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A Propane Fire Connected to Dumping Procedure in a Process Plant

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A propane gas cloud was released into the atmosphere during the loop rector dumping procedure in a process plant. After reactor inertization, the bottom valve of the dump tank was opened to collect spent powder and remove it. Unexpectedly, the powder on the floor started evaporating hydrocarbons. A propane cloud drifted very fast through the plant and ignited at the pump station area: even if the flash fire was extinguished immediately, there were several people injured and one fatality. The fire of the powdered material was extinguished later, by sprinkler system and fire brigade intervention. A detailed investigation was carried out and a multi-step methodology was applied to define the sequences and identify the most likely causes of the accident. It was adopted a complete fault tree, trying to find out without a structured scheme any critical causal factor in each relevant branch. Then, starting from the immediate cause, different sub-steps were identified as possible underlying cause, allowing to evidence in a sort of causal chain possible deficiencies in the safety management system, or in the safety culture of the company. Conclusions are drawn about practical recommendations to improve safety in dumping activities within a polymerization plant, adopting as well possible leading indicators for potential major incidents. The presented case study clearly shows how an effective HSE management system and a corresponding organization could have prevented or minimized the occurrence of such an unwanted event.

1. Introduction

As amply recognized, learning from accidents is essential for improving safety, so as to address possible inadequacies and prevent future occurrences. In recent high profile accident investigations (e.g. BP Texas City, Deepwater Horizon) it was evidenced that good records of lost time accidents LTA (or other safety indicators, such as frequency index FI and fatal accident frequency index FAFR), not only do not provide effective precursors for major process accidents, but can also lead to a sort of "complacency". In addition, as remarked by Kletz (1993), LTA has only limited value and should be supplemented by other measurements, such as the total accident rate, the cost of the damage caused by accidents and other dangerous incidents and, if possible, a numerical measure of the results of plant audits. Long-term studies on these indicators (e.g. Fabiano et al., 1998), put in evidence the positive trend over one century with declining trends in the number and rates of occupational fatalities and injuries for more than three decades in the chemical sector. Given this observation, there is a strong need to enforce a reporting culture and organizational climate that creates the conditions for collecting and analyzing process and plant safety near misses. A detailed reporting system, with a multi layer approach, can help in linking immediate causes of a near-miss to underlying causes that should be controlled by middle or higher management, or are parts of the corporate safety culture (Fabiano and Currò, 2012). In this way, it may be possible to identify appropriate leading indicators specific for the establishment under examination.
In a recent survey on chemical process industry, based on the Failure Knowledge Database (Kidam et al., 2010), it was evidenced that accidents related to chemical handling, maintenance and cleaning work are significantly caused by poor management of plant operations.

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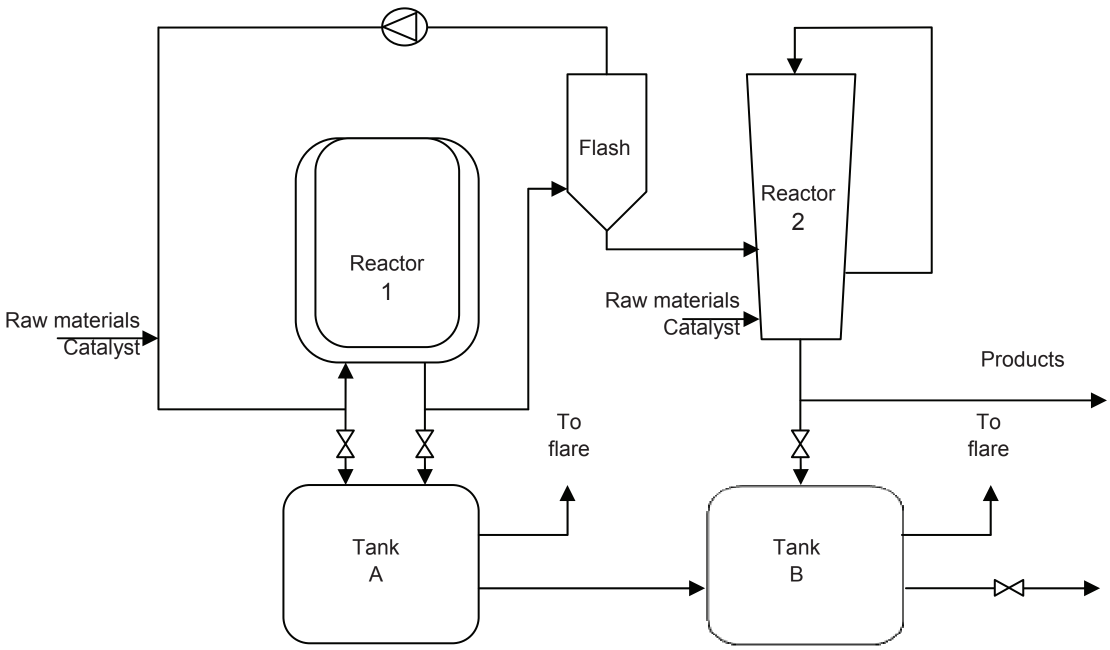

