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After the HAZOP
A Practical View of Process Hazards

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Abstract

Much focus within process safety and process safety education is on the basic engineering phase where the principles of process safety and inherently safer design can be incorporated into the process design. The culmination or capstone of these process safety-related activities is typically the HAZOP study, where the study team carefully reviews the process design and declares at the end that acceptable levels of risk are achieved (once Corrective Actions are implemented). Experience has shown, however, that incident-causing errors may be introduced into the design during many different stages in the project lifecycle including detailed design, construction, maintenance and even during normal operation; all of which are *After the HAZOP*. This paper examines a number of process safety incidents to demonstrate how such errors can creep into the design and provides a few key principles that engineers can use to limit such errors and the resulting incidents.

Introduction

Throughout the lifecycle of a chemical manufacturing facility there are many stages and many opportunities to influence the safety of the facility (See Figure 1), but none has the potential to influence – positively or negatively – the inherent safety of the plant as the development of the process chemistry. The hazards introduced in this stage must be safely managed for the entire operating life of the facility. But through the intelligent and often clever development of the chemical synthesis route and processing steps, the hazards that are removed at this stage will no longer need to be managed.

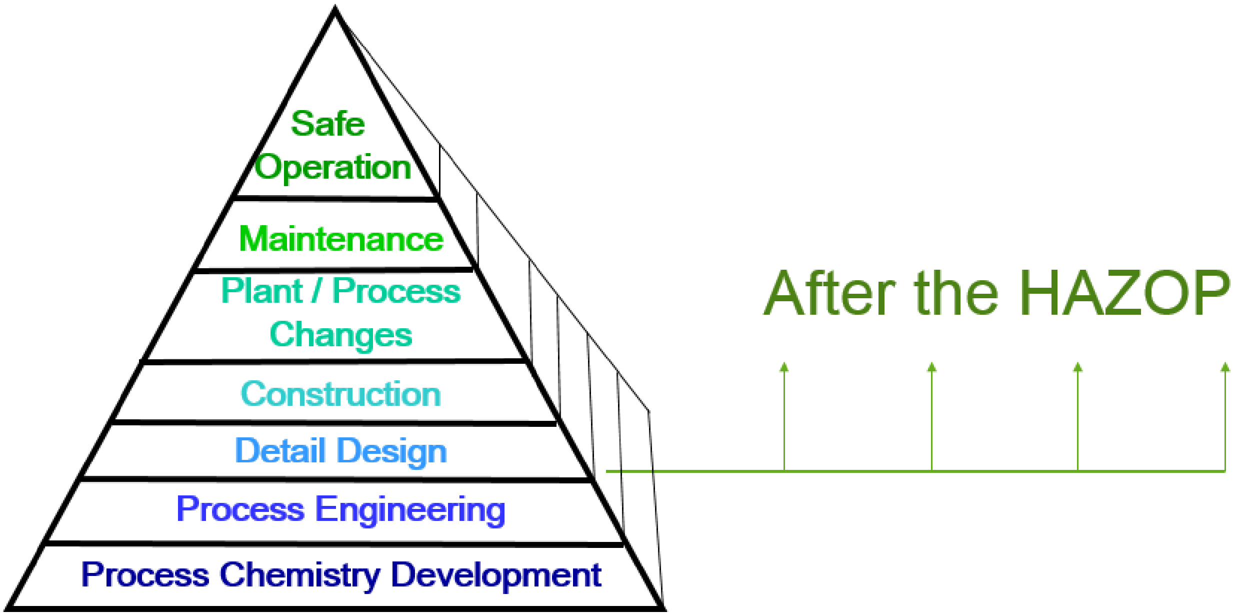


Figure 1: Stages of the Project / Plant Lifecycle

The process (design) engineering step that follows is the typical task of chemical engineers in industry; taking the lab scale chemical process and scaling it up to an industrial scale manufacturing facility. However, this role is typically limited to equipment design from a chemical process perspective. There are typically multiple design reviews throughout the process engineering stage, and the cap stone review, especially from the perspective of process safety is the process hazard analysis, often carried out as a Hazard and Operability (HAZOP) study. Because of the thorough, rigorous nature of a HAZOP study, it can be quite tempting for the project team to think that their work is done with regards to process safety. Experience has shown however that there are many opportunities for new hazards to be introduced in later stages of the plant life cycle.

