BILINGUAL PUBLISHING CO.
Pioneer of Global Academics Since 1984

Non-Metallic Material Science
https://ojs.bilpublishing.com/index.php/nmms

ARTICLE

Integrated Hazard Identification (IHI): A Quick Accident Analysis and Quantification Method for Practitioners

Muhammad Imran Rashid[1*] **Muhammad Athar**[2,3] **Izzat Iqbal Cheema**[1] **Emad Benhelal**[4]

1. Department of Chemical, Polymer and Composite Materials Engineering, University of Engineering and Technology, Lahore (New Campus), 39021, Pakistan
2. Centre for Advanced Process Safety (CAPS), Chemical Engineering Department, Universiti Tecknologi PETRONAS, 32610, Bandar Seri Iskandar, Perak Darul Ridzuan, Malaysia
3. Department of Chemical Engineering, Khwaja Fareed University of Engineering and Information Technology (KFUEIT), Abu Dhabi Road, Rahim Yar Khan, 64200, Pakistan
4. Discipline of Chemical Engineering, The University of Newcastle, Callaghan NSW 2308, Australia

ARTICLE INFO

Article history
Received: 17 September 2021
Accepted: 21 October 2021
Published Online: 31 October 2021

Keywords:
Integrated hazard identification
HAZOP
What-if
Risk assessment
Risk matrix

ABSTRACT

There are many techniques for hazard identification and are divided into shortcut, standard and advanced techniques. Among these, HAZOP and What-If techniques are mostly engaged by practitioners in the chemical process industry. Both of these have certain advantages and limitations, i.e., HAZOP is structured, and what-if covers broad range of scenarios. There is no hazard identification method, which can cover a broad range of scenarios and is structured in nature. For this purpose, a new technique namely integrated hazard identification (IHI) is proposed in this article that integrates HAZOP and What-If. The methodology is demonstrated via hazard identification study of urea synthesis section. Risk ranking is used to sort out the worst-case scenario. This worst-case scenario is further studied in detail for quantification that is performed using the ALOHA software. This quantification has assisted to detect ammonia concentrations in nearby control room and surroundings for worst-case scenario. It is revealed that if ammonia pump is not stopped within 10 minutes, concentration inside and outside the control room may reach to 384 ppm and 2630 ppm, compared to 1100 ppm (AEGL-3). Thus the proposed method would be easy, time saving and covers more details and would be handy for practicing engineers working in different chemical process industries.

1. Introduction

A safe work environment protects employees from unwanted scenarios and increases their determination, which would ultimately lead to enhancing productivity, efficiency and overall profit for an organization. There are many factors which compels for increased production rates namely population growth, changing demands and

---

**Corresponding Author:*
Muhammad Imran Rashid,
Department of Chemical, Polymer and Composite Materials Engineering, University of Engineering and Technology, Lahore (New Campus), 39021, Pakistan;
Email: imranrashid@uet.edu.pk

DOI: https://doi.org/10.30564/nmms.v3i2.3730

increased competition among competitors which have increased both the complexity of chemical processes and resources thus disturbing the balance of resources. For these reasons, hazardous chemicals storage, transportation and handling have raised many safety concerns. For instance, on April 17, 2013, there was a significant explosion at a fertilizer warehouse that killed 15 people including 12 emergency responders at West Fertilizer Company in West, Texas, USA [1]. Likewise, there are many other accidents such as Coffeyville Fertilizer Plant high-pressure Urea Ammonium Nitrate (UAN) vessel rupture in October 2010 [2], Port Neal Fertilizer plant explosion in December 1994 [3], Toulouse Fertilizer complex accident in September 2001 [4] and Texas City Disaster in April 1947 [4]. As all these accidents have been reported in fertilizers sectors, therefore, special attention seems necessary to be given to fertilizer plants for safe and uninterrupted operation.

Risk science is a key to enhance safety culture [5,6]. The post-accident investigation was analyzed by U.S. Chemical Safety and Hazard Investigation Board (CSB) for 48 recorded accident cases happened between 1998-2008 indicating that poorly conducted process hazard analysis/risk assessments were common in these cases [7]. An analysis of 400 operational incidents was reported by Rashid et al. and concluded that process hazard analysis (PHA) has 16% share as a root cause or contributing factor in the considered incidents [8]. PHA role in enhancing operational discipline is discussed in another study [9]. In another work, Rashid et al. has discussed significance of PHA, complications in performing PHA and hazardous scenarios which needs to be considered for conducting PHA [10]. Risk assessment is a method with a broader scope which assists in identifying and quantifying the hazards and is comprised of various steps [11]. Process hazard analysis and safety risk assessment are fundamentally different from each other as well as other activities of chemical engineering. For better understanding and implementation of these aforementioned techniques, a combination of art and science principles is highly solicited [12]. At present, various techniques, such as, Checklist Analysis, What-If-Analysis, What-If/Checklist Analysis, Hazard and Operability (HAZOP) Analysis, Failure Mode and Effects Analysis (FMEA), and Fault Tree Analysis (FTA) have been considered and applied for process hazard analysis/ safety risk assessment studies [13-15].

The techniques discussed above are generically classified among two categories namely qualitative and quantitative techniques. A detailed information regarding the classification of risk assessment techniques is available in the literature [16]. Qualitative hazard and operability studies have been integrated with risk potential matrix and is considered as the most popular method being practiced in chemical process industry (CPI). This study is based on experience of the experts team with various backgrounds, who evaluate the risks associated for facilities and activities [12]. There are many reasons which render quantitative risk analysis as a preferred choice. These include: 1) absence of quality failure rate data, 2) inadequate and inappropriate mathematical modeling tools to envisage the occurrence of events and subsequent consequences in any incident, 3) limitation of time for thorough and comprehensive quantification, 4) the results in quantitative risk analysis cannot be vouched for completeness and reproducibility. Despite of these mentioned limitations, a strong qualitative safety/risk analysis requires almost the same amount of effort in terms of work and time. Table 1 provides the fundamental aspects which needs to be considered for a well-structured safety/risk analysis.

