

Health Safety & Environment

Best Practices in Hazard and Operability Studies

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Hazard and Operability Studies (HAZOP) remains a very powerful tool in the armory of modern designers and engineers in minimizing hazard and operability related concerns from process plants in continuous as well as batch operations. In a world moving towards increased environmental awareness, HAZOP techniques will continue to find traditional as well as novel applications.

Bahrain Petroleum Company (BAPCO) Hazard and Operability Studies (HAZOP) process was recognized as an industry best practice by the Robert W Campbell Award review team in 2007. BAPCO started conducting HAZOP studies in the early 1980's for its refinery units following a risk-based prioritization program. The traditional Piping and Instrument Diagram (P&ID) line-by-line guideword-based HAZOP remains a very powerful tool in the armory of modern designers and engineers in minimizing hazard and operability related concerns from process plants in continuous as well as batch operations. Nonetheless, the company have strengthened the HAZOP effectiveness through developing some best practices of its own as well as adopting some recommended by other well-known authorities such as the American Institute of Chemical Engineers (AIChE) Center for Chemical Process Safety (CCPS). In addition to the Global Parameters, this paper describes several other best practices

that BAPCO has applied to HAZOPs.

A Historical Perspective

In 2007, BAPCO won the prestigious Robert W Campbell award [1] for integrating safety into its primary business processes. The company was the first non-North American company to have won this award. The ExxonMobil team who reviewed BAPCO processes on behalf of the awarding agency made specific reference to the excellent quality of HAZOPs that BAPCO had conducted and reported. Such commendation for BAPCO HAZOPs did not come by chance. BAPCO has a very strong and rich tradition in this field; arguably the pioneers in this region. Imperial Chemical Industries (ICI's), of UK Bert Lawley, inventor of the HAZOP process, published his first paper on the topic in 1976 [2] BAPCO conducted their first HAZOP meeting in as early as 1981 [3 and 4].

The Bahrain Refinery is one of the oldest refineries in the

Middle East with the first original units dating back to 1936. The plant has been modified and expanded over the years and has a current crude charge capacity of 267,000 BPD. The plant has been operating at capacity for the past several years. Crude oil processed consists of locally produced Bahraini oil and Arabian Light imported from Saudi Arabia via pipeline. The main product range consists of Liquefied Petroleum Gas (LPG), naphtha, gasoline, kerosene, jet fuel, diesel, fuel oil, asphalt and sulfur. The main markets for the products include the Gulf Cooperation Council (GCC) countries, the Indian Subcontinent, Japan, other Arab countries, other Middle East countries, East Asia, Africa, Australia and New Zealand.

In 1983 the refinery suffered a serious fire in one of the hydrodesulfurization unit furnaces with the result that the HAZOP program for the high risks unit was accelerated and the safety related recommendations arising from the HAZOP studies were implemented on a high priority basis. Initially the HAZOP program needed the support of expertise from external consultants who led the its teams and showed the way. In-house expertise was subsequently developed to carry out the bulk of work, utilizing the consultants only when detailed quantitative risk assessment was deemed essential to resolve differences of opinion.

It should be noted that in BAPCO, the term "HAZOP" has taken on a wide-ranging definition. It entails feasibility and/or safety reviews of projects, sites, processes, changes to plant or equipment, fire-prevention and loss-prevention engineering, adequacy of standards and operating instructions, design hazard reviews, qualitative as well as quantitative risk assessment, consequence analyses and a multitude of allied activities.

Risk-Based Schedule of HAZOPs

In order to enhance the cost-effectiveness of the entire HAZOP program a task force was appointed to develop a HAZOP schedule drawn up on the basis of a risk screening exercise of all process areas and other parts of the refinery. See Table 1. There were no up-to-date Piping and Instrument Diagrams (P&IDs) available for a majority of the units at the beginning of the HAZOP program. Many of the vendor-supplied drawings were considered out-of-date due to changes implemented in equipment and/or process configurations. Since HAZOPs could only be performed using up-to-date P&IDs, a major effort aimed at generating the requisite as-built drawings became an integral part of the program.

