How Maintaining Current Heat & Material Balances Commits to Process Safety

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Abstract

A Heat & Material Balance (H&MB) is a valuable component of Process Safety Management (PSM) because it helps to follow the four pillars of risk-based process safety. It is important to ensure H&MBs are updated on a regular basis to accurately represent how the process is running. An H&MB is a valuable source of information for many aspects of PSM such as; Relief Systems Analysis, Process Hazard Analysis (PHA), and Layers of Protection Analysis (LOPA). If the information is not accurate and current, the analysis may lead to inaccuracies and inconsistencies that could result in: increased expense (rework), increased exposure (citations), and greater potential for incidents. This paper will look at some of the possible consequences of not having up-to-date H&MB in regards to a Relief System Analysis, PHA, or a LOPA.

1. Introduction

OSHA's Process Safety Management standard cites Heat and Material Balances (H&MBs) for any process built after May 26, 1992 as a requirement for PSM Compliance for the oil and gas industries.[1] Any modification to an existing facility that requires installing a new line, unit, or train to supplement the process could be considered as a new process and therefore requires H&MBs.[2]

Even though a plant may have been built before 1992, the plant owner should still actively attempt to keep updated documentation at least as a means to decrease the probability of incidents, which in turn may result in additional expenses or citations. Chances are even if the process was built before 1992, a small change or the installation of additional equipment may both be interpreted by the authorities as a change in the process requiring updated H&MBs. In many cases, the owner of the plant may not even be aware of these small changes that may occur over time, hence, highlighting the importance of updated and organized documentation.

It is a common occurrence in today's oil and gas industry that an operating facility does not have updated or readily available documentation regarding its process or equipment. Over time, changes in the process may occur, additional pieces of equipment may be added, or modifications may be made to existing pieces of equipment. All of these changes have the potential to adversely affect previous analyses. Not only is it a requirement by OSHA to regularly update the applicable PSM Compliance documentation, but inaccuracies in the documentation may also lead to inaccurate results in other aspects of PSM such as relief systems analysis, LOPA, and PHA. Because they normally provide compositions, temperature, pressure, and flow rates related to the process, H&MBs are a major part of PSM Compliant documentation that can help in obtaining accurate results in the aforementioned areas of PSM. Keeping updated H&MBs speaks volumes about the commitment of a plant in keeping process safety as a priority.

2. Discussion

2.1 PHA and LOPA

A process hazard analysis (PHA), also referred to as process hazard evaluation, is a major part of the PSM program. A PHA is performed by a group of qualified engineers that leads to identifying the potential of hazards associated to the process or handling of a material. It is used as a tool to make risk based decisions on their process. A Layer of Protection Analysis (LOPA) is often used as an addition to a PHA in order to facilitate the decisions to be made for a plant. Both of these types of analyses are risk based and attempt to make important modifications or installation of additional layers of protection based on the probability and consequence of any given scenario.

OSHA's standard 1910.119 App. C highlights the importance of having knowledge about the process and how innovation or change may affect the methodology:

> *"The selection of a PHA methodology or technique will be influenced by many factors including the amount of existing knowledge about the process. Is it a process that has been operated for a long period of time with little or no innovation and extensive experience has been generated with its use? Or, is it a new process or one which has been changed frequently by the inclusion of innovative features [?]..."* [3]

Often times an H&MB is not available at the time of performing a Process Hazard Analysis or Layer of Protection Analysis. However, due to the nature of these analyses, which attempt to measure probability and consequence as a means to assess risk, the lack of an H&MB during the analysis could contribute to inaccuracies when measuring the consequence of an event. An H&MB includes information such as temperature, pressure, and composition of the fluid within a system; these variables can make a significant difference when measuring the consequence of a release.

For example, a large enough leak in a pipeline containing a liquid hydrocarbon at high pressure and temperature may result in an immediate loss of pressure and lead to a

Boiling Liquid Expanding Vapor Explosion (BLEVE). If one does not have the pressure, temperature, and composition of the fluid, the consequence of such an event could be miscalculated. The PHA analyst may reach the conclusion that a leak in the pipeline may only result in a vapor cloud that dissipates quickly. Having an H&MB during the PHA or LOPA could be the difference between assessing the consequence of the leak as a BLEVE, vapor cloud release, or the release of toxic fluid.

In a LOPA, the consequences of events are categorized depending on their severity. Examples of consequence categorization that can be used in a LOPA are shown in Table 1 (shown below). In the table, the event is categorized depending on the characteristics and the quantity of the fluid being released.[4] As can be seen from the example, the quantity and characteristics of a certain release can affect the categorization of an event, and can directly influence whether a decision is made to add additional safety measures to reduce the probability of an incident.

