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Risk Assessment Tool for Liquid Overfill of Process and Storage Vessels

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ABSTRACT

The paper describes the process that a large company uses to analyze the risk associated with liquid overfill from pressure vessels and atmospheric storage in both petrochemical and refining operations. Due to learnings from recent overfill events, a tool was developed to assess the risk of liquid overfill. This paper covers methodology and industry learnings that were used to develop a tool that is able to consistently assess liquid overfill risks across various operation types. The hope is that in sharing this information other companies may incorporate parts of the methodology or develop similar tools to identify overfill risks.

INTRODUCTION

In response to the Texas City Refinery (BP) incident that resulted in the release of flammable material from an Atmospheric Relief System (ARS) and the overfill of motor gasoline from an atmospheric storage tank which resulted in a vapor cloud explosion (VCE) at the Buncefield Terminal (Total/Texaco) in Hempstead, England ExxonMobil initiated a review of ARS facilities and atmospheric tankage to evaluate the potential risk associated with liquid overfill.

Due to the number of atmospheric pressure relief valves (part of ARSs) and atmospheric tanks that needed to be reviewed, it was recognized that a tool was required to allow consistent evaluation of liquid overfill risks. Since there was no clear guidance available to the industry on performing this review, ExxonMobil developed a Liquid Overfill Risk Assessment Tool (LORAT) to analyze and prioritize liquid overfill risks using various probability and consequence factors. The LORAT tool incorporates published correlations, industry data, and company historical data to develop the probability and consequence of liquid overfill. Some of the probability factors include effectiveness of operator intervention, type of operation, chance of ignition, probability of people in area, and failures of pumps and instrumentation. Consequence factors include modeling to estimate flash fraction, aerosol generation, vapor dispersion, liquid rainout, liquid pool evaporation, and cascading liquids. These probability and consequence factors combine to reflect the risks associated with liquid overfill.

LORAT focuses on the risk associated with the potential hazard of hydrocarbon liquids and vapors accumulating at grade and igniting, resulting in one of the following:

- Vapor cloud explosions (VCEs)
- Flash fires
- Pool fires
- Jet fires (for materials above AIT)

The tool develops separate event trees for each scenario to document the basis for the liquid overfill risk. The event trees are populated starting with the initiating event and are followed by the subsequent factors leading to the outcomes associated with the liquid overfill scenarios. The risks that are identified can be prioritized to assist in mitigation planning.

LIQUID OVERFILL SCENARIOS

In analyzing liquid overfill, all possible situations that can result in the discharge of liquid to the atmosphere were considered in the LORAT. These were reduced to the following five scenarios for process vessels:

- <u>Startup</u>: Procedural or coordination error results in a delay in flow forward and the vessel begin to build level.

- <u>Excessive Feed</u>: Liquid inflow increases above design flow rate (e.g. due to a control valve failing open) while liquid outflows continue at the normal rates. The extent of overfill possible may be limited by the source inventory.

- <u>Loss of Effluent</u>: Liquid outflows stop while liquid inflows continue at design flow rates.

- <u>Loss of Reboiler</u>: Loss of heating controls leads to loss of the reboiler, which could result in colder releases.

- <u>Tower Flooding</u>: Potential flooding or excessive vapor traffic at the top of the tower, which has potential to carry liquid out of the safety valve. This also includes situations where there could be internal icing or hydrate formation in a tower.

The following four scenarios were considered for storage tanks and storage vessels:

- <u>Batch Fill / Empty</u>: A potential for overfill exists for each instance a batch plan is executed and a tank is filled.

- <u>Rundown Fill / Empty</u>: Similar to batch filling, a potential for overfill exists each instance a rundown tank is filled.

- <u>Inadvertent In-Flow / Excessive Feed</u>: Inadvertent filling of the storage vessel or tank due to improper line-up or failure of inlet control valve.

- Loss of Outflow: Liquid outflows stop while liquid inflows continue at normal flow rates.

Unlike PRV discharges composed mostly of higher temperature liquids that form vapor or mist when released and rapidly disperse, atmospheric storage tank liquid overfill discharges can settle to grade.