Figure 1: Schematic layout of the polymerization plant section involved in the accident

According to the "Swiss Cheese model" (Reason, 2000), an accident develops when the hazards confronting the system are able to successfully penetrate the defences of the system (barriers), through aligned holes (deficiencies, weak zones) in the barriers forming the risk control system.
Application of the model to the present "indirect reactive chemistry accident" can help evidencing root causes and how the hazards associated with non conventional activities can be better managed.

2. The event

It is amply known that if unwanted reactions can occur in a process plant, especially in case of possible self-accelerating reactions, special safety measures are implemented, including measures such as quenching and dumping. Generally speaking, the latter measure offers the advantage of transferring the reaction mass to a safer place, thus theoretically protecting the plant where the polymerization reactor is localized.
A simplified diagram of the polymerization plant here considered is shown in Figure 1.
The polymerization reactor 1 is characterized by a volume of 90 m^3 and operates at standard conditions of 64 bar and 358 K. Hydrocarbon content in the polymerization reactor is nearly 25 ton, mainly consisting of propane. The dumping tank, with a volume of 100 m^3 allows separating vapour form solid powder and liquid, in case of dumping procedure. The first indication of an anomalous event is set, in the following timeline sequence at the conventional starting time 00.00. The discharge tank was blocked due to technical problems with the electrical supply system to the polymerization unit of the plant and, consequently, to the motor and control system of the discharge tank. At time 01:00 the flash lines of polymerization reactor were diverted to the dumping tank (tank A). The decision of killing the whole reaction by proper nitrogen injection into the loop reactor 1 and into the gas phase reactor 2, was taken nearly at 06.00, according to the time reference adopted. According to the standard procedure for the dumping activity, the solid concentration in the loopreactor was decreased gradually from the steady-state value of 38 % (w/w) to approximately 6% concentration (w/w).
Emergency response and inertization procedure were performed until 12.50 when all the remaining inventory of the loopreactor, mainly propane, was emptied into the damping tank. At this time, instead of completely flaring propane vapours, in order to recover as much vapours as possible emptying sequence was interrupted so as to allow the recycle gas compressor recovering flashed propane in the damping tank. According to the standard procedure, nearly at time 13.30 the loop reactor emptying was completed by transfer into the damping tank.

Table 1: Propane properties in air mixture at atmospheric conditions (Mannan, 2005)

Critical conditions T [K]	P [bar]	N-boiling point [K]	Flammability limits % v/v	Autoignition temperature [K]	Minimum ignition energy [mJ]	Laminar burning velocity [m s^{-1}]
370	43.6	231	231-9.5	470	0.25	0.464

At the same time, pre polymerization and loop reactors were fully emptied from propane and inertized. The procedure was performed firstly transferring the powder material into the damping tank A and subsequently into tank B. Several operators were involved in manual operations addressed to pump maintenance, for part removal and inspection.
Nearly ten hours later, the bottom valve of tank B was opened so as to complete the dumping sequence with transfer of the spent powder on the temporary storage area and subsequent packaging of it into proper big bags in view of final disposal. Unexpectedly, while the powder started to flow slowly, an evaporating flux of light hydrocarbons took place. Following prompt visual alarm by an operator in the control room, the bottom valve of tank B was quickly closed from the control room. However, in the time span from the start of the unloading phase to the manual activation of the alarm, a considerable amount of light hydrocarbon (mainly propane) were released into the surrounding atmosphere so as to form a flammable cloud. The gas cloud travelled through the congested plant area eventually reaching the loop reactor pump, where it was ignited, engulfing the pump area . Following ignition, a flash fire developed and the flame front propagated throughout the area from tank A to tank B, with secondary fire development of the powder. The accident evolution and damage analysis seem to confirm that under nearly unconfined or very partially confined conditions, propane flame from velocity results highly directional with directional speed of 10 $m \cdot s^{-1}$ and the maximum overpressure of 0.02 bar (Zeeuwen et al., 1983).
Fire-fighting measures in order to control the fire were promptly started by internal emergency crew and company fire brigade who activated rolling water hoses and manual hydrants. In addition, water sprinklers were activated and emergency activities were completed by the arrival of external fire brigades who provide further water load for tackling fire. The fire was completely extinguished after nearly half an hour.
Summarizing, on the basis of available information, the vapour cloud formed from the vaporizing liquid content of the powder resulted in a primary flash fire and in a secondary, long-lasting fire of the solid powder. The gas release, flash fire and at last the powder fire resulted in one fatality and several minor injuries, in addition to plant damages mainly to the electric power supply system of the pump station. Production was interrupted for some days with consequent economic losses. Internal and external emergency plans were successfully implemented, evidencing quick arrival of external intervention and medical services, as well as good cooperation among the firm personnel and external rescue teams.