In the detail design stage of the project, the chemical engineers hand over the process design to the other disciplines, who then create the blueprints from which the plant is built; blueprints for the foundations, the structures, the processing equipment and instrumentation. In the construction phase, the construction engineers and the fabrication teams make those blueprints become reality in concrete, steel and wires; making progress…but also making opportunities for new hazards to become reality.

Once the plant is commissioned and started-up, engineers cannot leave 'good enough' alone, so they optimize, increase the throughput, decrease the energy consumption…all good things, but also opportunities to introduce new hazards into the process and plant. As it does to all of us, time and the elements take their toll on the equipment and instrumentation, so they must undergo routine maintenance to keep system performance and integrity within the specified bounds. Maintenance also means putting people close to the equipment and potentially the process chemicals; an opportunity for the hazards of the process to be manifest in an incident.

Finally, if all goes well, the process operates smoothly more than 98% of the time. Yet even during these times of relatively smooth operation, because there are routine interactions between people and the process, there are still opportunities for something to go wrong.

Detail Design

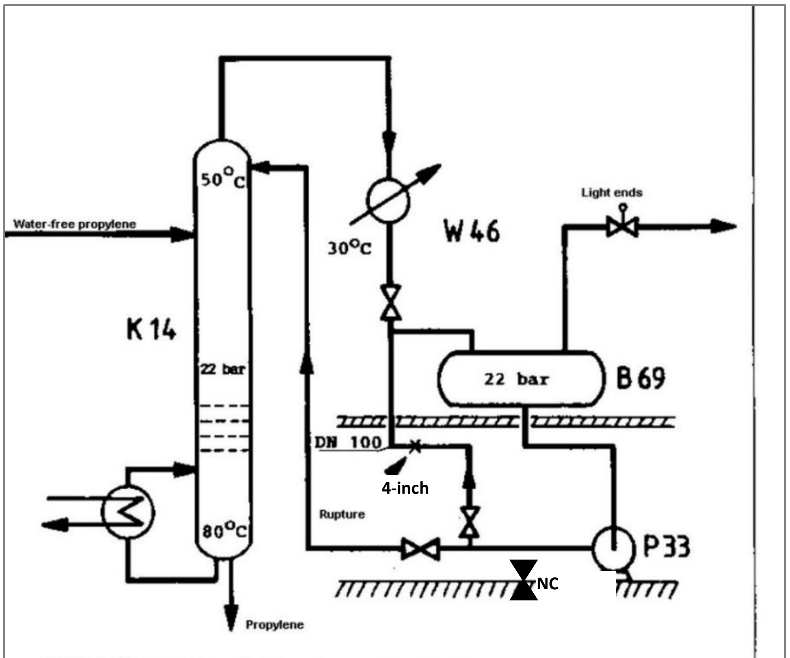
Many years ago, the propylene purification section of a Naphtha cracker was largely destroyed by a fire after a section of piping split (see Figure 2) releasing several tons of a propylene lights stream to atmosphere. The feed to the Propylene purification column was named “Water-free Propylene” because it had already undergone an initial de-watering step. The specification for this stream, however, allowed up to 3 ppm of water in the propylene. At first glance, that seems like a trivial amount of water, but with a throughput of roughly 100 million lbs/yr, the total amount of water entering the column was roughly 300 lbs.

The line in which the rupture occurred was a 4-inch diameter line used for the start-up of the system, then blocked in at the valve labeled as normally closed (NC) during normal operation. During normal operation, water – being denser than propylene – would settle and accumulate in the blocked-in start-up line. Over the course of one year of operation, enough water could potentially collect to fill roughly 50 feet of 4-inch piping.

Believing this system to contain only propylene and traces of lighter organics, the detail designers did not anticipate any freeze potential in the system, and since the overhead system operated close to ambient temperature, no insulation was specified for the system.

