THE HUMAN FACTOR IN SAFE PLANT OPERATION: Lessons learned from investigation of some major incidents

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Three explosion and fire incidents on separate plants on a large refinery operation resulted in four fatalities. The incidents occurred during plant maintenance, plant cleaning and after plant modification. The circumstances of each incident are outlined and the influence of the human factor is described. Management control of the human factor to complement systems of work and physical safeguards is recognised.

Key Words: Explosion & Fire; Human Factors; Hydrocarbon Processing; Plant Maintenance; systems of Work.

INTRODUCTION

Fatal accidents occur even in the large petrochemical industries where the principles of self regulation embodied in the Health and Safety at Work Act may be expected to be carried out. Prevention of some accidents however requires a greater reliance on the human factor for control than others. This paper discusses three incidents that occurred at a major refinery within the space of 3 months. The incidents resulted in four fatalities and, in one case, necessitated a major plant rebuild. The examples chosen illustrate the diversity of the human factor. They reinforce the points made in HSE Publications [1, 2] on maintenance hazards in the chemical industries and on human factors, that a plant and its operating personnel are at their most vulnerable during times of maintenance and abnormal running conditions.

Attention to technical aspects (the hardware) of safe plant operation can sometimes overshadow management systems (the software) required to assure and complement the effectiveness of the engineering safeguards. Management systems, in this context, are about control of the human factor - plant supervisory, operating and maintenance personnel.

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The following comments taken from reports of incidents in the UK and abroad in recent years, show the influence of the negative side of the human factor ie misunderstanding, failure to appreciate hazards and consequences, failure to follow instructions. The positive side of the human factor includes correct assessment and response to plant output data, adherence to plant instructions and company codes, attention to safe operation.

'An inexperienced electrician's mistake sparked off a full scale emergency. The worker misunderstood instructions in a routine trip test. A screwed plug blew out of a relief valve causing an uncontrollable escape of process gas into the compressor house'.

'Instructions to the operators were very strict indeed but the operators ignored them nevertheless. Operator errors involved systematic, persistent and conscious violation of clearly stated safety rules'.

'The persons responsible for issuing the permit failed to recognise the significance of solid deposits in the pipeline'.

THE INCIDENTS

The types of incident mentioned above are not unique and this paper describes incidents that the author has been involved in investigating. The paper does not contain a detailed description of the investigations nor a discussion of how potential causes of the incidents were assessed and eliminated to arrive at a consensus opinion as to the most likely cause. These are described in a full HSE report.[3]

Plant Maintenance

The first incident was on the main site flareline system. The system had evolved over many years, it was seldom shutdown, it was large, complex and had a high volume, low pressure throughput of gas and gas liquids. The need arose to replace a crossover valve which was passing gas between two streams. A method was devised for isolating the particular section of pipework; scaffolding was erected and the line checked for liquid. A permit to work was then issued. The permit recognised the possible presence of pyrophoric ferrous sulphide scale and so contractors working on the valve were instructed to wear self contained breathing apparatus to protect them against the possible presence of toxic hydrogen sulphide vapours. A compressor was provided for auxiliary air line breathing apparatus sets and a mobile crane was brought in to support and lift the valve during the maintenance operation. Site rules required that the compressor was fitted with a flame arresting exhaust box, however earlier mechanical failure meant that this rule was not complied with. As the valve flanges were being released the line sprang open and liquid poured out and fell to ground level where it ignited, presumably on the compressor and enveloped two men on the scaffold staging in flame. The bodies could not be removed from the site of the incident for about 24 hours until the flames were snuffed using a nitrogen purge.

The sample point used to test that the line was liquid free was remote from the part of the system where the job was to be done. It was also prone to blocking with scale. The remedies proposed to prevent similar occurrences were simple in that they were to mark valve bodies and stems to show the open and closed positions and to provide drain and sample points on or close to identified critical valves in the system.

A major point about this incident was that hazards involved in the operation were recognised but the consequences of those hazards being realised were not thought through and then acted upon to prevent their occurrence.

Plant Modifications

The second incident occurred on the hydrocracker unit on the plant. The hydrocracker was used for the catalytic hydrogenation of waxy sulphur containing residues to give more valuable products. The hydrogenation reactors operated at around 2,250 psi and 350^{o}C with a throughput of about 50,000 gallons per hour. Liquid from the reactor beds was cooled to around 50^{o}C to partially outgas hydrogen. Pressure was then reduced to about 120 psi to remove further hydrogen before liquids were passed forward to be fractionated. Critical aspects of the plant operation, from the production point of view, included control of reactor bed temperature to maximise the product yield and control of hydrogen quality because too much light hydrocarbon impurity could give rise to excessive compressor vibration with the potential for long and expensive shutdowns.

The incident itself centred around the principal high pressure/low pressure interface within the system. Liquid flow through this interface between high and low pressure separator vessels could be controlled by either of two parallel valves operating in the manual or automatic mode. In practice, both valves were used together to reduce vortex effects in the high pressure vessel. In the original design of the hydrocracker a turbine was included on the outlet side of the high pressure separator to utilise the energy available from the 2000 psi pressure drop. This turbine was designed with low and extra low level protection to shut off liquid flow and thus prevent damage to it from breakthrough of high pressure gas. Although the turbine was removed in the very early days of plant operation, the cut-off protection switches remained. This high/low pressure interface in the system relied on single valve operation for process control and safety isolation. Not all operators understood that the level control switches had a wider function than just protection of the (defunct) turbine.