3. Cause analysis

A fault tree can be developed starting from the top event defined as a flash fire following the formation of a flammable vapour cloud outside the dumping tank B. The qualitative evaluation depicted in Figure 2 was performed developing a logical expression for the top event, as a function of the primary events, according to a standard procedure. Table 1 (Mannan, 2005) summarizes main hazardous properties of propane-air mixture at atmospheric conditions useful for proper selection of the evolving scenario, following the release. A useful perspective of the accident can be obtained combining the fault tree with the causation sequence proposed by Reason (2000). He states that complex technological systems, such as a process plant, are dependent with a series of barriers, safeguards and defences in place to protect the system, assets and potential victims from hazards. Weaknesses and gaps in any protection layer can lead to an accident when the holes in many layers momentarily line up to permit a trajectory of accident opportunity, bringing hazards into damaging contact with victims (Reason, 2000).
We can distinguish barrier holes created by performed activities and active holes that are developed by workers operating in the plant. Latent conditions connected to process/plant design can be present for long time prior to combine with active holes.
Following defensive barriers were successfully penetrated, starting from the intrinsic hazards connected to the dumping sequence:

- *Procedures :* critical procedural steps in the dumping sequence were not followed. In fact, the transfer from A to B is allowed on condition that the pressure is below 0.9 bar, so as to exclude the presence of boiling liquid hydrocarbons. More generally, the failure of procedures controlling maintenance / non routine activities, such as permit issue and isolation control is connected to a failure in the management system.

- *Training and competence*: lack of knowledge including little or unknown physical properties of the handled material and the influence of operational parameters. Critical signs were not properly analyzed and appropriate actions were not taken: the icing of the flare line from dumping tank was not perceived as warning for the presence of liquid hydrocarbon in the dumping tank. Consequently, the scheduled inertization procedure was not effective owing to the considerable presence of hydrocarbons at the liquid phase.
- *Maintenance, inspection and testing*: LEL analysis in the dumping tank A before transfer and in B before final emptying represent critical testing steps to be recognized by operators. A specific guidance must should provided for interpretation of data in case of negative test.
- *Safety critical communications*: a detailed supervision during the execution of non routine activities and therefore during the whole dumping sequence is a critical item not covered in the case study.

Considering more technical items, following aspects can be summarized.

The identification of the release source requires a correct interpretation of all available information on intrinsic hazards. A network of gas detectors might be helpful in identifying promptly the source term. Further studies were undertaken on a more effective and safe disposal of dumping material, and removal of the reaction mass. Procedures for assessing the potential for flammable atmosphere inside reactor/dumping tank should include monitoring temperature and pressure during non standard recirculation and improved testing of the flammable level, after inertization.