LORAT SCENARIO FACTORS

The various characteristics of overfilling risks which determine the risk of the scenarios are outlined below. These factors are taken into consideration in the LORAT tool and affect the probability and consequence of the scenario. The factors effect on liquid overfill risk incorporates both industry data and company historical data to determine the extent the factor impacts the risk.

The factors are split into three sections: base factors, probability of events that lead up to an overfill, and post release factors determining the consequence of an overfill.

Base Factors

- Environmental characteristics: wind speed, ambient temperature, ground temperature and other environmental related factors are included which can affect the dispersion

- Unit location: factors included for onsite/offsite location as well as proximity to roads or other potential ignition sources.

- Process conditions: includes factors for the type of material being released, temperature and pressure and other parameters that characterize the material being released.

- Physical dimensions: PRV location, Vessel dimensions, alarm locations alarms, etc.

Pre-release Factors

- Initiating Events: Initiating events typically involve loss of liquid outflow, such as closed control valve or loss of bottoms pump from the vessel while feed continues. Power failure for pumps is also considered. For storage vessels each fill operation is considered an initiating event.

- In-Service Factor: The in-service factor reflects reduced probability when vessels are only operated for a portion of a year or in a batch mode. The value is based on operating days during the year.

- Pre-Conditioning: For storage tanks and vessels, a pre-conditioning factor provides credit for the planning that is involved in storage operations. The factor takes into account the planning that is done by the supplier as well as the receiver.

- Fill Monitoring: For storage tanks and vessels, provides credit for monitoring activities of an active fill to identify any issues with the fill operation (e.g. gauge failure).

• Failure to Respond to Alarm: This factor provides the combined failure probability of the instrument and for the operator to take action. Operator response failure is impacted by the instrument arrangement and the amount of time the operator has to take corrective action to prevent the liquid overfill.

• Level High Cut-Out (LHCO) Failure: LHCO failure is based on the availability of the instrument loop, which is a function of the instrument arrangement and testing frequency.

Post-Release Factors

• Flammable area: The considerations in determining the flammable area are depicted in Figure 1. The size of the flammable area has an impact on the overall risk of liquid overfill. For releases from pressure vessels the flammable area is determined based on many factors which include evaporation, liquid rain out, and aerosol generation. For storage vessels the area determination isn't as complicated but does take into consideration the diked area of the storage vessel as well as vapor generation from liquid cascade.