On the day of the incident the plant was on standby and only a small amount of liquid feed was passing forward through the plant. The plant was on manual control and downstream the low pressure separator was boxed in. Just after a shift changeover the plant blew up, shock waves were felt 18 kilometers away, metal fragments of up to 2 tonnes in weight travelled up to 1.2 kilometers from the scene of the explosion. One contractor was killed by the fireball associated with the explosion. There was no damage caused to other plant units on site by flying debris that led to any escalation of the incident.

A principal factor in this incident was failure to successfully control the high pressure/low pressure interface between two vessels designed for different duties. The downstream vessel was designed to handle the passage of liquid at low pressure. It was not designed to withstand the high pressure that could result from gas breakthrough when its liquid and gas outlets were shut. During a maintenance period several years before the incident a solenoid on one of the flow control valves had been by-passed. This solenoid was intended to dump air to the control valve on actuation by the extra low level switch on the high pressure vessel. The alarm signal announcing the trip condition had also been disconnected in an instrument panel in the control room. No record of the modification, its approval, reasons for carrying it out or analysis of the consequences could be found. It was suggested that trip function was a bit inconvenient as it caused unwanted plant stoppage.

Removal of the solenoid from the control loop meant that the protection provided by the extra low level trip was no longer available so that the system relied on the normal automatic process control to shut one valve and manual intervention to shut the other. With these critical valves mounted in parallel, any failure of either one could allow the high pressure vessel to empty of liquid. Loss of liquid seal would then mean that high pressure gas could feed forward into the low pressure vessel. Loss of the trip function meant that any failure of process monitoring or mis-interpretation of control room data by operators could result in valves mistakenly being opened or left open causing loss of the liquid seal level in the high pressure vessel with consequent gas breakthrough.

The consequences of disconnecting vital trips was not fully examined nor was the significance of these trips to plant safe operation appreciated. Although all the plant trips continued to be shown on the P & I diagram, the reality was that the system relied on a single valve for both isolation and control. There was nothing to protect the plant against the possibility of human error.

Systems of Work

The third incident involved the cleaning of a floating roof tank used to store stabilised crude oil. With the waxy nature of North Sea crude, sludge banks build up even in stirred tanks. In an 80 metre diameter crude oil tank, banks of sludge had built up to a height of about 2 metres and covered a large proportion of the base after only a few years of operation. One way in which these tanks could be successfully cleaned was for people to go inside them and remove the sludge either mechanically or by hand. To do this the tank had been drained and allowed to vent naturally through opened manholes but it was not purged nor provided with additional mechanical ventilation. The contractors employed to remove the sludge had been used before and were aware of site safety rules. They brought on site their own hydraulic pumps, hydraulic tractor unit and diesel generators to provide hydraulic power. They also supplied their own airline breathing apparatus for use inside the tank. During the cleaning operation a fire started in the tank followed by a low power explosion in which one of the men working in the tank died. The investigation revealed that the sludge the company believed to have a flashpoint of about 15°C actually flashed below 0°C. It was likely, therefore, that there would always be vapours within the flammable range somewhere within the tank. The range of potential sources of ignition for such vapours included pyrophoric scale; generation of static electricity on clothing, on flexible hoses etc; the proximity of diesel power packs to the tanks; hot surfaces on hydraulic pumps used within the tank etc. During the course of the investigation to discover which was the most likely of the many possibilities one of the contractors admitted to smoking in the tank. This turned out to be custom and practice for some of the cleaning gang including the outside fire watchman, who himself occasionally went inside for a smoke. The site was petroleum licensed and the contracting company had provided a specially designated smoking cabin for the contractors.

The salient points in this incident were that standards of supervision and control by the contractor's company were lax; monitoring of the contractors' competence and actual standards by the contracting company were not sufficiently thorough; observance of site procedures including dematching (which was a standing instruction) was poor but, in the end, disobeying fundamental safety rules either through ignorance of the dangers or foolhardiness caused the incident.

COMMENTS

Inspection

These three incidents occurred before CIMAH safety reports for the sites had been completed and submitted to the HSE but even if this were not the case it is questionable whether HSE inspectors reading the report or carrying out normal inspection duties on site would have been able to prevent four men dying. For instance, in the case of the hydrocracker examination of P & I diagrams showed protective systems to be in place. On paper the interface between the high and low pressure sides of the system seemed acceptable with both monitoring and alarm systems present. Finding that they were not, required painstaking inspection in inaccessible and remote parts of a physically large plant. Hindsight would lead to examination of a small part of a relatively small part of a large refinery, but when time is at a premium other parts of other plants may have to be omitted. Inspection has to be planned and targeted.

Management

The incidents involved the negative aspects of the human factor and it is a function of safety management to control and avoid the unacceptable consequences of these negative aspects. A determined person may succeed in carrying out deliberate acts such as smoking in a controlled area, as in the case of the tank fire. Nevertheless many things could and should have been done to deny the man the opportunity to smoke in the tank. In the case of the flareline, permit systems were used but more rigorous examination of the job should have highlighted the problems of sampling on an overhead line which was prone to scale formation. Plant safety management has to commit time resources to monitoring the effectiveness of laid down safe working procedures, to training and supervision of workers, to modifications and updating in the light of experience.

CONCLUSIONS

Many individual lessons can be drawn from these incidents and these are described in the full report.[3] However, the main points of this paper are; firstly, that it is vitally important for all persons involved with chemical plants whether in a production or a safety role, to take full account of the physical safeguards provided, to ensure they are adequate and continue to be so and; secondly and equally importantly, that these persons are alive to the human factor, its management and control. The costs of neglect in either area can be catastrophic.

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