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Emergency Isolation Valves at Pump Suction: Application for Flammable Liquids

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Emergency Isolation Valves (EIVs) are commonly provided at pump suction for butane and more volatile products and also for liquids handled above auto-ignition temperature. This practice of providing EIVs at pump suction is however, not widely followed for flammable liquids, particularly those operating at elevated temperatures as in many refinery units. The scope of this paper is to review the requirement for EIVs in such applications, considering the processing conditions, plant piping configurations and the hazards associated with such liquid releases. The paper draws on the authors' experience and observation from various plant design on different plant configurations.

1. Introduction

Loss of containment (LoC) from pump and associated piping caused due to seal failure, flange leakage, small bore piping failure is a common hazard encountered in chemical processing plants. One of the primary risk reduction measures used for LoC scenario is minimization of the leakage quantity by installing EIVs which could be activated automatically using Fire & Gas Detection System (FGS) or remotely by operators in control room or from field at a safe location. These EIVs, also called as Remotely Operable Shutoff Valves (ROSOVs) or Emergency Block Valves (EBVs) not only enhance the level of safety but also increase the availability of the rest of the plant (by containing the damaged zone) in case of a LoC event leading to a fire.

2. Typical safeguarding measures for pump handling LPG

Typical configuration of a pump taking suction from a process vessel, handling LPG (Liquefied Petroleum Gas) or lighter hydrocarbons is shown in Figure 1. To minimize leakage from pump seals, double mechanical seals with alarm for operator action is provided. Fire and Gas detectors are provided in the vicinity of pumps to detect any leakage or fire and automatically initiate shutdown of pump with closure of EIV (to minimize the inventory). Water spray is also provided for cooling in case of fire in the adjoining pump.

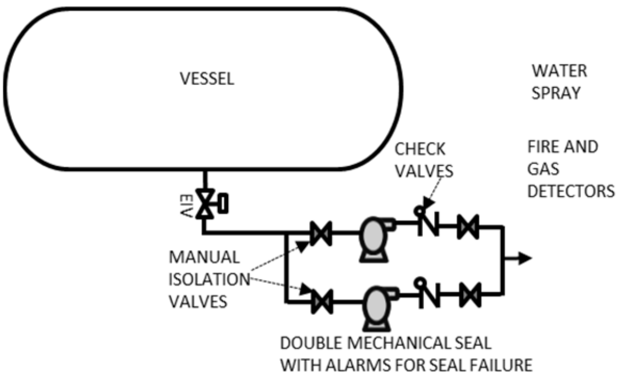

Figure 1: Typical depiction of an LPG Vessel and associated pump

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Release of inventory due to reverse flow from pump discharge piping is considered to be minimized by the check valve at the pump discharge. EIVs are not common in pump discharge piping. EIVs are typically provided close to the vessel bottom nozzle to enable isolation in the event of any leak in downstream piping and pump. On actuation of EIV, inventory in the piping between the EIV and the pump in such a configuration gets reduced to about 0.1 to 1 m3, depending on the pipe diameter and the length (assuming 8" to 20" pipe size and a length of about 3 to 5 m). The above safety measures are commonly provided for vessels/ pumps handling LPG or lighter hydrocarbon and in many cases for unstabilized naphtha, and unstabilized crude, which can generate significant flash vapors. These measures are also commonly applied for pumps handling liquids at or above auto-ignition temperature, such as atmospheric residue at crude column bottom or vacuum residue at vacuum column bottom. The requirement of these safety measures for other flammable liquids including stabilized crude, naphtha/gasoline, kerosene and diesel/ gas oils as well as for plant piping configurations other than Figure 1 is addressed in this paper.

3. Flammable Liquids Handled in a Refinery

The classification criteria adopted in Seveso III Directive (Seveso III Directive, 2015) as given in Table 1 is followed here. This criteria is based on the flash point and initial boiling point of hydrocarbon liquids. The classification in NFPA 30 (Flammable and combustible liquids code, 2012 Edition) follows a similar approach which is also included here.