The traditional P&ID line-by-line guideword-based HAZOP remains a very powerful tool in the armory of modern designers and engineers in minimizing hazard and operability related concerns from process plants in continuous

	Unit	HAZOP Date	Action Items
1.	Hydrogen Plant	September 1983	27
2.	Hydrodesulfurization Unit	September 1983	49
3.	Fluid Catalytic Cracking Unit (FCCU) and No. 5 Crude Unit	January 1985	83
4.	Hortonspheres	May 1985	14
5.	Incoming Crude Pipelines	November 1986	10
6.	Platformer/Unifiner	July 1985	31
7.	LPG Shipping and Blending	May 1987	11
8.	Sulfur Recovery Unit	February 1988	22
9.	No. 4A Crude Unit	March 1988	51
10.	No. 6 Vacuum Distillation Unit	April 1988	28
11.	Refinery Flare Headers	August 1988	4
12.	Low-sulfur Fuel Oil Heater	October 1988	18
13.	Asphalt Heater	October 1988	21
14.	Refinery Gas System	December 1988	57
15.	No. 1 LPG Treater	February 1989	35
16.	No. 5 Vacuum Distillation Unit	November 1989	38
17.	Remote High-level Flare	November 1989	8

Table 1: History of BAPCO HAZOPs

as well as batch operations. Nonetheless, the company have strengthened the HAZOP effectiveness through developing some best practices of its own as well as adopting some recommended by other well-known authorities such as the American Institute of Chemical Engineers (AIChE) Center for Chemical Process Safety (CCPS).

Risk Acceptance Criteria for HAZOPs

One of the key inputs to HAZOP studies is the application of the company's risk acceptance criteria in evaluating risk mitigation measures proposed by the HAZOP teams. BAPCO had developed in-house criteria at the beginning of the program based on industry guidelines [5, 6] which were subsequently aligned with other more recent publications such as that of the UK Health and Safety Executive.

The main premise of our overall enterprise-wide risk acceptance criteria is that the cumulative frequency of fatality resulting from Bapco's business is maintained at a rate lower than 1×10^{-3} per year. For acute risks related to the three business units (refinery, oil and gas and marketing), this acceptance is therefore dropped a further order of magnitude; i.e. the cumulative risk of a major event such as fatality, multiple irreversible injuries (public), major fire or explosion or major spill at sea that results in widespread adverse publicity nationally and internationally, is maintained at a rate lower than 1×10^{-4} per year in each of the three business units.

Major Consequence Event Rate	Decision	Design Requirement
1 x 10 ⁻⁴ to 1 x 10 ⁻⁵ per year	Do not accept risk	Change design
1 x 10 ⁻⁵ to 1 x 10 ⁻⁶ per year	Marginal	Consider cost/benefit
1 x 10 ⁻⁶ or less per year	Accept risk	No change needed

Table 2: Risk Acceptance Criterion

Note: In some cases, Worker/Operator Risk Criterion in terms of FAR (Fatal Accident Rate) is used. If so, then the Target FAR shall be 0.1 or less. FAR is defined as Number of Fatalities in 100 million hours of exposure. Note that FAR Targets are specified for plant operational life and not for plant construction period.

Therefore, for a given project or a process unit, the risk acceptance criteria as shown in the Table 2 above shall be applied.

The above criteria is based on the ALARP principle which calls for all known risk exposures to be reduced to a level As Low As is Reasonably Practicable (ALARP) (Fig 1).

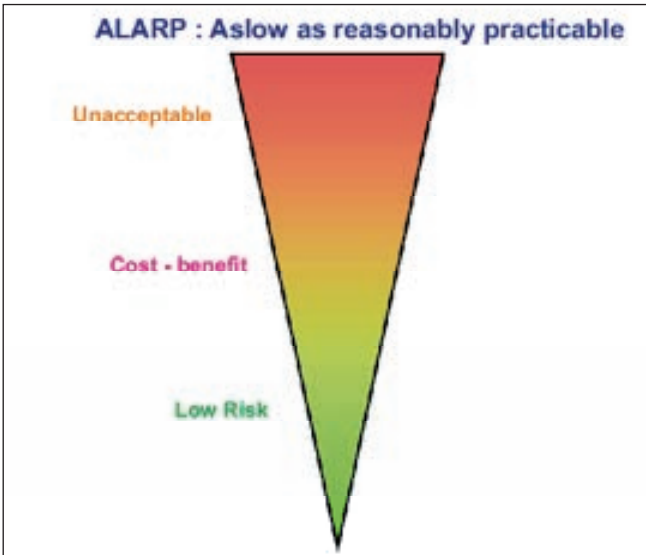


Fig 1 -ALARP : "it implies that a computation must be made in which the quantum of risk is placed on one scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time to trouble) ps placed in the other and that, if it be shown that there is gross disproportion between them the risk being insignificant in relation to the sacrifice the defendants discharge the onus upon them."

