J. Hum. Environ. Health Promot. 2015; 1(1): 19-27

**Journal of Human, Environment, and Health Promotion**

Journal homepage: www.zums.ac.ir/jhehp


# Comparison of Risk Assessment Using HAZOP and ETBA Techniques: Case Study of a Gasoline Refinery Unit in Iran

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**A R T I C L E I N F O**

*Article history:*
Received October 21, 2015
Accepted November 19, 2015

*Article Type:*
Original Article

***Keywords:***
Oil refinery
Hazard
ETBA
HAZOP

**A B S T R A C T**

**Background:** Prevention of accidents—a crucial requirement in oil industries—involves hazard recognition, risk assessment, and corrective actions. The purpose of this study was to compare the ETBA and HAZOP techniques for risk assessment in a gasoline refinery unit.
**Methods:** In this case study, data were collected using process flow diagram, walking–talking through method, piping and instrumentation diagram, and direct observations. Worksheets for both techniques were filled on the basis of the risk assessment matrix MIL-STD-882E.
**Results:** The HAZOP method identified 44 deviations attributable to 118 causes. In addition, 11.37% of the identified hazards were associated with unacceptable risk, and 36.36%, with unfavorable risk. The ETBA method detected 10 groups of energy (24 subgroups); 33 hazards were detected, 10.62% of which were associated with unacceptable risk.
**Conclusion:** HAZOP proved to be the more powerful technique for the prediction and identification of hazards. However, ETBA detected certain hazards that were not identifiable using HAZOP. Therefore, a combination of these two methods is desirable for the assessment of hazard risk in process industries.

## 1. Introduction

The industrialization of societies leads not only to welfare and advancement but also to numerous problems and ill effects on the environment and human health, and to increased risk of accidents and safety concerns. Accidents associated with the oil industry have the potential to cause various irreparable injuries and damages. The causes for such accidents are varied, and the recognition of hazards and corresponding corrective actions enable the prediction and prevention of such incidents. The prevention of accidents necessitates the recognition of potentially hazardous agents, which may be small, big, visible, or invisible [1]. The worldwide expansion of industries has led to

**To cite:** Abbasi S, Bakhtom Sh, Ziaei M, Arghami Sh. Comparison of Risk Assessment Using HAZOP and ETBA Techniques: Case Study of a Gasoline Refinery Unit in Iran. *J Hum Environ Health Promot*. 2015; 1(1): 19-27.

a rapid increase in the instances of accidents. Examples of major industrial accidents include Bhopal chemical disaster in India (1984), Feyzin refinery in France (1966), and the explosion of liquid fuel in North Sea (1988) [2]. The increase in the number of process industries in Iran necessitates the good maintenance of purifying units and risk assessment procedures for raising safety levels. An investigation of accidents shows that primary accidents often lead to subsequent incidents; an example is the PEMEX accident, where the subsequent explosions were, at times, more dangerous than the primary fire [3].

The irreparable damage and injuries caused by accidents to personnel and equipment every year draws attention away from an investigation of the causative factors, despite the fact that these accidents are predictable and preventable through the use of risk assessment and control strategies [4].

The importance of risk assessment lies in its ability to aid decision making in choosing the best and most appropriate solutions, and is also necessary to offer conclusive proof that spending on safety solutions is money well spent. The incidence of major disasters across several industries around the world encourages accident-control measures for decreasing the intensity of any unfortunate events [5]. Several methods exist for the diagnosis of hazards and assessment of its effects, each with their own advantages and disadvantages; these include the Preliminary Hazard analysis (PHA), Failure Mode and Effects analysis (FMEA), Failure Tree analysis (FTA), Hazard and Operability Study (HAZOP), and Energy Trace and Barrier Analysis (ETBA) [6].

The multifaceted nature of workplaces renders the use of single-oriented methods such as AEA (man-oriented), FMEA (system-oriented), or HAZOP (process-oriented) unsatisfactory [7]. These techniques provide a systematic method of evaluating system design to ensure that it operates as intended, and help in the identification of process areas that are likely to be involved in the release of a hazardous chemical, and also in suggesting modifications that improve process safety. These techniques vary in sophistication and scope, and no single technique is likely to be the best under all circumstances [8].

The present study is aimed towards recognizing and assessing safety risk in a gasoline refinery unit (Merox) in Iran. This unit of the refinery industry is at high risk of potential hazards. While HAZOP is the routinely employed technique in oil industries, other methods such as ETBA are less expensive and time-consuming. The purpose of this study was to compare these two techniques for risk assessment in the Merox gasoline refinery unit.