This article provides an easy qualitative and quantitative risk assessment for practicing engineers. In this paper, a methodology for risk assessment based on HAZOP integrated with What-If analysis is proposed and is named as integrated hazard identification (IHI). The methodology is coupled with a case study of urea synthesis section of Urea fertilizer plant. It is proposed in this work, that PHA experts may assign risk scores for risk potential matrix without using risk evaluation matrix, relying on their operational experience which may ease the job for practicing engineers.

Table 1. Fundamental aspects of safety/risk analysis

No.	Fundamental Aspects	Methods/ Required Documents
1	Plant & process information for safety/risk analysis	Plant documentation, commercial data bases and field experiments etc.
2	Hazard identification	Past accident analysis, HAZOP and PHA etc.
3	Frequency estimation	Analysis of failure statistics, fault tree analysis (FTA) and event tree analysis (ETA) etc.
4	Consequence analysis	Disturbance simulation, ETA, effect estimation models, damage estimation models and Past accident analysis (PAA)
5	Risk presentation	Risk contours, F-N curves and risk potential matrix
6	Acceptable risk criteria	Standards, company and/or state policies
7	Optimization	Cost benefit analysis and multi-objective optimization
8	Completeness	FMEA, check lists and detailed disturbance simulation
9	Quality	Experts & use of computer supported tools

2. Available Hazard Identification Techniques

Over the years, many techniques have been developed for hazard identification. These techniques are largely applied for evaluating the safety/risk of chemical processes in various stages of process lifecycle. However, the future emphasis is on the design of processes plants, so these can be inherently safer in nature thus avoiding the hazards [17]. In the chemical process industry tools which are typically practiced for hazard identification are safety reviews, checklists, indices, preliminary hazard analysis, what-If analysis, hazard and operability (HAZOP) Studies, failure mode and effect analysis (FMEA), fault tree analysis (FTA), event tree analysis (ETA), cost consequence analysis (CCA) and human reliability analysis. These techniques are further categorized into three groups, as depicted in Figure 1.

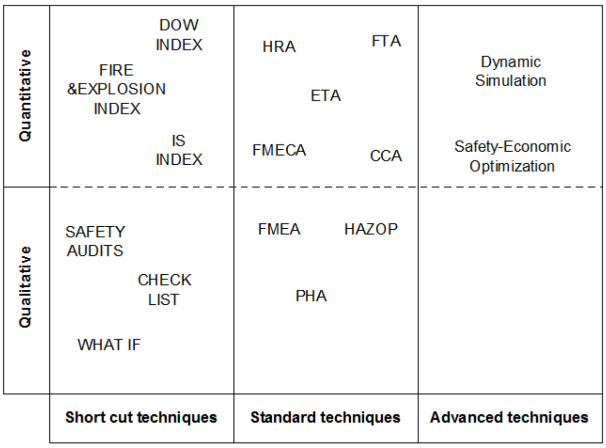

Figure 1. Categories of hazard identification techniques

29 CFR 1910.119 OSHA's regulation requires the use of what-If, checklists, HAZOP, FMEA or any other appropriate equivalent technique for hazard identification. Among these, HAZOP, was developed by imperial chemical industries (ICI) in 1963 and is considered as the widely accepted technique for hazard identification and is being widely used. A HAZOP study follows a strict regimen in which deviations of a process from its intended design are identified. The procedure is to analyze the process and the engineering design for new and/or already existing plants in a systematic, skillful and strict manner. The intent is to determine the possible malfunctioning of individual parts of the equipment and subsequently the overall process system. The what-if technique, as the name suggests, is based on asking a set of successive questions to identify hazards. This method is simple and convenient however it is reported to be inferior to HAZOP and FTA [14]. The reason is that these are well structured methods and operability problems and hazards associated with process deviations of design intent can be easily identified. However, HAZOP does not cover the weaknesses in the process layout and usage of wrong construction materials, as well as hazards which may occur due to equipment failure [14,18]. Contrary to this, what-if technique challenges the design and covers a broad range of hazards, such as. electricity, wrong material usage, line leakages, tank overflows, contaminations, pump seal leakages, moving machinery, pressurized fluids, acids usage, hot surfaces and falling materials. In order to avoid the limitations, an integrated what-If/HAZOP technique is proposed in this work. It capitalizes on the strengths and compensates individual shortcomings of HAZOP and What-If techniques. For instance, cause of process parameter deviation is studied in the HAZOP, however, it is not included in the typical worksheet of what-if analysis. Standard worksheets of what-if, HAZOP and proposed integrated what-if/HAZOP technique named as integrated hazard identification (IHI) are presented in Figure 2. In integrated What-If/HAZOP analysis, both causes and risk ranking are studied for what-If raised questions or parameter deviations.

Figure 2. Worksheet for integrated what-If/HAZOP analysis

3. Methodology

The important steps of the proposed methodology, integrated hazard identification (IHI), used for the risk potential assessment of the chemical process industry are shown in Figure 3 and are described as under:

(1) First of all, the process system is identified and described such that information regarding the process, its operating and design conditions, chemicals and specifically hazardous one and its impacts on the environment are known. This is typically available at the process plants and process safety information (PSI) element of process safety management (PSM) ensures that this information is made available at all times to all the relevant staff.

(2) A plant specific numerical rating based on the past history of the same plant or similar plants needs to be developed by keeping in view the plant specific information. However, for presenting this research, we have developed the numerical rating both for consequences and failure rate by using a fertilizer complex data located in Pakistan. These rating values with description are available in Table 2. Based on above mentioned plant specific scenarios, a numerical rating of various consequence classes (C) is provided in Table 2, ranging from C-1 to C-4. Here, C1 denotes lowest while C-4 is meant for severe consequences.