Allowable Land Use within Annual Individual Risk Bands

Third party land use acceptance with respect to annual individual risk bands is diagrammatically given in fig 2. Note that this standard does not permit any third party land use within the iso-risk contour of 1 x 10⁻⁴ per year (event rate of

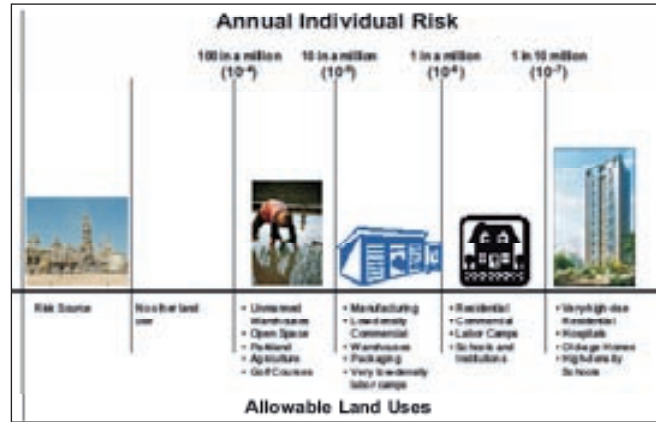


Fig 2 - Allowable Land Uses

individual fatality of 1 x 10⁻⁴ per year or higher).

Selecting a HAZOP Team Leader

A HAZOP seeks answers to two fundamental questions: Will it work? Will it harm anyone/anything? And since these two questions can be legitimately raised in the context of any product, process, project, material, activity, idea, concept, or thought, therein lies the seed of its all-pervasive applicability.

HAZOP is, by its very definition, a team effort, requiring input from many disciplines. A team performs well if it is led well. Therefore, the ultimate success of a HAZOP, to a large extent, is directly dependent upon the technical savvy and the interpersonal skills of the team leader. But is that all that is needed to make a good team leader? What are the essential qualities, traits and qualifications that make a good HAZOP team leader?

When the question was asked of a few known HAZOP practitioners in personal interviews, the answer invariably tended to be a recitation of the responder’s curriculum vitae, with a liberal sprinkling of self-aggrandizement. However, it soon transpired that in order to find out what makes a good HAZOP team leader, one has to research the opinions of a wide range of practitioners as well as managers.

A comprehensive questionnaire was developed in order to gather opinions on what is a good HAZOP and what makes a good HAZOP team leader. The underpinning theme of the questionnaire was to determine if there existed a set of attributes essential or ideal in the make up of a good HAZOP team leader; for example: academic qualification (engineering or science or logic/arts), profession (engineer or manager), experience (hands-on engineering, safety engineering or fire prevention, etc), skills (language, computing, mathematics, etc), knowledge (general knowledge or in-depth knowledge of the industry), attitude mix of management types (The

Questions	Number of Respondents With varying degrees of Agreement				
	A	75%	50%	25%	D
Listen and recall ability is essential for good HTL	66	16	2	0	1
HTL should be flexible, creative, involve members	41	24	6	7	7
HTL should have a good team interpersonal approach	31	28	7	9	10
Wrong personality can not make a good HTL	15	17	15	13	25
Adhering to procedures and system make a good HTL	41	25	8	5	6
Lateral thinking is attribute of a good HTL	26	35	14	5	5
A good HTL should be flexible	36	27	6	10	6
A good HTL explains to members overall study vision	42	27	6	6	4

Table 3 - Respondents Average Score to Attitude and Aptitude Questions related to the HAZOP Team Leaders Survey Questionnaire

Pedantic, the Classifier, the Procrastinator, or the Iconoclast), risk management aptitude per the doctrines of the UK Royal Society (Anticipation/Resilience, Absolution/Blame, Quantification/Qualitative, Design/ Design Agnostic, Complementary / Trade-off, Narrow participation/ Broad participation, and Outcome specification/ Process Specification).

The results of the above research are used extensively in BAPCO in the selection and training of our HAZOP team leaders. An example of the research results are shown in Table 3 above.

Use of a Comprehensive Global-Parameters Node (Best Practice)

The list of global parameters used during HAZOPs is shown in Table 4. These parameters are discussed for the plant as a whole instead covering each item on each node which will be a time consuming process.

For each of the global parameter listed above the company's Risk and Reliability Management Group have developed a list of generic questions that are raised in HAZOP meetings. On many occasions the list of questions is further augmented by including some specific questions related to the process equipment or process unit under consideration. Given below is a sample of the type of questions that are raised related to the Global Parameters.