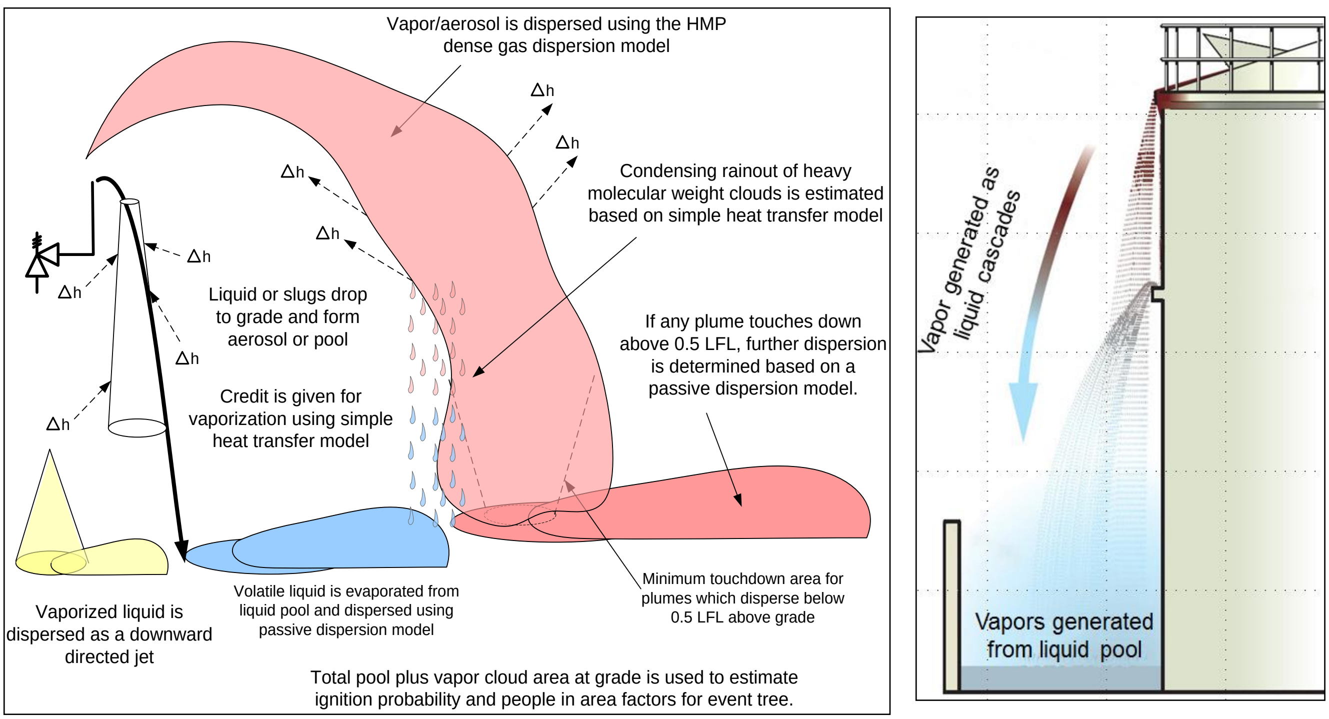


Figure 1: Liquid Overfill Relief / Exit Stream Treatment for releases from pressure vessels (left) and storage tanks (right)

• Ignition Probability: Ignition probability is a function of the density of ignition sources across the flammable area (plume) at grade, as illustrated in Figure 1. This probability is based on statistical ignition source density for a process area. The methodology used is documented in the IP Research Report.

• Ignition timing: the relative time (immediate or delayed) in which the ignition occurs is used to determine if there is time to allow for a vapor cloud to be generated before ignition.

Environmental factors such as constant ignition sources, hot surfaces in the area, and autoignition temperature are considered in determining the ignition timing.

- People in the Hazardous Area: The probability of people being in the hazardous area is determined by considering the average population density in or near the calculated flammable area. To estimate the population density in the hazardous area, personnel hours during a year is estimated considering typical operator rounds and maintenance activities. This factor is increased to reflect potential impact to personnel by overpressure and projectiles beyond the flammable area.

- Escape Probability: The impact probability is determined by assuming that personnel start in the middle of the combined pool or vapor cloud area and must travel through the impact area escape at a speed consistent with industry standards. For immediate ignition scenarios no credit is given for potential escape.

- Environmental and Public Impact: in the event of a non-ignition scenario the impact of the release material to the environment or public is determined.

LORAT EVENT TREES

Event trees are used as the overall basis for the liquid overfill risk assessment. A separate tree is developed for each scenario that could lead to liquid overfill to the atmosphere. The event tree is populated using the scenario factors for each scenario and probabilities are calculated to determine the effectiveness of barriers. The resulting consequence and probability combinations are used to determine the risk of overfill. This risk provides a basis for risk ranking of vessels and for evaluation of mitigation options.

The event trees can be broken up into two sections: events leading up to overfill and post overfill events. The events leading to overfill include the initiating events and other events that have the potential to stop the overfill from occurring (e.g. level high alarm response). The post overfill section of the event trees determine what is the potential impact the overfill (e.g. VCE, flash fire, etc.). An example of an Event Tree that was generated by the LORAT can be found below in Figure 2:

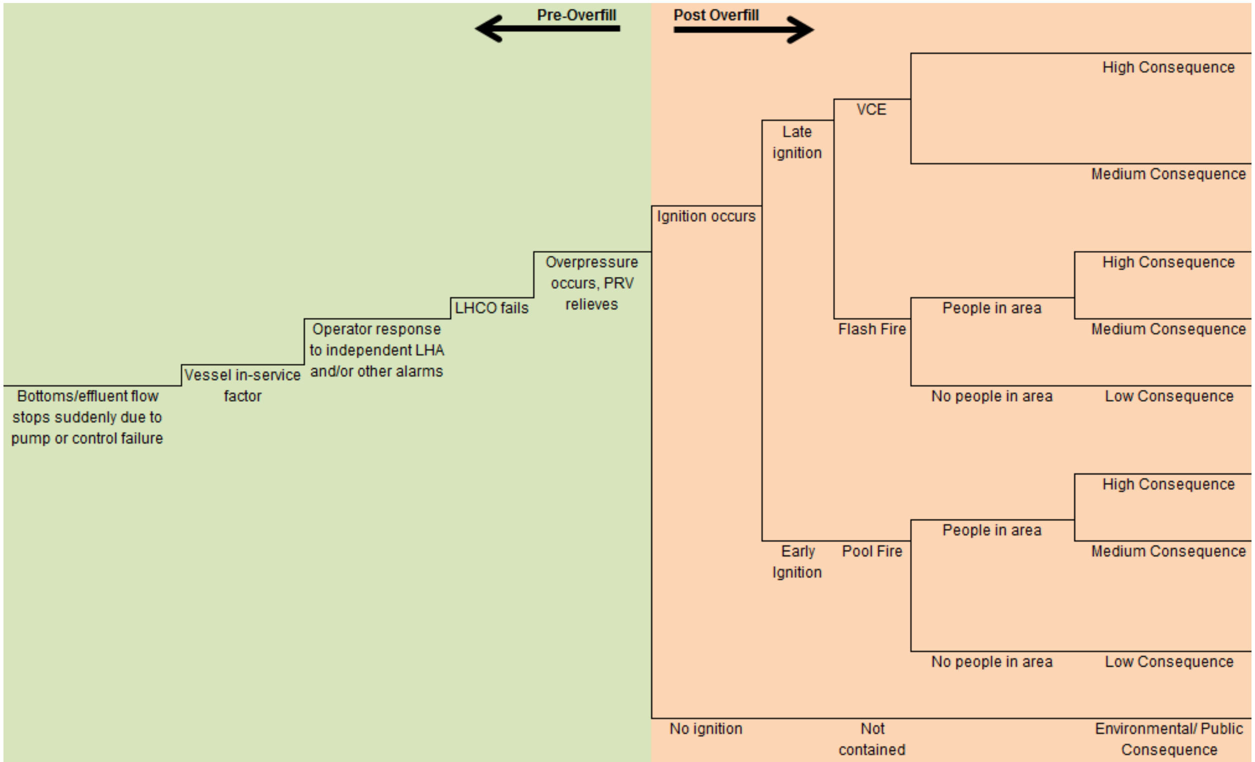


Figure 2: Example Event Tree generated by LORAT

In the event tree the full branches for the pre-overfill portion are not included for simplicity since the success of a barrier will prevent the overfill and have no consequence.

DATA REQUIREMENTS

To develop the probabilities in the event trees LORAT requires a detailed evaluation of the vessel design and vessel/unit operations. To complete a liquid overfill evaluation the following type of information is necessary for the review:

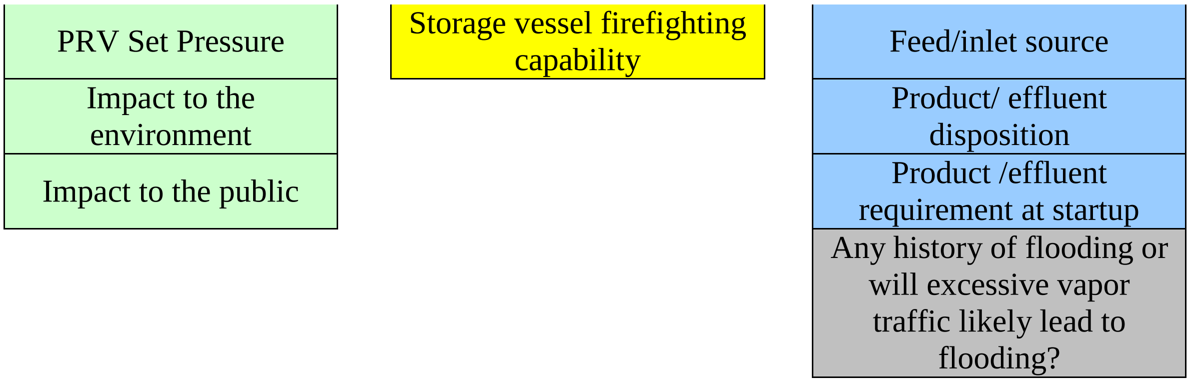
- Safety Relief Review Study
- P&ID's of systems protected by atmospheric pressure relief devices
- Process flow rates in and out of the system
- Process material information
- Heat and material balances
- Construction drawings of vessels to determine high level alarm location and liquid hold-up
- Plot plans (including proximity to fence-lines and Potential Explosion Domains)
- Isometric drawings (including PRV outlet line lengths and elevations)
- Incident information (Liquid overfill – Tower flooding)
- Start-up frequency and procedures