## 2. Materials and Methods

This case study has been carried out with the aim of detecting and assessing hazard risks in an oil refinery using both HAZOP and ETBA methods. A method of risk assessment, called "what if..?", has been employed for the recognition of all potential hazard risks in the system; this method is based on posing questions such as "what will happen if..?", and finding the right answer to each of these questions. Prior to the use of this method, the system should be separated into smaller sections, and questions posed for each section [9]. The HAZOP and ETBA methods are described in detail, as follows.

HAZOP, a methodology of hazard analysis, is a qualitative, systematic, creative, and group-based method that is easy to apply, and is effective in the detection of hazards and systems operability problems through a determination of their effects. The HAZOP technique is employed worldwide for studying not only the hazards of a system, but also its operability problems by exploring the effects of any deviations from design conditions. The method requires the formation of a group [10]; in the group comprised of 7 individuals, including process, chemical, electrical, and mechanical engineers from the refinery unit, and 3 safety experts (HSE team). The HAZOP method also requires that the scope of the study be divided into certain nodes [11]. In the present study, the following parts were examined: control valve-301, gasoline entrance line (feeding line), tower-301, floater, control valve-305, caustic entrance line into the tower, and gasoline exit line at the top of the tower. The nodes included: 1) from FRC-301 to the end of gasoline entrance pipelines, 2) tower-301 and floater, 3) from control valve-305 to the caustic entrance pipelines into the tower, and 4) gasoline exit pipeline at the top of the tower. The principle of HAZOP method is that a system is safe when key operability parameters such as temperature, pressure, fluid speed, and so forth are in their natural condition. The cause and consequence of each hazard is diagnosed through the use of parameters and key words. Finally, the HAZOP worksheet prepared includes deviation in nodes, possible reasons, available barriers, possibility of hazard occurrence, the intensity of the consequence, and the level of hazard risk prior and subsequent to corrective actions.

The required data is collected through the application of process flow diagram (PFD), direct observation, and interviews. The level of hazard risk is determined using risk assessment matrix, which assigns a risk assessment code; the MIL-STD-882E matrix was employed for both HAZOP and ETBA methods [9]. ETBA, which is based on a system-wide analysis, aids in hazard detection by focusing on the existence of energy in the system and the barriers that aid in controlling the energy [12]. Preventing the transmission of unwanted energy is essential for avoiding damages and injuries, which occur upon encounter with energy that is greater than the tolerance threshold of human bodies or equipment. Observation and walking-talking through method were employed for data collection and filling the worksheet. The ETBA method necessitates knowledge of the system's potential energy. In general, 15 types of energy (68 subtypes) are detectable using the ETBA check-list[4. In the second stage, the various types of energy in the system are traced from the beginning till the end of the path through the use of PFD and piping and instrumentation diagram (P&ID).

The third stage involves the detection of barriers and obstacles that are necessary for preventing the release of unwanted energy. In the fourth stage, the targets that are vulnerable to the release of unwanted energy are determined. Finally, data is entered into the ETBA worksheet, including types of energy in the system, hazard description, targets that are potentially vulnerable to the released energy, barriers present in the path of energy, and the level of hazard risk prior and subsequent to corrective actions.

## 3. Results

Sixty types of hazards and their consequences were detected with the use of "what if..?" method, and were employed as basic information for risk assessment. The results of risk assessment through the independent use of HAZOP and ETBA methods are shown.

**HAZOP:** In general, 44 deviations and 126 causes of deviations were detected. Moreover, the analysis revealed that 11.37%, 36.36%, 29.55%, and 22.72% of the hazards were associated with unacceptable risks, undesired risks, acceptable risks subject to reconsideration, and acceptable risks, respectively. The analysis also revealed that 46.03%, 40.47%, 7.95%, and 5.55% of the causes of hazard were associated with equipment failure, failure in system functions and controlling systems, human errors, and weather conditions and natural disasters, respectively. The main causes of hazard included the following: 1) opening of bypass paths, 2) dirty condition of pump filter, 3) corrosion of fluid transmission pipeline and salver in the tower, 4) tearing of gasket, 5) electrical power outage, 6) failure of alarm system, 7) closing of control valve, 8) failure in check valve, 9) increased plant air pressure, and 10) failure of pipe welding and welded connections. Following the diagnosis of 44 deviations in various nodes, a HAZOP worksheet was filled for each of them. Table 1 shows one such worksheet.

**ETBA:** In general, 10 different types of energy and 24 energy subtypes with the potential to damage targets (men, equipment, and products) were detected, as shown (Table 2). Thirty three hazards were detected, and ETBA worksheets were filled for each of them; Table 3 shows one such worksheet. The analysis revealed that 10.52%, 27.27%, 22.72%, and 39.39% of the hazards were associated with unacceptable risks, undesired risks, acceptable risks subject to reconsideration, and acceptable risks, respectively.