- Has the design basis for each relief system (e.g,

Relief	Structural	Civil
Small Bore Piping	Maintenance	Testing and Inspection
Instrumentation	Sampling/ Pipe Supports	Drains and Vents
Services/Utilities	Dead Legs/Redundant Items	Corrosion
Erosion	Material Spec	Safety/ Fire water
Emergency Escape	Purging/Inerting	Isolation
Area Classification	Lighting	Grounding
Spacing	Distance	Access
Roads	Effect Distance	Toxicity
Fire Hazard	Explosion Hazard	Ignition Sources
Noise	Warning/Evacuation	Workover/ Maintenance Frequency
Reliability/ Availability	Operating Procedures	Inspection / Maintenance Procedures
Major Incident Procedure and Disaster Recovery Plans	Mothballing	Start-up/Shutdown/ Emergency Shutdown System (ESD)
Mechanical/ Constructibility	Management of Change	Hot Tap/ Work Permit
Standards Compliance	Operability	Insulation
Drawings	Human Factors	Environment
Compliance to API752/753	Compliance to LASTFIRE (Large Atmospheric Storage Tank Fires)	

Table 4 - Global Parameters

- cooling failure, external fire, runaway reaction, and thermal expansion) been clearly specified in process documentation? Where more than one contingency is applicable, has the largest been taken as the design basis?
- Have multiple relief devices with staggered settings been considered to avoid chattering (particularly where the relief loads in the probable scenarios will be less than 25 percent of maximum capacity)?
 - Are instruments, displays, and controls promptly repaired after a malfunction? Are any instruments, displays, or controls deliberately disabled during any phase of operation? How are alarm set points and computer software protected from unauthorized changes?
 - Is equipment containing volatile flammable materials or materials above their auto-ignition temperature (e.g, hot pumps) protected by deluge systems? Do the deluge systems adequately protect small-diameter piping attached to vessels?

At a first glance it might appear that the questions raised during the global parameter discussion should not have been left to be tackled at the end of the HAZOP but ought to

have been considered earlier when the particular equipment or instrumentation loop first appeared in the node-by-node process. In the Bapco HAZOP procedure the questions are raised at the earliest opportunity; for example, all questions and concerns related to a particular relief valve or system configuration will be raised when discussing the HAZOP node where the relief valve first appears. However, the global parameter at the end ensures that the team has been consistent in their overall approach to all relief valve configurations for the entire process plant under consideration. It is seen on numerous occasions in practice that this over-arching approach ensured through the use of global parameters adds a tremendous value in resolving issues that are missed during discussion of specific nodes and helps the company in adopting a unified and consistent risk management approach.

Use of Checklists (Best Practice)

In addition to the global parameters listed above, the company developed and adopted, four specific checklists for use during our HAZOPs. The teams for major project or major process unit HAZOPs can be quite large, sometimes consisting of more than seven members. It was felt that for some specialist topics not all team members had to be present during the fact-finding phase. The four checklists are assigned to be researched and completed by smaller task forces derived from the larger HAZOP team. The findings of the checklists are then discussed in the full HAZOP team meetings and the recommendations arising from them are ratified by the entire team.

a. Maintainability Review Checklist: This checklist is used by the Maintenance Representative of the HAZOP team who coordinates the overall input from the all departments and sections in the maintenance function for the HAZOP team. The areas of interest and the responses from various functions (electrical, instrument and mechanical) within the Maintenance Division are captured here. There are 20 items that need to be addressed in this checklist, following are some examples that are covered in this checklist.

- Reliability reports on Rotating Equipment
- List of Bad Actors,
- Access for Maintenance
- Availability of Vendor Manuals and Documents
- Survey of Walkways and Ladders
- Compliance with Area Classification

b. Human Factors Checklist to Capture Issues Related to Human Factors (CCPS-based): This generic checklist

given in the publication of the Center of Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE) has been adapted for this purpose. The team discusses issues related to human factors addressing interactions in the work environment between people, plant and its management systems. This checklist contains 80 questions under various areas like housekeeping and general environment, accessibility/availability of controls and equipment, labeling and so on.

c. Facility Siting Checklist to Capture Issues Related to Siting (CCPS-based): This generic checklist is adopted from the publication of the Center of Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE). It includes spacing between process components, location of the motor control center, machine shops, welding shops, electrical substations, roads, rail spurs, and other likely ignition sources, engineering, laboratory, administration, or other occupied buildings, unit layout, unit relative to on-site and off-site surroundings, emergency stations (showers, respirators, personal protective equipment), electrical classification, contingency planning and adequacy of drains, spill basins, dikes, and sewers etc.

d. Facility and Process Modification Checklist to Capture Issues Related to Facility and Process Modifications since last HAZOP (CCPS-based): This generic checklists from the publication of the CCPS of the AIChE have been adapted for this purpose. This includes the facility and process modifications carried out in the unit under consideration for the HAZOP. The checklist covers all the Management of Changes (MOC) requests that were raised in the process plant under consideration over the past several years, including the period between successive HAZOPs.