Table 1: Seveso III classification criteria for flammable liquids

Seveso III - Category	Flash Point	Initial Boiling Point (°C)	NFPA 30 Category	Flash Point (°C)	Initial Boiling Point (°C)
1	< 23	≤ 35	IA	< 22.8	< 37.8
2	< 23	>35	IB	< 22.8	≥ 37.8
3	> 23	≤ 60	IC	≥ 22.8	Note: Flammable Liquids are Class I and Combustible liquids are Class II & III
Note: Gas oils, diesel and light heating oils having a flash point between ≥55 °C and ≤ 75 °C may be regarded as Category 3			II	≥ 37.8 and < 60	
			IIIA	≥ 60 and < 93	
			IIIB	≥ 93	

The flammable liquids handled in the various units of a refinery complex along with the processing conditions (temperature and pressure) is listed in Table 2. These can be broadly classified as stabilized crude, stabilized/ unstabilized naphtha, gasoline, kerosene/jet fuel, diesel/gas oils and heavy fuel oil/ residue. It is recognized that these are mixtures and their composition may vary across refineries. These liquids are handled at ambient temperatures as well as at elevated temperatures. Within the processing units, these liquids are mostly at elevated temperatures.

Table 2: Flammable Liquids handled in a refinery along with the process conditions

Unit	Material	Process Condition (Temperature/ Pressure)	Classification Criteria Seveso	NFPA	Equipment/ Location
CDU	Unstabilized	125-140 °C, 1 barg	2	IB	Crude column draw-off
	Naphtha	50 °C, 1 barg	2	IB	Crude reflux drum
	Stab. Naphtha	140-155 °C, 8.5 barg	2	IB	Naphtha stabilizer bottom
	Kerosene	140-170 °C, 1 barg	3	IC	Crude column, Kero Stripper
	Diesel	250-280 °C, 1 barg	3	IC	Crude column, Diesel Stripper
Diesel	Diesel	120 to 130 °C, 3 barg	3	IC	Feed surge drum
Hydrotreater		200 - 230 °C, 8.7 barg	3	IC	Stripper
Kerosene	Kerosene	120 - 130 °C, 3 barg	3	IC	Feed surge drum
Hydrotreater		200 - 230 °C, 5 barg	3	IC	Stripper
Fluidised	Unstabilized	50 °C, 1 barg	2	IB	Fractionator overhead drum
Catalytic	Naphtha	100 - 120 °C, 17 barg	2	IB	Stripper
Cracking	Stab. Naphtha	180 – 200 °C, 13 barg	2	IB	Debutaniser bottom
(FCC)	Diesel	170 – 180 °C, 1 barg	3	IC	Fractionator
DCU	Unstabilized Naphtha	140 – 160 °C, 15 barg	2	IB	Stripper
	Diesel	180 – 200 °C, 1 barg	3	IC	Fractionator
		160 – 180 °C, 1 barg	3	IC	Stripper

Based on Seveso III Classification criteria, all of the flammable liquids handled in a refinery would fall under Category 2 or 3. Only unstabilized crude or unstabilized condensate handled in the upstream oil & gas processing plants both, onshore or offshore would fall under Category 1. The main characteristics however, are the elevated temperatures and pressures at which these liquids are handled in the refinery. The hazard due to this specific processing condition is recognised in the Seveso III Directive and accordingly the threshold quantities that apply for regulation of sites handling liquids at elevated temperatures and pressures (P5b) are set lower, as given in Table 3. However, for the general category of petroleum products, a separate threshold quantity has been set which will apply. This is much higher than the quantity set for liquids under P5b hazard category, the category which would have been applicable otherwise for most of the petroleum liquids handled within the processing units of a refinery due to their elevated temperatures.