Likewise, using the past historical data of that plant, failure statistical analysis is conducted using failure data of various components. This is demonstrated via numerical rating of frequency class ranging from F-1 to F-4, while the lowest and highest rating is in similar fashion to consequence rating and is described in Table 2.

(3) Identification of all possible hazards in the chemical process needs to be carried out for a hybrid method, i.e., combo of already developed methods namely HAZOP and What-If is proposed. For this purpose, the plant is divided into sections such that an intensive analysis can be carried out via shortcut consequence analysis.

(4) Hazard identification results may be then analyzed using the developed risk matrix, where the scenarios are ranked to identify the risk potential categories. Ranking of these potential categories can lead to recognizing the worst-case scenario which is further analyzed in detail.

(5) The risk assessment is carried out for the worst-case scenario and can be represented using risk contours with the aid of ALOHA software. This risk estimation and assessment can be helpful to improve designs for process plants and developing risk control measures for existing process plants. For an existing process plant, the remedial actions are decided by the operation staff having required expertise to foresee the impacts of these remedial actions such that no other problem is caused.

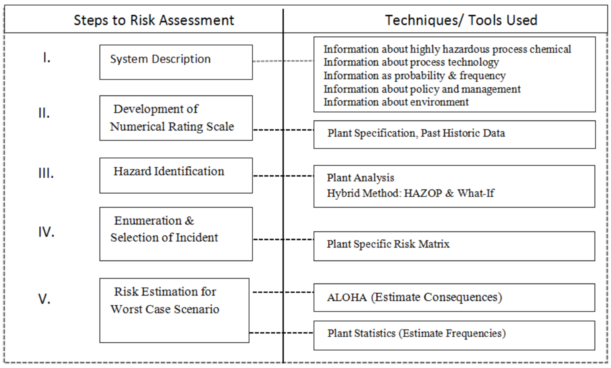

Figure 3. Methodological framework of integrated hazard identification (IHI) for quick assessment

Table 2. Numerical rating of different individual risk

Consequence	C-1	C-2	C-3	C-4
Type of Event	Extremely Unsevere	Very Unsevere	Unsevere	Severe
Public/ employee safety and health	No injury or health effects	Minor injury or reversible health effects	Injury or moderate health effects	Death or irreversible health effects
Frequency	F-1	F-2	F-3	F-4
Category	Extremely unlikely	Very unlikely	Unlikely	Likely
Description	Not expected to occur	Not expected to occur but not incredible	Can occur in one of similar plants	May occur once in plant life
Frequency/ Year	$< 10^{-4}$	10^{-3} to 10^{-4}	10^{-2} to 10^{-3}	$> 10^{-2}$

Table 3. Risk evaluation matrix

F-4	IV	II	I	I
F-3	IV	III	II	I
F-2	IV	IV	III	II
F-1	IV	IV	IV	III
	C-1	C-2	C-3	C-4

Frequency Category

→Increasing Likelihood→

→Increasing Severity

→Consequence Category

4. Results & Discussion

The Urea synthesis section of a real fertilizer complex is considered as a case study for elaborating the proposed integrated hazard identification (IHI) methodology. Firstly, a brief information regarding the process is provided followed by risk assessment results with our method.

4.1 Geographical Location of Plant

The data used in this study are taken from one of the largest urea fertilizer manufacturers in Pakistan, which is able to produce 500,000 metric tons per annum. The plant site is 205 meters above sea level, the climate of this area is semi-arid type. Geographically the plant is located in extreme climate region. The summer season lasts from April to October during which the temperature remains between 30 °C and 45 °C. On the other side, the winter season is from November to March and the lowest temperature is below 0 °C. The dust storms occur occasionally during the hot season, i.e., between June and August. Monsoon season alternates with oppressive weather. Average wind blows from east to west direction with speed of 4 m/s. The average rainfall per year is 500 mm noted. The mean minimum and maximum humidity during winter season stays between 37% and 84%. The fertilizer complex facility layout is shown in Figure 4, where the urea plant is highlighted and the synthesis section is part of this urea plant.

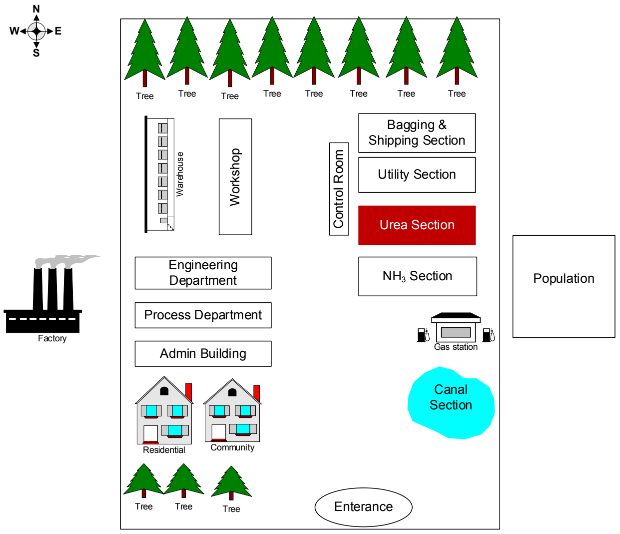

Figure 4. Fertilizer facility layout

4.2 Process Description for Urea Production

Overall urea process is divided into six sections named as below:

- synthesis
- high pressure decomposition and absorption
- low pressure decomposition and absorption
- recovery
- vacuum concentration
- finishing and prilling

Among these sections, this study has focused on the risk assessment of urea synthesis section. A simplified process flow diagram of urea synthesis section is provided below in Figure 4. The major chemicals involved in this section are urea, ammonium carbamate, ammonia and carbon dioxide and the associated lines are demonstrated in different colors for easy understanding of readers. For detail study of urea synthesis section and manufacturing process, please read our previous article [19].