Emergency Inventory Isolation Block Valves (Best Practice)

As a part of our HAZOPs, a review is carried out of the Emergency Inventory Isolation Block Valves (EIBV) requirement for hydrocarbon vessels with respect to the company engineering standard. The primary intent of this standard is to ensure that liquid hydrocarbon inventory can be isolated (safely by an operator) in case of an emergency such as a release or fire involving the equipment so as not to continue feeding the fire or release. This standard insists on safe distances for the location of isolation valve of equipment. If the valve is located in close proximity of the potential release site (or fire) or in an area of congestion, then it cannot be regarded as a sufficient safeguard. This could lead to a

Explanations:
Light ends present: If $(C_1 \text{ to } C_3) > 1\%$ or $(C_1 \text{ to } C_3) > 10\%$ in the liquid at operating conditions.

T = Liquid temperature, °F,

T_f = Flash point, °F

Light Ends	Preventable Potential Release	Temperature	Selection of EIBV
Any	< or = 10 bbl	Any	No requirement under this standard.
Absent	> 10 bbl	T < (T _f - 10) and T < 250 °F	Manual EIBV at the vessel or any other convenient, easily accessible location in the line. (See Note 1).
		T > = (T _f - 10) or T > = 250°F	Manual EIBV, located at a safe distance (preferably 25 feet) from the potential release point. EIBV to be accessible at grade or within 15 feet of grade (platform access for valves above 2"). (See Note 1).
Present	>10 bbl < = 50 bbl	T < (T _f - 10) and T < 250°F	Manual EIBV, located at a safe distance (preferably 25 feet) from the potential release point. EIBV to be accessible at grade or within 15 feet of grade (platform access for valves above 2"). (See Note 1).
		T > = (T _f - 10) or T > = 250°F	Manual EIBV, located at least 25 feet from the potential release point and also from the likely drain point which the released liquid might flow to. EIBV to be accessible at grade or within 15 feet of grade (platform access for valves above 2"). (See Note 1, 2).
	> 50 bbl	T < (T _f - 10) and T < 250°F	Manual EIBV, located at least 25 feet from the potential release point and also from the likely drain point which the released liquid might flow to. EIBV to be accessible at grade or within 15 feet of grade (platform access for valves above 2"). (See Note 1, 2).
		T > = (T _f - 10) or T > = 250°F	MOV. Actuating push button located at least 50 feet from the potential release point and from the likely drain point which the release might travel to and outside the unit FEE (Fire-Exposed Envelope). MOV fireproofing per Company standards.

Table 5: Selection of EIBV

Note 1: If a T&I shutdown valve at the vessel or a pump suction valve is already included in the design, then those can be regarded as EIBV as well (i.e. no need for duplication) provided the applicable criteria such as access, distance and 30-minute fire resistance are met. If for any reason, such as valve size, space, congestion, ergonomics, line hydraulics or process-related, a manual EIBV cannot be installed, then specify an MOV instead (fireproofing per GPS-M2, actuating push button on site at a convenient location). **Note 2:** If MOV is specified in lieu of manual EIBV, push button shall be located outside the FEE of the two pieces of equipment being isolated (for example, the pump and the vessel).

situation where fuel continues to get added to a fire, leading to the likelihood of a small event turning into a major disaster. The main criteria in selecting the location of EIBV depend on the inventory, properties of hydrocarbon in the vessel

(operating temperature, and flash point). Table 5 above which is a part of the company's engineering standard provides a guideline to the team in establishing the requirement of an EIBV.

Gas Blow-by Scenario Prevention (Best Practice)

A gas blow-by case can occur when a liquid control valve fails fully open that results in a loss of liquid level in the vessel upstream permitting gas from the upstream high pressure vessel to blow into the downstream vessel (which in many cases is designed to handle low pressure only). The BP Grangemouth hydrocracker incident (7) is a classic case that illustrates this scenario.

The Hydrocracker Explosion and Fire at BP Oil, Grangemouth Refinery. 22nd March 1987

The investigation of the accident suggested that an air operated control valve on the High Pressure (HP) separator had been opened and closed on manual control at least three times. Liquid level in the LP separator fell and the valve was opened. This action allowed the remaining liquid in the HP separator to drain away and for high pressure gas to break through into the LP separator. As the pressure relief on the LP separator had been designed for a fire relief case, not gas breakthrough the vessel subsequently exploded.

In view of the above recognized hazard, we provide time calculations are provided for vessel volumes to operating personnel so that they can determine if human intervention can be considered as a viable layer of protection against a blow-by case scenario. Identification of time available for the column and vessel levels under various failure scenarios thus assists the operators to act positively in case of emergencies. For example, the time available from low-level alarm to gas blow-by case or pump starving case and high-level alarm to tray damage in the column or liquid carryover to flare header from the vessel gives operators a clear indication of how much time they have before the ESD system will shutdown the unit. The following illustration is an example of this best practice.