After several years of operation, a particularly cold stretch of winter hit, and ambient temperatures were below freezing for many hours off and on over the course of several weeks. It was determined following the incident that sufficient water had accumulated in the dead leg to freeze during those cold stretches. During the third freeze cycle, the freezing water caused the pipe to split. When the ice thawed, the water escaped through the crack, followed by propylene and “light-ends.”

Here, the use of the term “water-free propylene” for a stream that could and did indeed contain water, misled the design team into making a poor choice for the design of the start-up line. The take-away from this incident is that it is important to consider cumulative effects, especially for high volume or high-throughput systems, and to avoid dead legs in piping systems whenever possible (unless important to the design).



Propylene Distillation

Figure 2: A Propylene Purification System

Construction

A particular project was implementing as part of the design a medium pressure, superheated steam line. As the project was running short of engineering funds, the designed included instructions to field-support the steam line. The construction team identified a convenient location for supporting the line and added a cross-beam which was about 4 inches beyond a condensate drop on the steam header. What the construction team did not fully understand is that a superheated steam line can “grow” several inches or even feet due to thermal expansion of the steel piping from ambient start-up temperature to operating temperatures. As the steam head approached operating temperatures, due to the improper supporting of the steam header, the growth of the header caused the condensate header to impinge on the cross-beam which eventually sheared off the smaller pipe, allowing a jet of medium pressure steam to escape, deflecting the pipe like a jet engine.

Field routing / design of piping, instrumentation and other components often leads to sub-optimal performance and/or the introduction of new hazards into the system.

Plant or Process Changes

During the debottlenecking of an overseas syngas plant, the process engineer determined that the existing relief device might not have sufficient capacity for the largest relief scenario. The existing plant had 2 x 100% relief valves installed, with one always in operation and the other valved-out to allow for inspection, testing and maintenance, see Figure 3. In order to provide enough relief capacity, the two existing relief valves and associated piping would need to be replaced with the next larger sized valve. A cheaper option was identified, in which a third relief valve, the same size as the two existing valves, could be added in parallel. In future operation, two of the three valves would be in operation and one would be valved-out. For convenience, the set-point of all three valves was kept the same so that the maintenance and operations teams would not have to keep up with the various set-points.

During a high-pressure excursion following start-up of the new system, the two operational relief valves both opened in an effort to relieve the excess pressure. However, since there was far more relief capacity than needed for this scenario, the two valves started 'fighting' each other leading to chattering of the relief valves. This led to such severe vibration in the newly installed PSV inlet piping that the weld connection to the Syngas header cracked, leading to a significant jet fire.