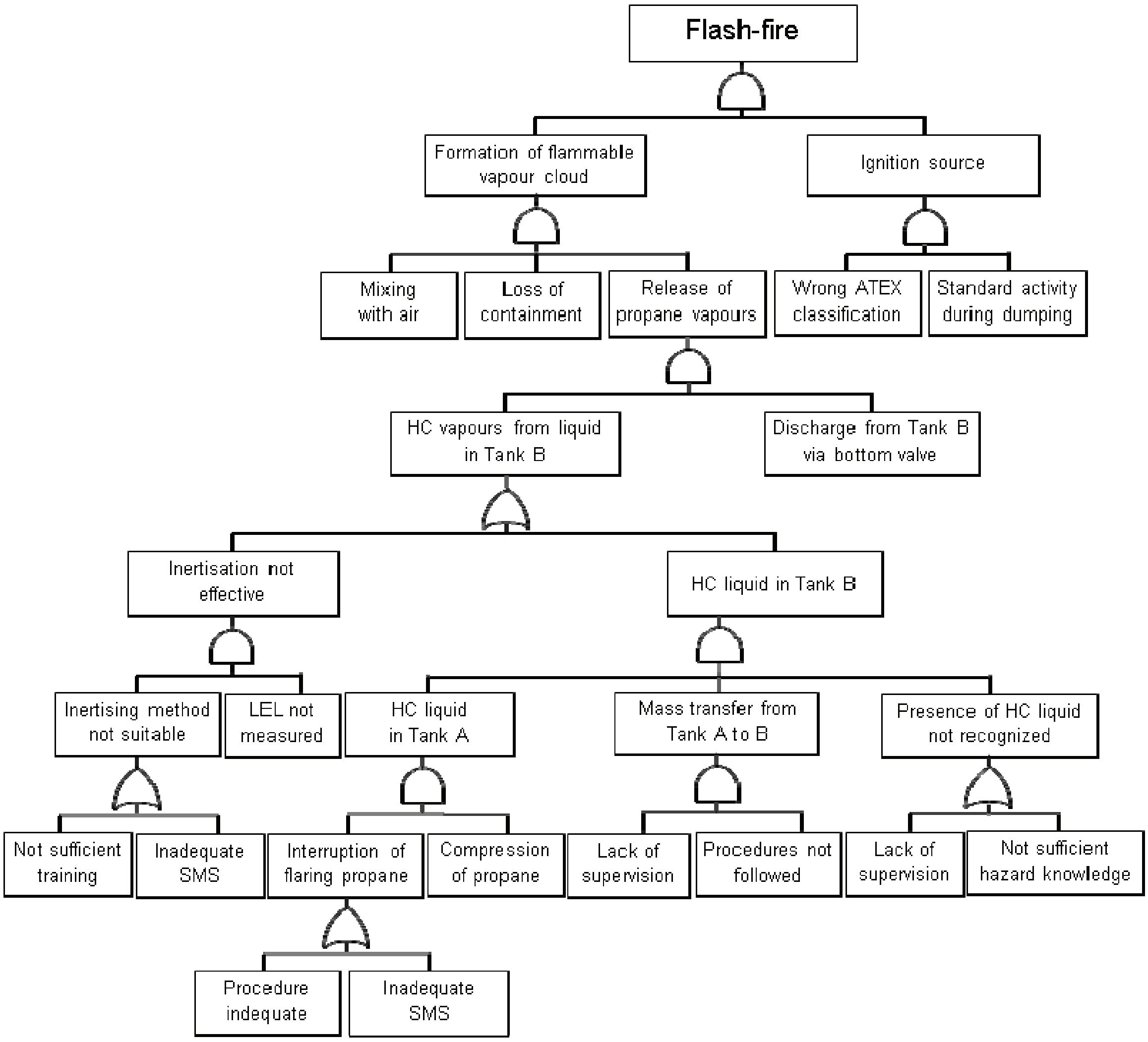

Figure 2: Simplified fault tree for flash-fire, following propane release during dumping sequence.

The importance of extending safety studies, especially HazOp beyond the main plant boundaries and to integrate them with connected sections, including services such as flare systems.
We should observe that HSE guidance HSG245 clearly states that management is responsible for ALL accidents, incidents and ill-health so that 'the root cause of adverse events are almost inevitably management, organisational or planning failures" (HSE, 2004). Globally, from the evidences of this case study it appears that the management system of the company failed in developing a complete hazard awareness at each level of the structure: from top management to plant operator.

4. Lessons from an organizational perspective

According to the approach proposed in another accident investigation (Pasman and Baron, 2001), in the following we try to put in evidence main elements of the corporate safety management system needing a sharp improvement within the organization. In fact, the main root cause of the accident can be associated at the higher level of the organization with the fallible decision of top management not to develop an effective corporate safety culture by promoting an integral safety policy. By the way, the problem of improving the organizational memory and the need for a new look at the sort of injury and accident data that are collected was already highlighted by Kletz (1995).

- *Accountability.* A clear line of responsibility for communication, reporting and auditing procedure, must be enforced. Critical items are represented by permit to work and the procedure for checking and controlling possible by-passing of safety systems.
- *Human factors.* Human error assessment pertinent to error opportunities and job task design must be fully implemented.
- *Training and performance.* Design of procedures requires sharp improvement. Normal and emergency operating procedures must be extended with more comprehensive information based on the operator experience, in order to execute safely the task. Moreover, safety critical procedure must be executed only by specialized operators under strict supervision. The development of training programs creating understanding and awareness of hazards associated to minor physical deviations (e.g. hazards connected to pressure build-up at levels, not dangerous for equipment integrity).
- *Incident investigation*. A detailed near-miss reporting system will be applied, in addition to in-depth accident investigation and consequent follow-up. These items clearly require an organizational climate encouraging workers to report their errors according to what is known as a just culture.
- *Audits and corrective actions.* Regular proactive checks and safety audits will be incorporated into an updated safety information system. Design of proper leading performance indicators associated to critical tasks, to be used as benchmark at the company level.

5. Conclusions

The accident here summarized from one side evidences that the apparent simple measure of safe stopping a chemical reaction by quenching and dumping is certainly not a trivial one. From the other side, it recalls the importance of having a Health, Safety and Environment management system fully implemented in each part and rigorously audited. At last, recalling the Swiss cheese model, we mention the most critical barrier needing to be strengthened: continuous learning and open communication between all levels of the organization (top/middle managers, engineers and supervisors, operators and production personnel at the sharp end of the system) can improve "organizational memory" contributing to achieve a high safety level.

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