A vessel containing light hydrocarbon could have a situation of loss of level in the event of failure of control valve located at the discharge of the pump. The potential consequences of this event will be gas blow-by and possible pump damage. This could be mitigated if the operator is aware of the time required for the vessel level to go from low or low-low level to gas blow by scenario. The following discussion presents Bapco's approach in implementing corrective actions to prevent this worst case scenario.

To calculate the required relief capacity during gas

breakthrough, Bapco HAZOP teams consider the maximum vapor flow through either the main liquid control valve or its bypass, but not both. This unwritten philosophy had been applied to all relief systems in Bapco including the relatively recent Low Sulfur Diesel Production (LSDP) facilities. For safe application of this philosophy the following assumptions are needed

- Main control valve is adequately sized for its service and with good margin for control to eliminate the need for the bypass valve to be cracked open during normal operation.
- The bypass valve may be put into service only when the main control valve is out of service for repair and its isolating valves are positively shut. The bypass valve should remain positively shut at all other times.
- The transfer of liquid control duty from the main control valve to the bypass valve is carried out smoothly and under close control and supervision to maintain operating parameters.

Bapco believes that questioning this philosophy can have a widespread ramification beyond the scope of this exercise and the facilities under a HAZOP study. Potential ramifications include increased flare system requirements or installation of restriction orifices and larger control valves. Therefore the present philosophy is maintained on the basis that

- a) Undersized control valves or trims are identified and replaced in accordance with item (1) above.
- b) OPD does exercise close control and supervision during transfer of control duty from control valves to bypass valves and visa versa.
- c) Under conditions of item (1), (2) and (3) above the probability of having more than the equivalent of one valve fully open is low.
- d) Pressure in the upstream (HP) vessel somehow reaches a maximum pressure equivalent to its relief valve set pressure.

Bapco is fully aware that the current trend in some companies considers designing downstream equipment to cater for both main control valve and its bypass valve simultaneously fully open, recognizing that although the frequency is low the consequences can be extremely high. This is why HAZOP teams provide additional guidance to operators by providing estimates of 'time available to react' in case of control valve failure situations.

BLEVE Hazard Estimation (Best Practice)

BLEVE calculation for all inventory holding vessels: BLEVE

hazard calculations are carried out to ensure the facility siting and the drainage pattern during fire fighting is adequate and does not present an unacceptably high level of risk.

BLEVE is an explosion resulting from the failure of a vessel containing a liquid at a temperature significantly above its boiling point at normal atmospheric pressure, e.g. pressurized liquefied gases. The fluid in the vessel is usually a combination of liquid and vapor. Before rupture, the liquid contained is more or less in equilibrium with the saturated vapor. If the vessel ruptures, vapor is vented and the pressure in the liquid drops sharply. Upon loss of equilibrium, liquid flashes at the liquid-vapor interface, the liquid-container-wall interface, and, depending on temperature, throughout the liquid.

There are many methods for carrying out BLEVE modeling. One of these methods is the TNT Equivalent mass. This is illustrated through an example below

TNT Equivalent mass can be calculated as

$$W = 1.4 \cdot 10^4 \cdot V \cdot \left[\frac{P_1}{P_0} \right] \cdot \left[\frac{T_1}{T_0} \right] \cdot R \cdot T_1 \cdot \ln \left(\frac{P_1}{P_2} \right)$$

Where

- W = Mass of equivalent TNT (lbs).
- V = Volume of the compressed gas in the vessel (ft³)
Vessel volume (maximum) ≈ 23425 ft³ for the vessel under consideration
- P₁ = Initial pressure of compressed gas (psia)
= Burst pressure of vessel ≈ 400 + 15 = 415 psia.
- P₂ = Final pressure of expanded gas ≈ 14.7 psia.
- P₀ = Standard pressure ≈ 14.7 psia.
- T₁ = Temperature of compressed gas (°R)
- T₀ = Standard temperature ≈ 492°R
- R = Gas constant ≈ 1.987 Btu/lb-mol °R

Substituting data for the vessel under consideration in the above equation gives

$$W = 1.4 \times 10^{-6} (23425) (415/14.7) (492/T_1) (1.987 T_1) \ln(415/14.7) = 3023 \text{ lbs of TNT.}$$

The overpressure generated due to a blast of TNT is correlated to the mass of TNT and the distance from the center of explosion as follows (in SI units):

$$\log P_0 = 0.1597 (\log z)^2 - 1.7794 (\log z) + 5.6657$$

Where P₀ is the overpressure generated, Pascals; and

z , the scaled distance = $r/W^{1/3}$, where
 r = distance from the center of explosion, m
 W = mass of TNT, kg