A detailed investigation has been carried out by studying the urea synthesis section logbooks, data sheets, safety inspection reports, incident and near miss investigation reports for the last 10 years. From this investigation, following major operational and safety problems have been identified:

- once the plant is shutdown, the atmospheric temperature conditions might cause an increase in pressure of ammonia feed tank
- ammonia turbine leakage from oil cup and bearing housing
- frequent ammonia pump mechanical seal leakage during both initial startup and normal running operation
- ammonia counter stop working due to icing on it
- an abrupt increase in ammonia strainers' pressure drops ΔP
- ammonia feed pump vapor lock if the speed of the pump is reduced
- ammonia feed pump speed indicator control valve stuck during operation
- one plunger of ammonia feed pump out of five plungers stops moving due to broken cross-head
- frequent leakage of ammonia feed pump plunger packing
- ammonium carbamate recycle pump discharge block valve opens automatically
- leakage of ammonium carbamate recycle pump working barrel
- leakage from ammonium carbamate recycle pump discharge 'O' rings
- in ammonium carbamate recycle pump, moisture is present in the crankcase oil
- when ammonium carbamate recycle pump is stopped, suction non-return valve (NRV) demonstrated leakage
- rainwater enters into lube oil's low-pressure switch and as a result it is unwillingly actuated
- leakage in CO_2 compressor knock out drum (KOD) top patch plate
- increase in CO_2 compressor KOD level
- CO_2 compressor capacity pockets becomes loose
- CO_2 compressor inter-stage cooler tube leakage
- CO_2 compressor stages tempered water circulation lost due to pump tripping
- during the phase of plant shut down, when the urea reactor is isolated, malfunctioning of pressure indicator with ammonia pump stoppage is observed
- when there is an emergency situation, urea reactors are operated occasionally on slightly less load, i.e. lower ammonia intake
- urea reactor gasket and inside coil leakages
- after isolation, urea reactors pressure becomes abruptly high