Table 1. Example Consequence Categorization[4]

	Size of a release (beyond a dike)					
Release Characteristic	**1 to 10 pound release**	**10 to 100 pound release**	**100 to 1,000 pound release**	**1,000 to 10,000 pound release**	**10,000 to 100,000 pound release**	**>100,000 pound release**
Extremely toxic above BP*	Category 3	Category 4	Category 5	Category 5	Category 5	Category 5
Extremely toxic below BP or highly toxic above BP	Category 2	Category 3	Category 4	Category 5	Category 5	Category 5
Highly toxic below BP or flammable above BP	Category 2	Category 2	Category 3	Category 4	Category 5	Category 5
Flammable below BP	Category 1	Category 2	Category 2	Category 3	Category 4	Category 5
Combustible liquid	Category 1	Category 1	Category 1	Category 2	Category 2	Category 3

*BP = atmospheric boiling point

	Magnitude of Loss					
Consequence Characteristic	**Spared or non-essential equipment**	**Plant Outage <1 month**	**Plant Outage 1-3 months**	**Plant Outage >3 months**	**Vessel rupture 3,000 to 10,000 gal 100-300 psi**	**Vessel rupture >10,000 gal >300 psi**
Mechanical damage to large main product plant	Category 2	Category 3	Category 4	Category 4	Category 4	Category 5
Mechanical damage to small by-product plant	Category 2	Category 2	Category 3	Category 4	Category 4	Category 5

2.2 Relief Systems Design

Relief systems design is also recognized as part of PSM compliant documentation. During relief systems design, the entire plant, one piece of equipment at a time, is analyzed for the potential scenarios that could lead to overpressuring a piece of equipment over the safe limit. All potential applicable scenarios are considered, and calculations are performed in order to determine the rate, temperature, and thermodynamic properties of the fluid that needs to be relieved, so as to keep the vessel from being pressurized over the acceptable limit. A relief device is then sized and recommendations can be made if any changes should be performed. Any change in the conditions of the process, including temperature, pressure, composition, or process rate, may lead to a relief device of different size.

As part of this research paper, a blocked vapor outlet scenario was simulated for a depropanizer column. The purpose of the simulation was to find the effect of changing feed compositions in relief valve sizing. The column was simulated with different propane compositions; the other hydrocarbons in the feed stream were ethane, isobutane, n-butane, isopentane, n-pentane, n-hexane, and n-heptane in the same ratio. The composition of the aforementioned components was lowered equally with increasing compositions of propane. The diagram of the Aspen HYSYS Simulation © is shown in Figure 1.

The following specifications were used in order to simulate the column:

- Feed charge of 200,000 lb/hr
- Relieving pressure of 300 psig
- Constant reflux rate of 80,000 lb/hr
- Reboiler duty of 20 MMBtu/hr

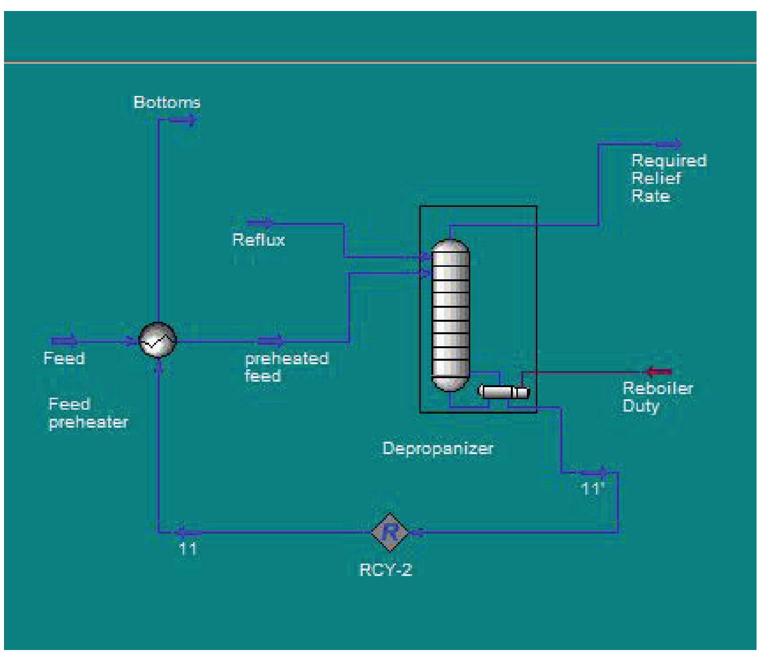

Figure 1. Depropanizer column simulation

The resulting effective discharge area required to achieve the required flowrate was found for each composition of propane using the derived critical flow sizing equations from API Standard 520 Part I, shown as Equation 1 below.[5]

$$w = A \times C \times K_d \times K_B \times P \times \sqrt{\frac{M}{TZ}} \qquad \text{Eq. (1)}$$

Where

$w =$ mass flow through the orifice
$A =$ Effective orifice area
$C =$ function of the ratio of specific heats
$K_d =$ Effective coefficient of discharge
$K_B =$ Backpressure correction factor
$P =$ Relieving pressure
$M =$ Molecular Weight
$T =$ Relieving Temperature
$Z =$ Compressibility Factor

The function of the ratio of specific heats, *C*, is defined by Equation 2.

$$C = \sqrt{k\left(\frac{2}{k+1}\right)^{\frac{(k+1)}{(k-1)}}} \qquad \text{Eq. (2)}$$

Where
$k =$ ideal ratio of the specific heats

Figure 2 shows the effective discharge area as a function of propane compositions. As shown in the figure, the effective discharge area has a direct correlation with increasing compositions of propane. While the composition of a feed stream is only a portion of all the information contained in an H&MB, it can make a difference in the results of the design.