For a location 2270 feet away,

$$z = \frac{2270 \times 0.3048}{(3023 + 2.204)^{1/3}} = 62.27$$

This gives

$$\log P_0 = 0.1597 (1.7943)^2 - 1.7794 (1.7943) + 5.6657 = 2.987$$

Therefore, $P_0 = 971$ Pascals = 0.971 kPa
 ≈ 0.14 psi

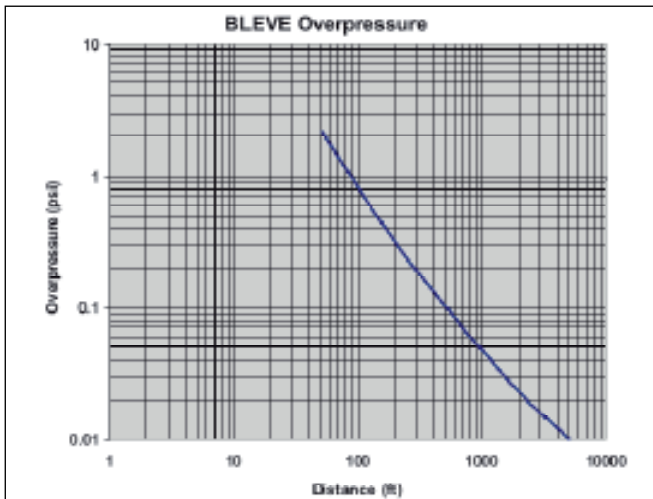


Fig 3 - BLEVE Overpressure

Boiling Liquid Expanding Vapor Explosion (BLEVE) phenomenon is more predominant in the case of Grout-lined vessels. If these vessels are exposed to external fire (jet fire impinging on vessel or pool fire underneath vessel), then there are chances of vessels BLEVE. The possible spill due to BLEVE incident is expected to drop down underneath the vessel and hence pool fire could last for some time. This indicates the requirement of well-defined grade underneath the vessels for containment of spill and fire pre-plan could be developed accordingly to mitigate the consequences of such fires.

Detailed Review of RV Data (Best Practice)

Relief valves are considered to be the last line of defense for protection of any equipment from overpressure. The HAZOP

team reviews all relief valves from its design standpoint, i.e., relieving capacity and relieving contingency, to ensure that they are in compliance with API520/521 requirements. The following are typical areas that HAZOP teams look for during the meetings

- Review RV records / documentation
- A quick review of size of RV laterals and / or flare header
- Review of bad actors, e.g. thermal RVs on salt water lines frequently jammed due to formation of salt deposit or RVs passing, fouling and damaged internals
- Review of pockets in discharge piping of RVs present likelihood of these to fill with scale and debris, which is a violation of API520.
- Review of generic problems with RVs, for example, make or model becoming obsolete.
- A critical review of maintenance of RVs: there may be cases that the preventive maintenance of some RVs can only be done during Turnaround and Inspection (T&I) due to operational reasons. This could lead to a possible violation of vendor's recommended frequency of testing.

HAZOP Software

There are numerous software packages available in the market for recording HAZOP proceedings but not all of them are user-friendly in terms of on-line scribing, interfacing with other software for editing of the proceedings as a part of team's review post meetings and exporting the worksheets for further analysis like Safety Integrity Level (SIL) reviews. Hence the selection of software is a challenge for the HAZOP Leader.

Selecting HAZOP Consultants

With the current proliferation of safety related projects, one, as a plant manager / engineer in the Hydrocarbon Processing Industries (HPI), are bound to face a decision involving selection of consultants to carry out HAZOP work in one's area. There are several options available.

In a mid- to large-size company, there often exists a corporate group, which can provide HAZOP assistance. This may be the fire prevention engineering group or the loss prevention group, or some other safety specialist group. The main advantage of using personnel from such a corporate group is that they are familiar, to some extent, with one's plant site and will therefore require less time during the initial data collection phase of a HAZOP study. With the current workload of implementation programs aimed at compliance with safety-related regulations; the most prominent of which

is the Occupational Safety and Health Administration (OSHA) 1910.119 (8), the corporate safety groups in most process industry companies are extremely busy and hence may not be able to accommodate a request for assistance in their current schedule.

The alternative is to seek external consultants. Many large, well-known engineering and construction consultants have established specialist groups providing HAZOP service. Additionally, there are many smaller companies, which deal exclusively in HAZOPs and other hazard evaluation work. The main advantage in using a large engineering company as a HAZOP consultant is that they generally possess in-house expertise in almost all branches of engineering and therefore, their HAZOP work is likely to be internally audited by their subject matter experts before it is presented to you. However, large engineering companies generally limit their HAZOP services to only those who are their clients for other engineering services as well. That is, they seldom provide HAZOP service on a stand-alone basis.