This information is used to determine details such as available inventory prior to overfill should a stream be stopped, location and availability of level alarms, and other vessel design details.

Participation by site operations' representatives is essential to confirm all process information, including details related to start-ups, normal operating conditions, available instrumentation, and site operating history.

The following table shows the various inputs that are required to be completed which will fully characterize the overfill risk in the LORAT.

Site	Storage Operation	LHA Description
Unit	Normal Fill Level	Is LHA classified/ maintained as Safety Critical?
Vessel	Hi Alarm Level	Does LHA have poor service history?
In-service factor	Hi-Hi or EHL Alarm Level	LHCO available?
Vessel Type	At which Alarm does operator first take action?	LHCO Type
Length/ Height	Automatic Cut-out Level	PHCO available
Diameter	Overfill Level	PHCO action
LHA Height	Cut-out valve time to close	Inflow phase
NLL Height	How often filled per year?	Normal inflow
PRV Inlet Flange Height	Site Type	Max. possible inflow
Vent Exit Height	Operator arrangement	Startup inflow
Exit Pipe Length	Preconditioning and pre-planning	Inflow Liquid Mass Fraction
Exit Pipe Diameter	Console/operator gauging activity	Normal Bottoms
Unit Type	Enhanced task execution and/or monitoring tools in place	Stream 1 Pumped?
Vessel Location	Field operations	Reboiler Type
Service	Fills per Console Operator per shift	Normal Overhead/ Distillate Liquid
Process Fluid	Fills per Outside Operator per shift	Stream 2 Pumped?
Normal Process Operating Temperature	Valves per lineup	Normal Overhead/ Distillate Vapor
Normal Feed Temp.	Product Supply Source	How many startups per year?
Normal operating pressure	Gauging System Type	Fill up past LHA on startup?
Max feed/ supply pressure	Storage Vessel Bunding	LHCO bypassed for startup?



RESULTS

After applying the LORAT to all ExxonMobil manufacturing sites a total of ~3,200 vessels were reviewed which included: ~500 pressure vessels and ~2,700 atmospheric tanks. Based on the risks that were identified, fit for purpose recommendations were made for each vessel which would mitigate the risk to an acceptable level. The main types of mitigations that were recommended are outlined below:

- High level cut out: implement a high level cut out that will stop the level build in the vessel. The amount of risk reduction is dependent on the arrangement of the cut out (e.g. SIL rating)

- Alarm upgrade: this includes upgrades to the alarm architecture, increasing testing frequency, upgrading the type of level instrument, lowering alarm set point, etc.

- Procedures: increase surveillance during tank fills, reducing frequency of tank fills, changing pre-conditioning steps to be more thorough, changing start-up procedures, etc.

- Other: re-routing the relief stream to flare, upgrading pumps, installing a pressure high cut out, reducing feed rates, etc.

Depending on the risk associated with liquid overfill one or a combination of the above mitigations may have been required to further reduce the risk. The LORAT tool was utilized to identify the necessary mitigations by creating a “mitigated” case where the proposed mitigation is assumed to be implemented and is compared to the base case risk to determine the risk reduction.

The following figures show the breakdown on the types of mitigations that were recommended globally. The “none” part of the charts are those vessels that were evaluated to be at an acceptable risk level and did not require any additional reduction.

