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Use of combustible gas detectors in Safety Instrumented Systems – A practical application case study

Seyi Famuyiro

ABSTRACT

A risk assessment carried out on a chemical process identified a flammable liquid release as a potential hazard. The flammable liquid, hexane, is used as a solvent in the process and is present in a dryer vessel during normal operations. The product from this vessel is a dry powder that is transferred to a packaging room directly below the vessel. Any leaks through the product discharge valve or inadvertent opening of the valve during the drying process or inadvertent opening/leak through of the hexane feed valves during the discharge process could lead to hexane release in the packaging room with potential for fire and explosion.

It was determined that it was difficult to detect the absence of hexane in the dryer vessel as a prerequisite for discharging the final product to the packaging room using conventional process variables like level and pressure due to the complexity of the process. It was further determined that the best way to detect the release hazard was to use combustible gas detectors. An analysis was conducted which led to the design being considered a Safety Instrumented System and not a Fire and Gas System. Further risk assessments were conducted including a Fault Tree Analysis, Event Tree Analysis, and Probability of Failure on Demand (PFD) calculations for the combustible sensors as well as PFD average calculations for the Safety Instrumented Function (SIF) to confirm that the design of the SIF met the required risk reduction targets.

1. Introduction

There has been a lot of discussion in the industry about what constitutes a Fire and Gas System (FGS) and if a fire and gas system device can be considered part of a Safety Instrumented System (SIS). This was a consideration as a Process Hazard Analysis (PHA) on a new process identified hexane release as a potential hazard. Regardless of if a safety instrumented preventive or mitigating function is labelled an FGS or an SIS, it is important that applicable industry standards for risk identification and assessment as well as the design of systems to mitigate the risks are followed.

1.1. Process overview

The final product from the process is a dry powder. However, in several steps of the process, a flammable liquid, hexane, is used as a transport medium. Fig. 1shows the simplified process diagram.

Liquid hexane is present in the dryer vessel during normal operations and is eventually evaporated and the final product is left in the vessel. This product is transferred to the packaging room for packaging into drums.

1.2. Process Hazard Analysis

Even though the properties of hexane make it useful as an industrial solvent, its use introduces new hazards in the process. Per the Material Safety Data Sheet (MSDS) for hexane, it has a flash point of $-26\,^{\circ}C$, Lower Explosive Limit (LEL) of 1.2%(V) and Upper Explosive Limit (UEL) of 7.7%.

The process in the dryer vessel takes place at a normal temperature of $21\,^{\circ}C$ and per OSHA 29 CFR 1910.106 (Occupational Health and Safety Administration, 2017), a flammable liquid with flash point below its storage temperature has a tendency for rapid spread of flame on the surface of the liquid.

A PHA was carried out on the process and identified several hazards. A summary of the PHA findings is shown in Table 1.

1.3. Fault Tree Analysis

A Fault Tree Analysis (FTA) was carried out to determine the initiating event frequency. The initiating event (liquid hexane release) can be because of

- General human error of commission: Probability 0.003 (Mannan, Table 14.15 (Mannan, 2005),)

E-mail address: structuredcontrols@gmail.com.

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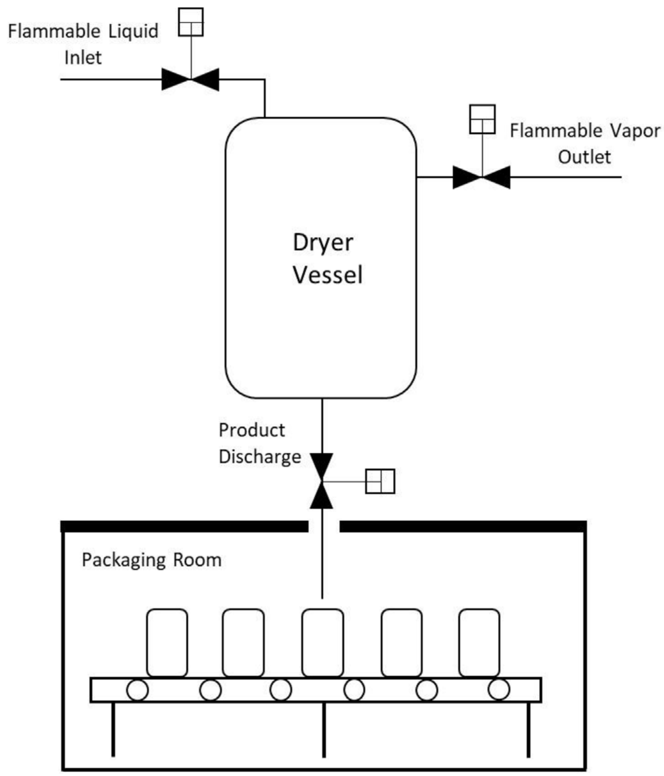

Fig. 1. Simplified process diagram.