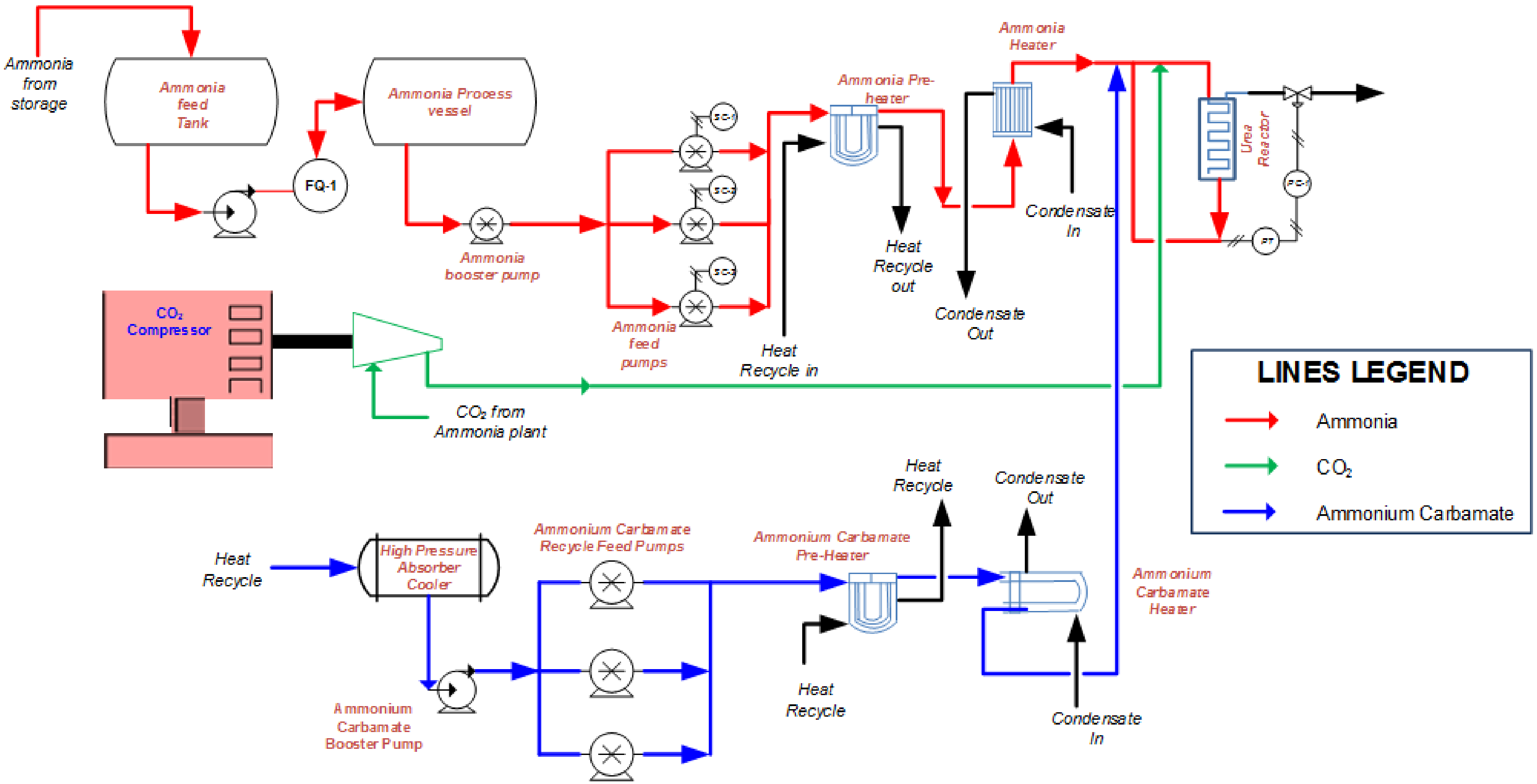

Figure 4. Process flow diagram of urea synthesis section

4.3 Hazards Identification and Risk Potential Matrix

The integrated hazard identification (IHI) combining HAZOP and What-If is applied to identify the hazards and associated risk of urea synthesis section. The process is divided into four manageable sections and for each section important nodes are identified for performing the IHI. Detailed worksheet for conducted IHI of urea synthesis section is given in Table 4. For the first scenario, in case of excessive mechanical seal leakage of ammonia supply pump (P-1 A/B), one possible cause of this leakage is the dirty material in the ammonia. Another reason is the blockage of flushing line strainers due to oil present in the ammonia. On the other side, as a consequence of this leakage, there would be an excessive release of ammonia, which is harmful for humans working in the surrounding. The values assigned to severity and likelihood are entirely decided based on the plant historical data, i.e., plant daily log sheets, shift reports and down time records of the same plant and other similar facilities. Both the severity and likelihood are assigned values as C3 and F4 respectively, the estimated Risk Ranking (RR) is identified to be I. For this issue, in the list of existing protections, we have weir at outlet line of T-1 (ammonia feed tank) and draining facility of oil from T-1 to avoid strainers blockage. Additionally, in mechanical seal flushing line, strainers are available and pump isolation can be made to deal with emergency situations. Likewise, all deviations for the nodes identified for urea synthesis section are studied and the summary is provided in Table 4. The associated risk is ranked from category I to IV (high to low) and the risk ranking for all deviations mentioned in Table 4 are shown in Table 5 which is in accordance to the severity and likelihood values defined in this work. Risk potential matrix for all the identified deviations, i.e., twenty-one in count, is prepared and shown in Table 5 and is prepared by engaging the criterion already mentioned in Table 3. These risk scores values have also been mentioned for each deviation in Table 4. Table 5 is the representation of all the deviations or hazards available in urea synthesis section according to the relevant risk category. Practitioners may use it without using any kind of risk evaluation matrix, if they have sufficient operational experience. Furthermore, the practitioners in any industry may modify the risk matrix according to their own requirement or conditions. Management and community may also use this risk matrix for accessing, evaluating the risks such that they may contribute their role in mitigating associated risks and hazards. This tool may enhance the management judgment and decision making. It may assist operational and maintenance staff to take extra precautions for certain deviation, in case that identified deviation, highlighted via the risk potential matrix, happens. Among the identified deviations, a worst-case scenario, namely ammonia pump plunger flown away mentioned as serial number 6 in Table 4, is selected for further studies which is provided in the next subsection. A list of incidents and injuries which have occurred in urea synthesis section are mentioned in Table 6 just for sharing the experience with fellow researchers and practitioners.

4.4 Detailed Analysis and Accident Quantification

The incident of ammonia pump, one out of five plunger release has happened in XYZ fertilizer during plant installation. This issue is considered as the worst-case scenario as in this case, ammonia had been released in enormous amount. To study the outcome of severeness by leakage of excessive amount of ammonia, the scenario was modeled by using ALOHA (Areal Locations of Hazardous Atmospheres) software, as it is easily available software and can be widely used by practitioners for quick detailed assessment. The modelling details are as mentioned; gaussian model for dispersion, which occurs in air. The quantity of ammonia released was 150 gpm and the release is pertained for 10 minutes. Building air exchanges per hour was considered as 0.95, for unsheltered single storied, and wind speed of 4 m/s from east to west direction with 50% relative humidity was applied based on the studied plant information. No inversion height was considered for this model, source and fixed air temperatures were 38 °C and 41 °C respectively. When the simulation was run, ALOHA displayed a threat zone plot, which showed one or more areas where toxicity may exceed the Levels of Concern (LOCs) and can be translated as a threat to all entities namely environment, people and property. Three LOCs have been considered, and ALOHA is able to display all three threat zones, highlighted by red, orange and yellow colors. Acute Exposure Guideline Levels (AEGL) were engaged to represent three zones in red, orange and yellow colors, respectively and named as AEGL-3, AEGL-2 and AEGL-1. These exposures are considered for 60 minutes duration. The threat zone indicated by ALOHA for above-mentioned worst-case scenario of plunger removal is depicted in Figure 5.

Table 4. Integrated hazard identification (IHI) of urea synthesis section

Plant: XYZ **Equipment:** ABC	**Process:** Urea synthesis section **Function:** Transfer of ammonia, carbon dioxide and recycle ammonium carbamate to urea reactors **Operating conditions:** $T_{opt} = 283$ °F, $P_{opt} = 3200$ psig	**Document:** **Page No :** 1