Table 3: Threshold Quantities (tonnes) for flammable liquids

	Description	Lower Tier	Upper Tier
P5a	Category 2/3 liquids maintained at temperature above their boiling point	10	50
P5b	Category 2/3 liquids where particular processing conditions, such as high pressure or high temperature, may create major-accident hazards,	50	200
P5c	Category 2/3 liquids other than P5a or P5b	5,000	50,0000
Gen	Petroleum products (gasoline/ naphtha, kerosene, gas oils/ diesel, heavy fuel oil)	2,500	25,000

Although the threshold quantities listed above apply for regulation of the sites and is not directly related to the subject of this paper which is EIV, the consideration of hazards relating to specific processing conditions such as elevated temperatures serves as a useful reference while reviewing the subject of EIV.

4. Hazards from Flammable Liquids and Processing Conditions

The main hazard due to release of flammable liquid when operating at elevated temperatures is the potential for generation of flash vapours, and the associated increased ignition probability leading to a fire or an explosion. This hazard was recognised after the Flixborough accident (Lees), where about 30 tonnes of cyclohexane liquid at 155 °C and 8.8 barg escaped resulting in a vapour cloud explosion. Flammable liquids such as gasoline, even when handled at ambient temperatures, upon an accidental release, can generate significant flash vapours. Liquid droplet entrainment or mist carried along with the flash vapours, particularly when released under pressure can increase the potential for a vapour cloud explosion under certain environment as observed in the Buncefield incident (Buncefield) when gasoline overflowed from a storage tank. The amount of flash vapours that will be generated upon an accidental release is therefore a significant factor in determining the fire and explosion potential. Flash calculations performed for the liquids handled in a refinery at elevated temperatures such as naphtha, kerosene and diesel show significant amount of flash vapours which combined with droplet entrainment present a significant fire and explosion hazard.

5. Incidents involving release of flammable liquids

A brief review of incidents involving a release of flammable liquid from pump or associated piping (following a pump seal leak or other piping failure associated with the pump) is included here. While the 1st incident involved kerosene at elevated temperature, the 2nd and 3rd incidents may have involved liquids at or above auto-ignition temperatures. However, the financial loss following a fire at the pump illustrates the extent of damage.

(i) An explosion and fire occurred in the kerosene stripper of a Crude Distillation Unit (CDU) at an 80,000-barrels per day refinery in Thailand in 2012. The estimated damage to CDU unit was USD140 million. (Marsh).

(ii) An oil spill occurred due to a failure of a block valve to seal properly during maintenance of a pump strainer in the visbreaker unit at a plant in Wickland, Aruba, Dutch Antilles in 2001. The oil auto-ignited and the ensuing fire spread and destroyed the visbreaker and damaged adjacent equipment. Estimated loss was USD 250 million current value. (Marsh)

(iii) An emergency shutdown at a fuel oil direct desulfurization unit caused by malfunction of recycle gas compressor resulted in reverse flow of oil to the feed pump. The check valve at the pump discharge did not function and the pump mechanical seal was exposed to high temperature and was damaged. The leaked oil at 310 °C spontaneously ignited and further escalated. The estimated damage was about Yen 90 Million. The incident occurred in a refinery in Chiba, Japan in 1991. (Failure knowledge database)

(iv) An incident in an Olefins Plant in the US in 2005 wherein a trailer being towed by a forklift snagged and pulled a small drain valve out of a strainer in a liquid propylene system resulted in a major fire. The investigation report by CSB has concluded that had a remotely actuated valve been installed upstream of the pumps, this incident would likely have ended quickly, possibly even before ignition occurred (CSB). Although this incident relates to LPG type liquid, it is relevant to the discussion here as the pump was drawing suction from a column tray, which is discussed further.