The most important hazards that were detected include the following:

1. Gasoline leak resulting from corrosion in pipes, torn gasket, or loose flanges that could lead to fire accidents because of the mechanical beats of cranes or hammers, solar heat, and static electricity.
2. Corrosion of transmission pipelines, tower body, and salver because of gasoline and caustic solutions.
3. Reaction between water and spilled caustic solutions leading to the generation of explosive hydrogen gas.
4. Effects on health (dermal, ocular, and respiratory damage) resulting from exposure to gasoline and caustic solutions.
5. Electric shock resulting from contact of bare wire with the tower body.
6. Falling due to slippery surface.
7. Smashing of crane into the tower and pipelines.
8. Pipe explosion resulting from buildup of high pressure.
9. Hearing loss because of sound generated from the pump and generator.

The following main energy barriers were detected:

1. Encasing of the power transmission cable in a metallic cover.
2. Use of electrical grounding
3. Use of fuses.
4. Installation of guardrails in the stairways and landing.
5. Use of a reticulated metallic guard.
6. Installation of a pressure indicator.
7. Application of anti-spark rails in the crane.
8. Detection of gas using a gas detector.
9. Providing employees with ear muffs.
10. Determination of the pipeline thickness using gamma rays.
11. Providing exterior insulation.
12. Application of the caustic solution as fuel after completion of its primary use.

13. Construction of the refinery unit at a safe site.

## 4. Discussion and conclusion

**HAZOP:** In this study, 44 deviations resulting from 118 causes were detected; the most important (46.03%) cause pertained to equipment failure, while human errors did not appear to play an important role. These results are in conflict with previous studies, where equipment failure (43.5%) and human error (35.8%) [12], or just human error (31.35%) [6], were implicated as the main

**Table1:** HAZOP Worksheet.

**Operational Node Description: Desulphurization Process at 301 Tower**

Unit component: FRC 301, L.S.R.G, Vessel 301, FRC 305, L.S.R.G Caustic, Gasoline output lines, Floater, Caustic check valve, Feed check valve, Safety valve top vessel.

| No | Guide Word | Element | Deviation | Possible causes | Consequences | Safeguards | Risk Level | Action Required | Risk Level |
|---|---|---|---|---|---|---|---|---|---|
| **1** | Increase | Flow | Feed flow increase | -by pass trace entered<br>- Pressure drop in tower 301<br>- Operator don't close the By pass | - Corrosion is cause increasing velocity<br>- Reduce Desulphurization Adverse effect on product quality full tower salver<br>-Damage to equipment | -Installation S.V | A3 | -Using pressure control system the tower 301<br>-Inspection continue By pass | C4 |
| **2** | None | Flow | None fluid feed | -Fault pump mechanical part &transmission<br>- power outage<br>- dirty pump refine<br>-Closed FRC(301) | -outage fluid feed<br>-Oxygen increase<br>-Fire<br>-Damage to equipment & people<br>-Imposing costs | -Operational instruction should be done<br>-Emergence power Installation FRC<br>-Installation of fire extinguisher | B2 | -Writing & regular program for inspection of Pump & FRC<br>-Using method maintains of device<br>-Use methods Maintenance of Equipment<br>- Coordination with plants, water, electricity, steam | D3 |

Causes of hazard. HAZOP analysis showed that training, equipment design changes, preventive maintenance, material compatibilities, and correct operating procedures aid in the prevention of inadvertent releases [13]. The results of these studies show that different hazards could be detected using the HAZOP method depending on the process style, and provide an explanation for why the same result was not obtained in the present study despite the use of the same method for the same process.

**ETBA**: The most important corrective actions identified in the present study were associated with improvement of equipment, in contrast to another study [6], where the use of correct operating methods and prevention of human errors were shown to be important for hazard control. In order to achieve similar results in comparable industries using the HAZOP and ETBA methods, these 2 methods could be employed in a complementary manner, particularly with respect to the oil industry. This approach would facilitate the