Sr. No.	**Equipment No.**	**What If/ Parameter Deviation**	**Causes**	**Consequences**	**Existing Protections**	**Risk Score**	**Recommended Actions**
1	P-1A/B	Excessive mechanical seal leakage	- Weir at outlet line T-1 - Draining of oil from T-1 - Fire water available - Strainer in flushing water line - Pump isolation is possible	- Dirty material in ammonia - Flushing line strainers blockage due to oil	Excessive ammonia leakage may cause fatal human injury	I	- Before starting clean strainer - Weir inspection after two years - Oil removal system at inlet line of T-1 - Before starting P-1 give settling time in T-1 - Stop Option at Control room panel
2	P-1A/B	Pump trips during operation	- Breaker fault - Overload tripping - Power failure	- T-2, level will decrease - P-2AB may vapor lock	Standby pump is present	IV	Breaker/motor schedule preventive maintenance to be done
3	P-1A/B	Pump discharge pressure does not increase on starting	- Pump impeller damage - Suction valve close or partially open - Suction strainer choke - Pump vapor lock	Level of tank will disturb	- Standby pump is present - Priming line available	IV	None
4	T-1	High temperature	- Ammonia stays in tank for long time - P-1AB on close circulation for long time	High pressure. Stresses in metal	Provision of fresh ammonia from TK-601 & ammonia plant side	IV	Provide a pipeline from T-1 to TK-601
5	T-1	High Pressure	- High temperature - Condenser depressurizing - P-1AB on close circulation for long time	-Leakage may start at any point -Restrict the ammonia inlet flow	- PCV (pressure control valve) - PSVs - Vent valve	IV	Provide a pipeline from T-1 to TK-601
6	P-3ABC/P-5 ABC	Plunger flown away from pump stuffing box	Broken bolts of plunger yoke	NH_3 leakage due to plunger may flown away can cause human injuries like - Eyes & skin irritation - Chemical burn - Breathing difficulties like suffocation	- Daily preventive maintenance - Two hourly basis operator readings - Tripping from control room - PPEs - S.C.B.A - MSDS available in C/R - Supplied air masks	I	Schedule maintenance is essential
7	P-3 ABC/P-5 ABC	Plunger's Packing leakage	-Loose packing's -Packing water is not on	NH_3 leakage can cause human injuries like - Eyes & skin irritation - Frost bites - Breathing difficulties like suffocation	- Tripping from control room - PPEs - MSDS available in C/R - Extra safety equipment like acid proof suit in C/R	IV	- Keep pumps packing water on if pump is primed - Replace packing on regular intervals
8	P-3 ABC/ P-5ABC	PSV leakage from notch nut	PSV seat leakage	NH_3 leakage can cause human injuries like - Eyes & skin irritation - Frost bites - Breathing difficulties like suffocation	- Tripping from control room - PPEs - MSDS available in C/R - Extra safety equipment like acid proof suit in C/R	II	- Annually calibrate the PSVs - Replace PSV if and when seat leakage of PSV detected

9	P-3 ABC	Suction and discharge bottles leakage	Pitting of welding joints	- NH_3 leakage can cause human injuries like - Eyes & skin irritation - Frost bites - Breathing difficulties like suffocation	- Tripping from control room - PPEs - S.C.B.A - MSDS available in C/R - Extra safety equipment like acid proof suit in C/R	III	Annually ultrasonic flaw test of welding joints is required
10	E-2 AB	Tube leakage	- Erosion - High temperature - Aging	NH3 due to tube leakage can cause human - Breathing difficulties like suffocation - Pollution	- Supplied air masks - MSDS available in C/R	II	Automatic closing of TIC-2/TIC-4 with tripping of Motoyama valves
11	V-1 / V-2	Reactor coil leakage	- Hot spot formation - Corrosion	Conversion in reactor will decrease	Temperature control on carbamate heaters	IV	Reactor coil to be inspected in shut down
12	P-5 ABC	Pump tripped	PSLL (Lube oil low low pressure)	- Shaft driven pump not making proper pressure due to low speed of pump and auxiliary not start b/c its switch was not on auto - Oil filter choked - Less crankcase oil level - Working barrel of pump leak - Short circuiting of PSLL switch due to rainwater intake	- Two hourly basis operator readings - Daily preventive maintenance of pump - Switches conduits are covered	IV	None
13	P-5 ABC	Pump stop while its motor is running	Instrument air failure	- E-3 level will increase - Reactors temperature will increase	Spare pump available	IV	None
14	E-4 A/B	Tube leaks	Erosion Corrosion due to high concentration of Carbamate	- E-3 level increases - Carbamate pumps speed increases - Carbamate temperature (E-5 A/B) increases - Rx. A/B Bottom/Top temperature increases	- LT-2711 - SC-1/2/3 - TIC-1 - TIC-3	IV	- Inspection of tubes should be done in T/A - Detailed study should be carried out due to tube leakage
15	C-1A/B	1st K.O.D. level increases	Auto drainers not working	- Moisture carries over to stage - Mechanical damage	- LSH (level switch high) - LSHH (level switch high) and tripping of compressor - Preventive maintenance - Bypass valve - LG	IV	None
16	C-1A/B	CO_2 suction line very low pressure	Ammonia unit carbon dioxide absorber problem	Formation of vacuum	- PSL, PSLL - Vacuum breaker	IV	None
17	C-1A/B	If high condensate along with CO_2	After ammonia unit absorber KODs high level	Damage the stages	- LSH, LSHH - Steam tracing at suction bottle	IV	None
18	C-1A/B	CO_2 discharge line PSHH not operated	Instrument fault	Can damage discharge line	- PSV - PIC-69/70	IV	None
19	C-1A/B	PCV-20/29 control valve open	Instrument air failure	- CO_2 flow to RX A/B decrease RX A/B - E-3 level decreases temperature decreases	Isolating valve	IV	None

20	C-1A/B	4th & 5th stages excessive packing leakage	- Loss of lubrication - Loss of C.W. - Packing damaged	- CO_2 flow to RX A/B decrease - RX A/B temperature decreases - Production loss.	Plant water provision is also provided	II	Packing should be inspected in annual turn around
21	C-1A/B	Tempered water circulation pump (P-30 A or B) trip	- Bearing damage - Coupling damage	Less circulation of tempered water	PSL @35# will start the stand-by pump	IV	- Provide low pressure alarm at DCS - Schedule checking of auto-start switch

Table 5. Risk potential matrix (Red blocks:Risk score I, Yellow blocks:Risk Score II, Blue blocks:Risk Score III, Green blocks:Risk Score IV)