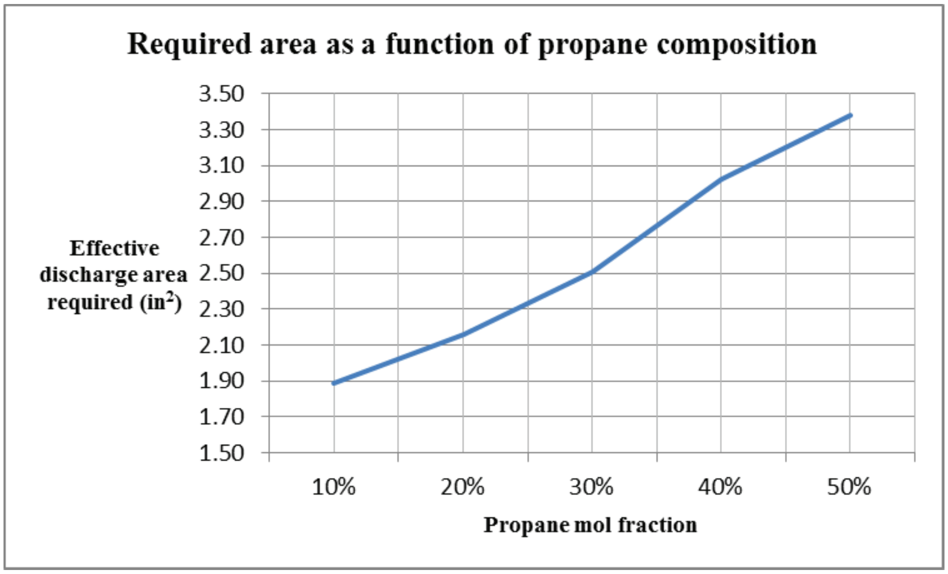

Figure 2. Depropanizer relief valve effective discharge area vs propane composition.

It is common in the industry that the process safety analyst who performs the relief systems design is provided with an outdated H&MB or no H&MB at all as supporting documentation. If this situation occurs, the analyst is forced to make conservative assumptions for the process that can often result in oversizing a relief device; this can lead to relief device chattering and additional cost.

If the relief systems analysis is performed with an inaccurate H&MB, the results of the work performed may be unreasonable to the plant owner. When the analysis is performed based on outdated information, the result of the analysis may not be what the client initially expects due to the conservative measures that need to be assumed by the engineer. A significant number of action items may be generated due to the conservative measures, and the plant may have to choose to perform the entire analysis again after they have updated the corresponding documentation; this decision may depend on the cost associated with mitigating the extensive list of action items versus the combined cost of updating H&MBs, performing the analysis for a second time, and dealing with any leftover action items. Therefore, in order to avoid rework and additional expenses, keeping updated H&MBs should be a priority.

3. Conclusion

The main reason to maintain current H&MBs is to make the plant safer. It is common in the process safety industry that the H&MBs, provided as supporting documentation for performing PSM related analyses, are outdated or not provided at all. Flow rates, compositions, pressures, and temperatures shown in H&MBs can affect the sizing during relief systems design, decision making during a PHA, and consequence categorization during a LOPA, all of which can contribute to process safety.

Current H&MBs are an important aspect of PSM documentation that relates directly to the commitment to process safety. Any process built after 1992 must have updated H&MBs in order to comply with the PSM standard. In addition, modifications made to a plant could be interpreted by OSHA as a change to the process requiring updated H&MBs.

In addition to being an integral part of process safety, maintaining current Heat and Material Balances can help in:

- Providing accurate sizing for relief devices
- Avoiding rework related to PHA, LOPA, and relief systems design
- Reducing action items from relief systems design
- Preventing citations related to outdated documentation
- Reducing the potential for incidents
- Accurately measuring the consequence of incidents

4. References

[1] "Process Safety Management of Highly Hazardous Chemicals -- Compliance Guidelines and Enforcement Procedures", 29 CFR 1910.119, 09/28/1992

[2] "Clarification of the Process Safety Management standard with regard to material and energy balances", 29 CFR 1910.119, 09/25/1995

[3] "Compliance Guidelines and Recommendations for Process Safety Management (Nonmandatory)", 29 CFR 1910.119 App C

[4] "Layer of Protection Analysis – Simplified Process Risk Assessment", Center for Chemical Process Safety of the American Institute of Chemical Engineers

[5] Sizing, Selection, and Installation of Pressure-relieving Devices Part I – Sizing and Selection, API Standard 520, 9th Edition, July 2014