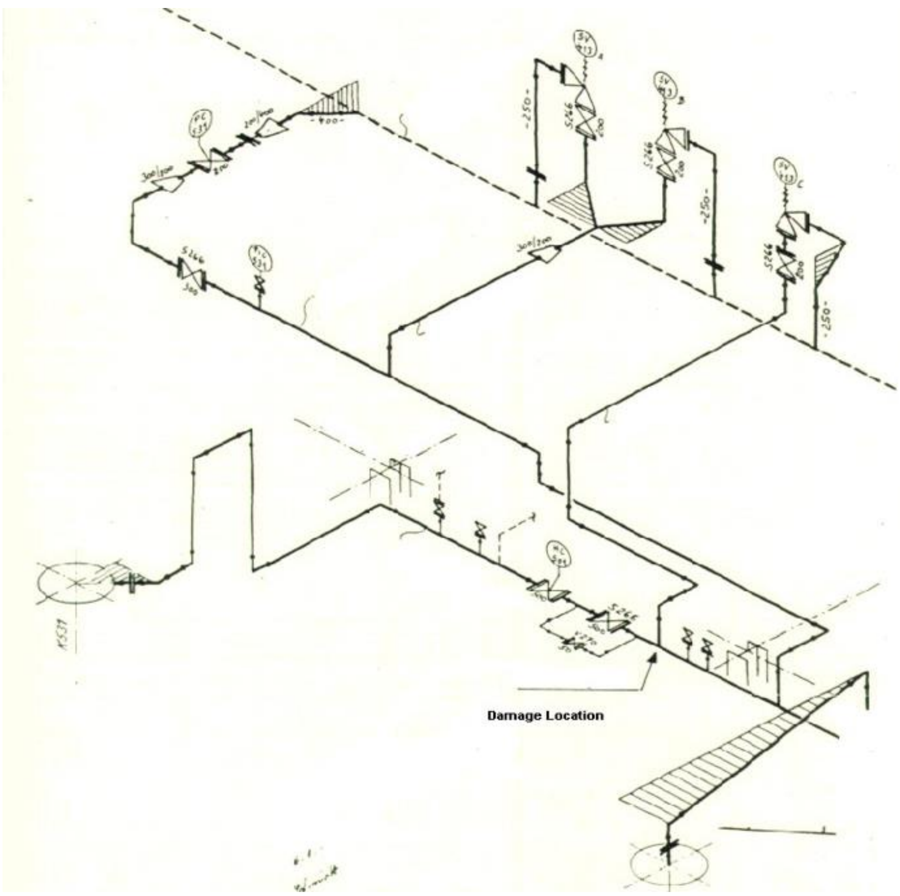


Figure 3: A Syngas header with additional relief capacity.

Due to the need to cover a variety of scenarios, relief devices will always have some level of over-design with regards to capacity. However, the installation of too much capacity can increase the likelihood and severity of relief device chatter. In addition, installing two relief devices on the same system with the same set-pressure is a recipe for disaster. In fact, API 520 recommends a setpoint offset of approx. 5% when using multiple valves.

Maintenance

During a proactive mechanical integrity thickness check, a pipeline was found to have several spots of thinning in one area. Once the replacement piping spools were fabricated, the line was taken out of service and cleared for line cutting activities. The contractor selected for the job was experienced with the type of work, the company and the work location. In order to remove the almost 200 feet of piping to be replaced, the line had to be cut several times at roughly 20-foot intervals. The piping contractor was walked through the job and made several cuts on the first day. Following a 3-day weekend, the contractor resumed work and made several more successful cuts on the line. On the third cut of that day, the contractor mistakenly cut the neighboring active pipeline full of flammable organic liquid. A significant fire immediately resulted, damaging a large portion of the pipeway and many of the pipelines.

We learn from this incident that in crucial communications, we must never assume that we have been understood. In addition, when administrative systems are used to manage hazards that can have catastrophic results – such as for hot work or confined space entry – the measures taken must be sufficiently robust and taken deadly serious by all parties involved.

Normal Operation

Even under so called normal operation, process-related incidents can occur. In one plant, a water system was circulated by a centrifugal pump. An installed spare was provided to improve the reliability of this important stream. During a storm near the plant, the plant experienced a momentary power 'blip'. Most of the electric motors in the plant continued to operate, but a few of the motors tripped as a result of the power blip. In an effort to maintain/regain normal operation of the plant, an operator was quickly sent to each of the motors that had tripped in order to restart each one.

When the operator reached the water pumps, he inadvertently started the offline pump, which had been blocked in, but not yet drained of water or locked out as the storm had disrupted maintenance activities. The operator confirmed that the pump started running then rushed to restart the next pump. He did not take time however to confirm the flow of water or the correct discharge pressure of the pump. Several minutes later, the pump ruptured, tearing the motor from the base and causing significant damage to the surrounding piping and equipment, see Figure 4.

It can be tempting to rush through certain jobs, especially when we have performed them many times before or are under time pressure. Yet it is at these times when we are more likely to make a mistake…and fail to recognize it. Multi-tasking and rushing greatly increase the likelihood of error. How do you ensure complete engagement of mind and body when performing important tasks? Do you ensure that appropriate safeguards are installed to help catch errors? A simple flowmeter on the pump discharge could have prevented such an incident.

Figure 4: Damage caused by a running blocked-in water pump

Conclusion

Process safety starts during chemical process development and is also strongly influenced throughout the process design engineering phase, but it does not end with the HAZOP. Constant vigilance is needed throughout the project / plant lifecycle to identify and manage new and developing hazards. Successful process safety is a team effort throughout the life of the facility.