Increasing Frequency

F-4	2, 3, 4, 5, 7, 11, 12, 13, 14, 15, 16, 18, 19, 21	8, 10, 20	1, 6	
F-3	17	9		
F-2				
F-1				
	C-1	C-2	C-3	C-4

Increasing Severity

Table 6. Incidents and injuries

Incidents and Injuries				
No.	**Accident**	**Injuries**	**Down Time**	**Remedial Action**
1	Operator was opening the reactor main drain valve when its handle broke and key strike with head	Operator got wound on his head	-----------	Valves were replaced and preventive schedule for replacement was made
2	Operator rises on compressor crankcase to open cooler valve and fell down	Operator nose bone was fractured	-----------	A stand was provided for operation of valve
4	Ammonia feed pump discharge pressure transmitter rubber tubing was detached	Area operator was affected due to ammonia (vomiting)	6 hours plant shut down	Rubber tubing was replaced with permanent mild steel line
5	Urea reactor main angle valve gland leak heavily	cause area operators nose swelling and vomiting	5 hours plant shut down	Preventive maintenance schedule was made for main angle valve replacement
6	Ammonium carbamate recycle pump discharge bottle was leaked	Area operators nose and lips swelling	8 hours plant shut down	Ultrasonic non-destructive testing (NDT) to check discharge bottles material started on regular intervals
7	Ammonia pump mechanical seal leak excessively and made difficult to start stand by pump due to ammonia	Made area operator unconscious	3 hours plant shut down	Clean mechanical seal strainers before starting the pump. Also oil is drained from Ammonia feed tank
8	Engineer fell from oil on floor	Shoulder joint was dislocated	-----------	Preventive maintenance of pumps scheduled to remove oil leakages

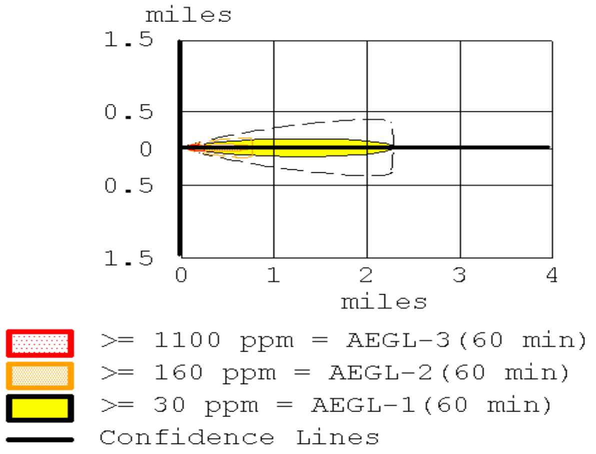

Figure 5. ALOHA footprints for worst-case scenario

From Figure 5, the highly threat zone indicated via red line stays up to 403 meters from the source of ammonia release. After this distance, the amount dispersed in the air falls below the AEGL-3 range and is the medium level of threat. This medium area of threat is displayed via orange line and may exist up to 1245 meters from source of release. The last region which is considered as the region with the lowest possible threat and is indicated as yellow zone and stays up to 2.3 miles. After this distance, the amount of ammonia available in the air has negligible threats. Next, threat at a point (inside and outside control room), 20 meters west and 5 meters north direction was estimated by using ALOHA modeling and the relevant output is presented in the Figure 6.

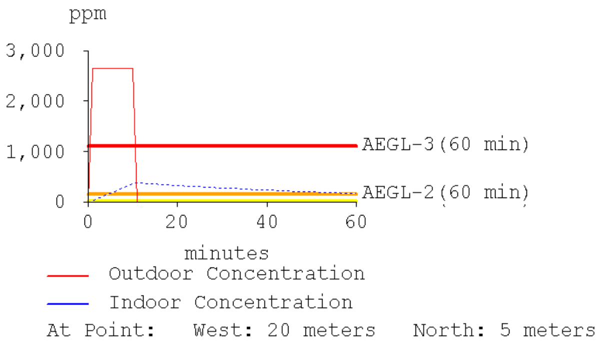

Figure 6. ALOHA footprints for threat at a point

It is clearly indicated by the Figure 6 that control room indoor concentration would reach 384 ppm while outdoor would be 2630 ppm compared to 1100 ppm (AEGL-3) [20], which demonstrates clearly that ammonia concentrations would increase instantaneously if pump is not stopped and isolated immediately. This abrupt increment in ammonia concentration would lead to many health and process related issues and might lead to some catastrophic scenario.

5. Conclusions

For risk assessment, hazard identification is the first and most crucial step. For this task, many methods have been in practice and many classifications of these techniques are available such as qualitative and quantitative, and shortcut techniques, standard techniques and advanced techniques. Among the practicing techniques, HAZOP and What-if are mostly practiced. And standard templates of both are available. Studying and comparing of these methods have revealed that what-If technique challenges the design basis, on the other hand HAZOP challenges the operating parameters consideration. Furthermore, HAZOP is structured however it is unable to accommodate most of the scenarios. Contrary to this, What-if is able to cover a broad range of scenarios, however, it is not a structured method. In this context, a hazard identification method, IHI, which can cover a broad range of scenarios and is structured in nature, seems necessitated. For this purpose, a new technique namely integrated hazard identification (IHI) is proposed in this work. The proposed technique provides detailed analysis of a facility than any of two mentioned techniques. In this integrated technique, a handy risk potential matrix is also developed and is presented for the considered case study of urea synthesis section of a real fertilizer complex. The risk potential matrix is based on risk evaluation by combing consequences and frequency. For this purpose, consequence class C1-C4 and frequency class F1-F4 have been defined. Risk ranking/risk score was assigned from I to IV translated as highest to lowest risk respectively. Consequence and frequency values are merely based on historical data of plant, e.g., daily log sheets, shift reports and down time records of the same plant and other similar facilities. Incidents and injuries occurred during the last 10 years were enlisted followed by studying all possible scenarios with proposed methodology. By using ALOHA footprints, a major accident of ammonia pump plunger flown away was studied and quantified in detail. ALOHA indicated that inside and outside the control room, concentrations of ammonia would be 384 ppm and 2630 ppm, compared to 1100 (AEGL-3). This article attempts to signifies the importance of rapidity in emergency handling and response of similar scenarios.