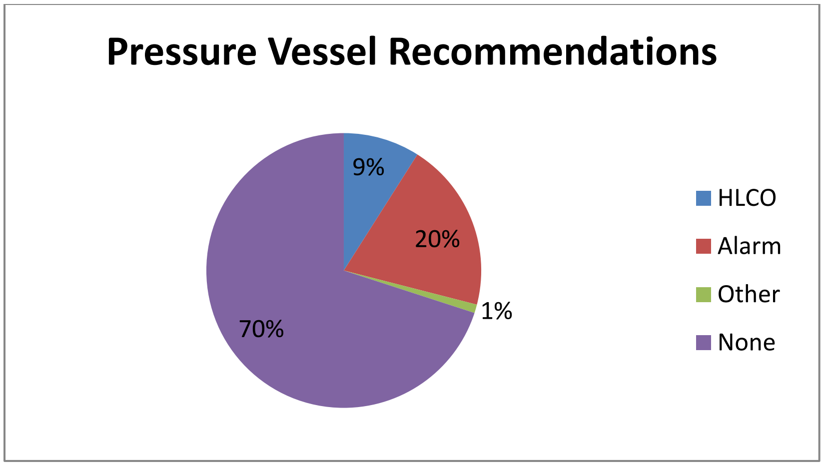


Figure 3: Summary of Pressure Vessel Recommendations

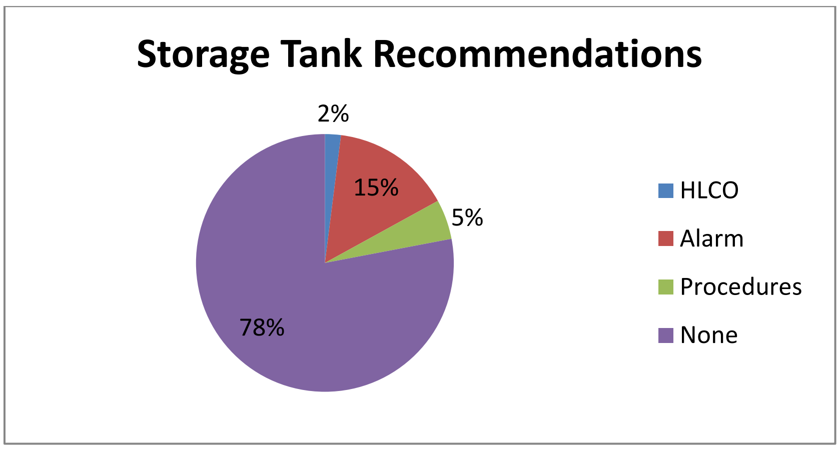


Figure 4: Summary of Storage Tank Recommendations

Though the charts represent the global view of the types of mitigation it is important to note that on a site level this may not accurately represent the types of mitigations required. Due to the different design and construction of sites the types of risks are generally consistent (i.e. a site may mitigate the risks with mostly procedures and less alarm upgrades) amongst a site but may not align with the global averages.

CONCLUSION

Due to recent liquid overfill incidents that have occurred in industry, ExxonMobil decided that a tool that can consistently evaluate the risks of liquid overfill was needed. To address this need the LORAT tool was developed which uses a mix of data and correlations from industry as well as internal company information. To fully characterize the risk associated with liquid overfill detailed information about the operation and vessel being reviewed is necessary. The detailed information is used to define the factors that affect the risks associated with liquid overfill; this allows the tool to generate event trees that define the probability and consequence associated with liquid overfill.

The implementation of LORAT to both pressure vessel and storage vessels has identified the risks associated with liquid overfill on a consistent basis. LORAT has also identified recommended mitigations, varying from facilities upgrades to procedural changes, which will reduce the risk to an acceptable level. And finally, the consistent application of LORAT allows the prioritization of the risk and associated mitigations to assist the manufacturing sites in planning and decision making.

REFERENCES

1. IP Research Report, Ignition Probability Review, Model Development and Look-up Correlations, Published by the Energy Institute, January 2006
2. API 2350 Overfill Protection for Storage Tanks in Petroleum Facilities - Fourth Edition, American Petroleum Institute, May 2012