(v) A large leak of gasoline occurred from a hammer blind valve at a tank outlet in a petroleum storage terminal located in Jaipur, India. The leak resulted in a jet of gasoline directed upwards from the valve. The nature of the release is likely to have assisted in the production of vapour and analysis indicates that a flammable cloud appears to have covered large area. It is estimated that over 1000 tonnes of gasoline was released from the tank prior to ignition and vapour cloud explosion (VCE) resulting in eleven fatalities and tank fires. Overpressures in excess of 200 kPa (2 barg) were generated across almost the entire site. The VCE in the Jaipur incident shared a number of characteristics with the VCE at the Buncefield terminal in the UK in December 2005 (Buncefield Report), both of which involved gasoline at ambient temperatures. (Johnson).

The above incidents demonstrate the potential for significant damage due to release of flammable liquids and the potential for flash vapours leading to an explosion.

6. Guidelines for installing EIVs

The guidelines adopted in the industry for the provision of EIVs are briefly discussed here.

(i) HSE UK (UK HSE Report 2004, HSG 244) provides a method for determining the requirement of EIV by a combination of Primary and Secondary Criteria which takes into account the quantity, type of fuel, duration of release, accessibility to isolate etc. Additional requirements include: (a) the maximum foreseeable release of a hazardous substance in the event of failure to isolate manually is less than 1% of the controlled quantity (Q) specified in COMAH Regulations 1995. [If 1% of the controlled quantity as per the COMAH Regulations 2015 (following the Seveso III Directive) is considered, the relevant quantities will be 500 kg for flammable liquids (P5b), 50 tonnes for flammable liquids (P5c) and 25 tonnes for named substances (petroleum products)]. (b) Failure to isolate a release of a flammable substance, the direct consequences of which (e.g. thermal radiation or overpressure) are confined to the site, could result in escalation involving a release of another hazardous substance with off-site consequences.

(ii) Many Oil & Gas companies and engineering consultants typically consider an inventory of 4 m3 or more for butane and more volatile product and 10 m3 or more for liquids at or above auto-ignition temperature, as the basis for providing EIVs. However no specific guidance is available for other flammable liquids like naphtha, gasoline, kerosene, diesel and liquids operating at elevated temperatures.

(iii) Another methodology that could be adopted is that developed by Bunn and Lees (A.R.Bunn, 1987) which is based on a set of rules for the provision of EIVs. The methodology is a qualitative tool based on hazard, leak history, likelihood, and inventory size.

The guidelines contained in HSE UK HSG 244 is the most comprehensive in its requirements which require to follow a risk based assessment. However, such assessments may not be widely followed. Furthermore, if the 1% criteria is adopted considering the threshold quantity for P5b flammable liquids rather than for the petroleum products, then 500 kg limit may apply.

7. Plant Piping Configurations

There are a number of configurations different from the typical configuration shown in Figure 1, for which EIVs are not commonly considered. Three such examples are shown below:

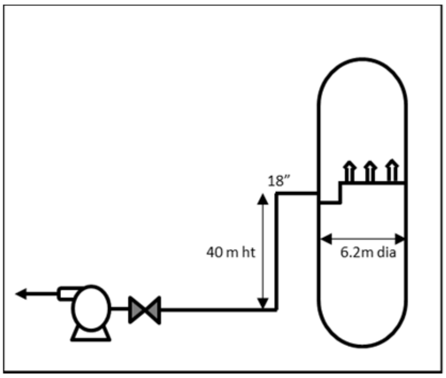

Figure 2: Pump drawing suction from chimney tray

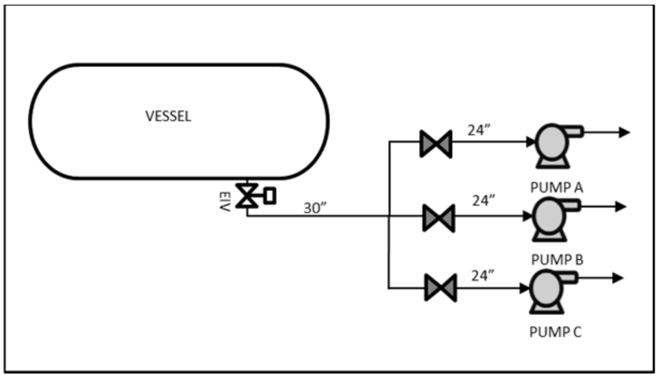

Figure 3: Multiple pumps with large volume in suction

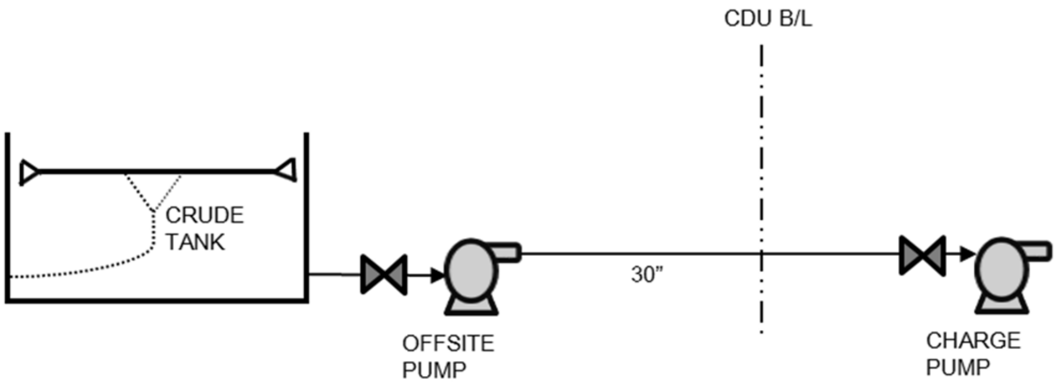

Figure 4: Pumps operating in series, with long suction header

7.1 Pump taking suction from a Chimney tray of a Column

Pumps that operate with suction from the chimney tray of a column are not often provided with EIVs. There are many such examples in a refinery. Pump around circuits in units such as crude distillation column (CDU), vacuum distillation column (VDU) and other fractionators (in FCC, HCU, DCU) to cite a few. Other examples include product draw-offs such as ethylene from ethylene fractionator and benzene from a benzene column.
The common misunderstanding is that the piping inventory is small and the material under consideration is a heavier product and not in the range of butane/ lighter product or that the material is not flowing from a vessel or column bottom (as in Figure 1) but from a chimney tray. Consider a typical refinery processing 135,000 barrels per day of crude. The vacuum column dimension, the size of suction header and elevation of the draw-off tray is shown in Figure 2. The quantity of hydrocarbon in Heavy vacuum gas oil tray and suction piping is estimated to be about 40 m3. It must also be noted that hydrocarbon from the down comers of trays in the upper section of the column will continue even if emergency shutdown of the column is activated. The liquid in this case is at its bubble point temperature of about 300 °C. Upon an accidental release, the liquid will flash and the release could continue for more than 30 minutes. The liquid may also be above auto-ignition temperature. The risk of fire and explosion therefore becomes significant, considering the material property and the system inventory.

7.2 Multiple pumps with significant suction piping volume

Due to increasing operating capacities in the process plants, the size of suction headers and the number of pumps that operate in parallel have increased from a typical 1 out of 2 configuration (one running, one standby) shown in Figure 1 to multiple pumps in parallel. Also, to improve the availability, 2 out of 3 configuration is being adopted (3 x 50% pumps, with two running and one spare, so that even in the case of one pump trip, 50% production is maintained). An example is that of Main Oil Line (MOL) pumps in offshore where 2 out of 3 configuration or even higher number of pumps are provided. Another example is crude flash drum (Figure 3) operating with three pumps. The suction piping sizes are as shown in Figure 3 and the inventory held between the EIV provided at the immediate outlet of the flash drum and pumps for a suction length of 20 meters is estimated as 10 m3.

