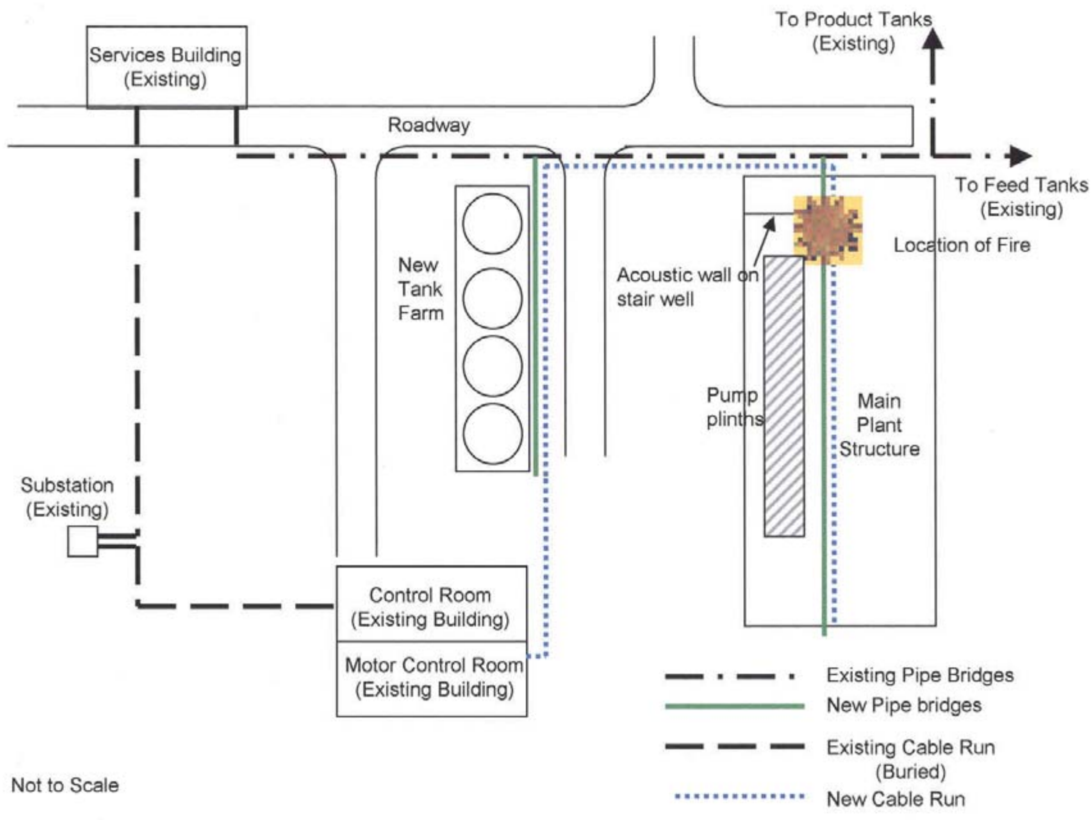

Figure 1.

REFERENCES

1. ASTM Test Method D86-01e1 "Standard Test Method for Distillation of Petroleum Products at Atmospheric Pressure".
2. Youds, P., "Financial risk management - Pharmaceutical capital projects", I.Chem.E. Project Management and Pharma Subject Groups joint meeting, Birchwood Park, Warrington, 13th February 2002.