The HAZOP specialist consulting companies, on the other hand, are geared to provide HAZOP service on a stand-alone basis only. They generally have personnel who are highly trained, specifically in HAZOPs, but may not possess in-depth engineering know-how. BAPCO have carried out a detailed pre-qualification exercise and have developed an approved vendor list HAZOP consultancy work.

Conclusion

- Many companies have gained valuable HAZOP related experience and have adopted various best practices. This is a healthy trend. Frank and free exchange of such data between companies will be a dream-come-true.
- There has been a proliferation of computer software, especially for HAZOP scribing. Software available from government or quasi-government bodies will perhaps assist in establishing certain standards of performance capability and uniformity in the methods applied. Packages that can handle complete, integrated HAZOPs have also become available and are likely to grow with market demand.
- It is wrong to claim that HAZOP is a purely 'objective' methodology. Even if the large number of assumptions, estimates, technical judgments and opinions from experts using their best knowledge (and fully recorded) are considered as 'objective' input, there still remains an extremely important 'subjective' element; viz, judgment of the significance of the results by the decision-makers.
- Considerable skill is needed to carry out and then interpret the results of a HAZOP. It should be used by

those who understand the limitations of these techniques.

- HAZOP is a time-consuming and expensive exercise. The scope of a study should be tailored to the specific situations and the analysis should be limited to generating information considered essential for making a sound decision. However, before making a commitment to conduct a HAZOP study, it should be clearly understood that significant costs may be involved in implementing risk mitigation measures.
- The use of mathematics and statistical theory is unavoidable in generating many scenario logics. The onus is upon the HAZOP team leader to ensure that information presented to the decision-makers is in a format acceptable to them.
- The public's perception of a risk should be taken into account by incorporating suitable risk-aversion factors in the acceptability criteria.
- In a world moving towards increased environmental awareness, HAZOP techniques will continue to find traditional as well as novel applications. Acceptability criteria used by HAZOP teams have thus far addressed acute risk issues on the basis of people's exposure to a hazard. The teams need to take into account the environmental exposure/impact criteria that have been developed for chronic exposures. Only then can the analysis be considered complete.
- For controversial issues identified during HAZOPs, there are no shortcuts. One must carry out detailed hazard analyses or Quantitative Risk Assessment (QRA) studies to evaluate such issues. The need is to develop the capability of doing QRAs, in-house, in a fast and efficient manner. A total dependence on external consultants is not advised. Developing in-house expertise and capabilities can be difficult, especially in companies where usage is low.
- Do not be reluctant to raise some of these issues with others in your company, especially with the corporate safety group or a Process Safety Management (PSM) implementation group. Frank and open communication can pay handsome dividends.
- Central departments (such as: corporate fire and safety departments, loss prevention departments, technical services departments) have a key responsibility in evaluating safety-related investment projects, and then in updating the company's design and engineering practices and standards. Do not hesitate to get them involved in your HAZOP work.
- The need for many QRA studies arises from

recommendations made by the HAZOP teams carrying out hazard evaluation of one plant. Therefore, train one's HAZOP team leaders to make sure that the recommendations included in their study reports have all been duly discussed with the team members and that enough information is provided in the study reports to carry out subsequent evaluations by the engineering department or any QRA consultant. Computer software is available these days, which can assist in generating comprehensive HAZOP reports as well as in the follow-up activity. Additionally, retention of all HAZOP documents in a safe (though easily accessible) place will be extremely useful for any follow-up effort.

- The primary objective is to identify the hazards and then generate a quantitative assessment of those rather than promote a particular technique. Many times this primary objective can get missed, even by seasoned HAZOP experts.
- Start training some of your in-house personnel in HAZOP now. They will be the key to successful HAZOPs in your company, irrespective of whether the studies are done by them or by external consultants.
- There is still a lot of room for improvement in the versatility of the software packages currently available. Baseline standards need to be specified by government bodies or professional associations.
- Start demanding a higher quality output from one's corporate safety groups or any consultants one hire to conduct HAZOPs.
- The HAZOP methodology is an excellent tool for tapping into the experiences of your plant personnel in

identifying and evaluating the risks associated with plant operation. Hence, ensure one operators are also a part of the HAZOP effort.

- Use HAZOP as the preferred method for hazard identification. However, note that from the list of six techniques mandated by OSHA [8], selection of a particular technique should be wholly governed by the nature of the problem at hand. The emphasis has to be on the results, rather than a particular technique.
- In view of the continual changes in equipment layout, production requirements, maintenance practices and operator skills, it is essential that follow-up HAZOP studies are carried out. HAZOP needs to become a useful tool in the armory of the decision-maker rather than an externally-imposed painful process. ■



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