7.3 Pumps operating in series

Pumps operating in series have long suction/ discharge headers. In some scenarios the inventory held in the piping could be significant and could result in a large release. Consider an example of crude charge pumps within CDU with unit capacity of 135,000 barrels per day, operating in series with the offsite pump (refer to Figure 4). Typically in a refinery, the offsite storage and transfer is located far from the process unit. Assuming a line of 30" size, the inventory could be more than 100 m3. In some cases, EIV is provided at the unit battery limit. Even in such a scenario, the inventory in the piping up to the pump suction could be in the range of 5 to 10 m3 depending on the location of the pump inside the unit.

7.4 Pumps taking suction from storage tanks

Storage tanks for products like crude, gasoline, naphtha are generally provided with EIVs at the pump suction (at the tank outlet nozzle) for isolating leaks. However this may not be adopted in all storage terminals. Although these are stabilized products, the inventory is very large and the incidents at Buncefield and Jaipur show that liquid gasoline release can generate explosion hazards.

8. Fire & Explosion risk due to release of flammable liquids at elevated temperatures

The frequency of small leak for pumps (e.g. seal leaks) is in the range of 5E-3 to 1E-4 per year (UK HSE, RIVM, Bloch), while the frequency of flange leak and small bore piping leaks associated with pumps is also similar. A leak of naphtha (at 1.5 barg and 100 °C in the suction line of a pump from crude column) was modelled using PHASTv6.7. For small leaks (10 mm or lower), the release duration is calculated to be more than 30 minutes considering an inventory of 2 to 4 m3. Calculation for jet and pool fire shows that the 35 kW/m2 thermal radiation contour can extend to 10 to 20 m. The fire impingement or radiation impacts of 32 kW/m2 or higher on adjoining equipment for over 5 minutes may cause equipment to fail leading to escalation. This implies that there is considerable escalation risk associated with pump leaks. Similar results were also obtained for Diesel (at 1 barg and 275 °C). The release generates significant flash vapours which increases the potential for explosion. As specified by UK HSE, 150 mbar is normally considered as the overpressure threshold required for causing significant equipment and piping damage. Typically, streams containing light hydrocarbons (say pure methane) require a stoichiometric volume in the region of 2,000~4,000 m3 in order to generate 150 mbar overpressure (under a moderately congested layout typical to refineries) based on CFD studies carried out in-house in IRESC. Stoichiometric volume required to result in similar overpressure will be lower, about 1,500 m3 for LPG and further lower in case of heavier hydrocarbons. In the event of a release of 2 m3 of kerosene (near bubble point) equivalent to 20,000 m3 of vapours and assuming some flash may result in significant degree of overpressure which could be the case for naphtha and diesel as well. The results show that limiting the inventory released will effectively limit the associated consequences of damage caused by fire and explosion. Assuming a fire/explosion frequency of 1E-05 per year per pump (based on a leak frequency of 1E-04 per year and ignition probability of 0.1) and damage costs of USD100M per event, the justifiable expenditure over a 20 year period is estimated as about USD 20,000. If additionally production loss equivalent of USD100M is considered particularly for mother units such as CDU/VDU, safeguards such as EIVs, fire and gas detection and double mechanical seal for pumps handling flammable liquids at elevated temperatures will provide economic value for business.

9. Conclusion

EIVs are normally provided at pump suction for vessels handling butane, LPG or more volatile product. The use of EIVs for flammable liquids, particularly those handled at elevated temperatures and pressures is not so common though the consequences of release of such material would be similar in nature as that of LPG. This paper has highlighted various plant configurations where the inventory in the piping and associated equipment such as vessels or column draw off trays could be significant that use of EIVs at the pump suction header, individual pump suction, and pump discharge needs to be evaluated based on risk considerations. Additionally, double mechanical seals, fire and gas detection with automatic isolation to be considered for pumps in similar services.

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