**Table 2:** Energy Sources Recognized Using ETBA Checklist.

| | |
|---|---|
| **1- Electric** | **6- Moisture/Humidity** |
| 1-1- AC/DC flows | 6-1- Humidity |
| 1-2- Control voltages/currents | **7- Chemical energy (acute and chronic)** |
| 1-3- Wire connection without insulation | 7-1- Corrosion |
| **2- Mass/Gravity/Height (m/g/h)** | 7-2- Lubricants/solvent/solution |
| 2-1- Falls and trips | 7-3- Oxidizing/combustible/pyrophoric |
| 2-2- Falling/dropping objects | 7-4- Waste/mixture(air/land/water) |
| 2-3- Suspended objects | **8- Terrestrial** |
| **3- Pressure/Volume/Kinetic Displacement (P/V/KD)** | 8-1- Earthquake |
| 3-1- Rupture/explosion due to increased pressure | 8-2- Glacial |
| 3-2- Liquid spillage/increase and decrease in liquid level/buoyancy | **9- Atmospheric** |
| | 9-1- Rain (warm/cold/freezing) |
| **4- Linear kinetics** | 9-2- Snow/hail/sleet |
| 4-1- Vehicular movement/moving equipment | 9-3- Electrostasis/lightning |
| **5- Noise/Vibration** | 9-4- Dust/aerosols/powders |
| 5-1- Noise | 9-5- Sunshine/solar |
| 5-2- Vibration | **10- Mechanical energy** |
| | 10- Hammering in refinery unit |

Detection of greater number of hazards with increased precision.

The use of ETBA method in process industries has shown that 68% of the potential hazards are associated with high risk, the most important being scaffolding and excavation [14]. In the Abadan oil refinery, 236 hazards were detected, of which 37.5% were associated with extreme risk; the proper use of machinery through good instructions, and repair and maintenance of the equipment were found to be the best ways of hazard control [15]. Were detected, of which 108 were associated with unacceptable risk [16].

These studies portray the expanded application of the ETBA method in process industries. Moreover, the application of the HAZOP method serves as a beneficial guideline for the observation of hazards and implementation of risk control procedures in order to achieve a safe system [17]. The chief advantage of ETBA is the ease of the method compared to HAZOP. ETBA has acceptable sensitivity for hazard detection and risk assessment. While HAZOP is more appropriate compared to ETBA for the prediction and detection of hazards, a combination of both the methods is desirable, as certain hazards are detectable only by the ETBA method. Finally, the suggestions for corrective actions that result in decreased level of hazard risk include:

1) Maintenance and repair of the equipment, including FRC, check valves, pumps, safety valves, and floaters.

2) Use of pressure control system in tower-301.

3) Installation of PC (regulator) in feed transmission pipelines.

4) Application of cathode protectors or injection of anticorrosion agents in the tower and pipelines.

5) Installation of gas detectors for the detection of hydrogen gas.

6) Use of safety alarms for preventing accidents from the crushing of vehicles and pipelines.

7) Installation of ambulant guard on control valves for protection from tearing.

8) Educational programs of standard structure for all the operators.

**Table 3:** ETBA Worksheet: Entrance Pipelines to Tower-301.

| Row | Type of Energy | Description of Risk | Potential Targets | Protection against Flow of Energy | Risk Level | Proposed Regulatory Actions | Risk Level |
|---|---|---|---|---|---|---|---|
| **1** | Corrosive (Caustic) | Chemical spills and fires, accumulation of flammable liquids and gases | People, equipment, and product | - Thickness estimation using gamma rays<br>- External insulation of the building<br>- Repairs (maintenance) | 3C | - Application of cathode protectors on the right external surface of the pipe<br>- Injection of anti-corrosion materials<br>- Replacement of tubes if needed<br>- Use of personal protective equipment, especially goggles and masks | 4D |
| **2** | Oxidizing/combustible (gasoline) | Respiratory tract irritation and difficulty breathing, severe burns in eye and skin | People | - Restricted to use of personal protective equipment<br>- Instructions on emergency shower and eye wash<br>- Use of appropriate clothing and gloves | 2C | - Educating people about the safe handling and dangers of working with caustic solutions<br>- Solvent-resistant gloves, oil-resistant material<br>- Regular use of personal protective equipment, especially goggles and masks<br>- People who regularly use the system need to encourage the use of personal protective equipment<br>- Educating people to maintain cleanliness of personal protective equipment | 4D |

In conclusion, the HAZOP method places more emphasis on industrial processes than the ETBA method, but is time-consuming. On the other hand, ETBA is easier to perform than HAZOP, requires lesser time, and unlike HAZOP, recognizes unwanted release of free energy with the potential to cause accidents. In general, a combination of these two methods is appropriate for the precise detection of hazards in complex industrial systems, particularly chemical process industries.

- There are various methods of hazard detection that vary in sophistication and scope, and have their own advantages and disadvantages; no single method is always suitable in all circumstances.
- The HAZOP method places more emphasis on industrial processes than the ETBA method, but is more time-consuming.
- The ETBA method is easier to perform, and unlike HAZOP,

recognizes unwanted release of free energy that can cause an accident.
- In general, the concurrent use of multiple methods is desirable for hazard detection in complex industrial systems.

## Conflicts of Interest

None declared.


## Acknowledgements

The authors are grateful to the Zanjan University of Medical Sciences, Zanjan, Iran, for financial support.


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