- DCS failure: 10^{-5}/hr or 0.0876/yr (ANSI/ISA-84.00.01–1 (International Society for Automation, 2004),)
- Ball Valve Failure: Failure rate of 0.5 failures/106 h = 4.38 × 10-3 failures/y (Mannan, Table A14.3 (Mannan, 2005),)

Assuming a test interval of 1 year, the PFD can be gotten using the equation PFD = 0.5 λt. Applying this, the probability figures for the initiating events listed above are shown in the Table 1.

The fault tree for the top event is shown in Fig. 2.

The top event probability can be converted to a frequency using PFD = 0.5 λt, which gives λ = 0.10236 failures/year.

1.4. Allocation of safety functions

Available protection layers include

- Basic Process Control System (BPCS) – Determines when product is completely dry based on certain predefined criteria and gives signal to field operators to open product discharge valves and start the packaging process.
- Heating, Ventilation and Air Conditioning (HVAC) system – HVAC installed in packaging room.
- Portable combustible gas monitors – Required to be carried by every personnel working in the packaging room.

Following industry and organization standards, it was determined that available safeguards were insufficient based on the risk classification and that a Safety Instrumented Function (SIF) that meets Safety Integrity Level (SIL) 3 was required to meet the risk reduction targets.

Table 2
PFD for initiating events.

Event	Failure Rate/Year	Probability of Failure on Demand
General human error of commission	N/A	0.003
DCS failure	0.0876	0.0438
Ball valve failure	4.38×10^{-3}	2.19×10^{-3}

1.5. Safety function design

The hazards identified could not be detected by measuring or monitoring conventional process variables such as level or flow. The key consideration was that during normal operations, a flammable liquid, hexane, is present in the dryer vessel. Determination that the product is dry is done by monitoring process pressure, temperature, residence time, and level rise in the downstream liquid hexane collection vessel by the DCS. A DCS malfunction could lead to inadvertent valve opening. Even if somehow the process of determining when the product discharge valves can be opened can be managed with a SIF, valve leakage is still a potential source of the identified hazards.

It was determined that the best chance of detecting the hazard was with combustible gas detectors in the packaging room to detect the flammable hexane release before the lower explosive limit is reached and to carryout actions to mitigate the release. It was further determined that the hexane inlet valves and product discharge valves be interlocked such that inlet valves cannot be opened if discharge valves are already open and that the discharge valves cannot be opened if the inlet valves are open. Fig. 3 shows the representation of the SIS design.

The gas detectors specified were catalytic bead sensors based on prior experience using similar sensors in similar process conditions at the site with good results. Due to the likelihood of liquid hexane to pool on the floor and then form vapors, the detectors were placed about a foot above the floor and within a three-foot radius of the fill head. The detectors were calibrated to sense 0–100% LEL with the trip point set at 40% LEL.

The action on detection of a flammable liquid release was to

1. Close the 2 SIS valves on the product discharge from the dryer vessel
2. Close the 2 SIS valves on the hexane inlet to the dryer vessel

1.6. Probability of Failure on Demand

Per the manufacturer safety manual (Drager, 2017), the gas detector Mean Time Between Failure (MTBF) is 29 years with a diagnostic coverage of 94%. Assuming a Mean Time to Repair (MTTR) of ≤8 h, then Mean Time to Failure (MTTF) ≈ MTBF ≈ 29 years.

$$\lambda_D = \frac{1}{MTTF_D} = \frac{1}{29} = 0.034483/y$$

Using simplified equations for Safety Integrity Level (SIL) 1oo3 calculations from the ISA technical report (International Society for

Table 1
Summary of PHA.

Cause	Hazard	Consequence
Failure of liquid hexane inlet valve, valve leaks or inadvertent opening of valve when not intended	Potential to introduce liquid hexane into an already dry product batch during discharge to the packaging room.	Potential for fire and explosion with one or more onsite fatalities.
Failure of product discharge valve, valve leaks or inadvertent opening of valve when not intended	Potential for liquid hexane flow into packaging room during normal dryer vessel operations.	Potential for fire and explosion with one or more onsite fatalities.