Recommendations

This research is important if a major ammonia leakage occur from industry pumps or elsewhere how safe will be nearby occupants, nearby villages, cities or even control room located inside the industry. Integrated Hazard Identification technique is very easy for practitioners as it will overcome hazardous situations and will prevent small or major hazards which may lead to a catastrophic event. These results can be used to calculate ammonia concentrations in nearby area and for emergency escape or vacating the area. All available hazard identification techniques are categorized. Fundamental aspects of risk and hazard are provided. IHI technique is graphically depicted. Methodological framework for quick risk assessment is provided. Fertilizer facility layout is provided to identify location of the specific industry units e.g. Urea unit is red highlighted. Urea synthesis section colorful diagram is provided to identify different streams such as ammonia, CO_2, Ammonium carbamate. This research also indirectly highlights that Urea formation from CO_2 is a better option for Carbon Capture Storage and Utilization (CCS). Different occurred incidents in last ten years are shown hence that other industries all over the world can safeguard their self. Detailed IHI of Urea synthesis section is provided. Risk potential matrix is shown with scores in different colors. Major occurred incidents and injuries are shown in a table. Accident quantification and detailed ALOHA footprints indicating AEGL-3, AEGL-2, AEGL-1 are shown. Threat at different points is shown and future recommendations are provided.

References

[1] CSB (U.S. Chemical Safety and Hazard Investigation Board), *Investigation Report, West Fertilizer Company Fire and Explosion*: WEST, TX. R, Jan, 2016.

[2] L. insider, (2010). Coffeyville Nitrogen Fertilizer Plant Adjusts Turnaround Dates: CVR Energy, R, Retrieved, https://www.lawinsider.com/contracts/2TwRT2x8GqCkV1lUFnK4vK/cvr-energy-inc/0/2010-10-01.

[3] Wikipedia, (2019). Port Neal fertilizer plant explosion, C, Retrieved 1st October, 2019, https://en.wikipedia.org/wiki/Port_Neal_fertilizer_plant_explosion.

[4] N. Hyatt, Guidelines for Process Hazards Analysis (PHA, HAZOP), Hazards Identification, and Risk Analysis. M. 1st ed. CRC Press, 2003.

[5] K. van Nunen, G. Reniers, and K. Ponnet. Measuring and improving safety culture in organisations: an exploration of tools developed and used in Belgium. [J]. Journal of Risk Research, 21. 5. (2018), 622-644, https://doi.org/10.1080/13669877.2016.1235602.

[6] T. Aven and M. Ylönen. How the risk science can help us establish a good safety culture. [J]. Journal of Risk Research. (2021), 1-19, https://doi.org/10.1080/13669877.2020.1871056.

[7] M. Kaszniak. Oversights and omissions in process hazard analyses: Lessons learned from CSB investigations. [J]. Process Safety Progress, 29. 3. (2010), 264-269, https://doi.org/10.1002/prs.10373.

[8] M.I. Rashid, N. Ramzan, and Q. Almas. Incident investigation in Pakistan's fertilizer industry—Common safety management system failures and issues. [J]. Process Safety Progress, 33. 4. (2014), 399-404, https://doi.org/10.1002/prs.11664.

[9] M.I. Rashid, C.H. Ali, K. Mukhtar, E. Benhelal, and M. Athar. Operational discipline in practice. [J]. Process Safety Progress, 40. 2. (2021). e12207, https://doi.org/10.1002/prs.12207.

[10] M.I. Rashid, N. Ramzan, T. Iqbal, S. Yasin, and S. Yousaf. Implementation Issues of PSM in a Fertilizer Plant: An Operations Engineer's Point of View. [J]. Process Safety Progress, 32. 1. (2013), 59-65, https://doi.org/10.1002/prs.11553.

[11] M. Athar, A. Mohd Shariff, A. Buang, M. Shuaib Shaikh, and M. Ishaq Khan. Review of Process Industry Accidents Analysis towards Safety System Improvement and Sustainable Process Design. [J]. Chemical Engineering & Technology, 42. 3. (2019), 524-538, https://doi.org/10.1002/ceat.201800215.

[12] N. Ramzan and W. Witt, *Fundamental aspects to improve risk potential assessment of chemical process industry*, in *18th European Symposium on Computer Aided Process Engineering – ESCAPE 18*, 2008.

[13] J. Dunjó, V. Fthenakis, [J].A. Vílchez, and [J]. Arnaldos. Hazard and operability (HAZOP) analysis. A literature review. [J]. Journal of Hazardous Materials, 173. 1. (2010), 19-32, https://doi.org/10.1016/j.jhazmat.2009.08.076.

[14] M.I. Rashid and N. Ramzan, Urea Synthesis Hazard Analysis: PHA, HAZOP and Quantitative Risk Assessment. Book. LAP LAMBERT Academic Publishing, 2012.

[15] S.A.H. Guidelines, *Guidelines for conducting HAZOP studies*, Loss prevention department Saudi Aramco, 2017.

[16] P.K. Marhavilas, D. Koulouriotis, and V. Gemeni. Risk analysis and assessment methodologies in the work sites: On a review, classification and comparative study of the scientific literature of the period 2000–2009. [J]. Journal of Loss Prevention in the Process Industries, 24. 5. (2011), 477-523, http://doi.org/10.1016/j.jlp.2011.03.004.

[17] M. Athar, A.M. Shariff, and A. Buang. A review of inherent assessment for sustainable process design. [J]. Journal of Cleaner Production, 233. (2019), 242-263, https://doi.org/10.1016/j.jclepro.2019.06.060.

[18] M.I. Rashid, *Urea synthesis hazard analysis and simulation studies,* University of Engineering & Technology, Lahore, Pakistan, 2012.

[19] M.I. Rashid and N. Ramzan. Fluid Mechanics and Heat-Transfer Operations Combination Involved in Urea Unit of Fertilizer Complex. [J]. Non-Metallic Material Science, 1. 1. (2019), 5-10, https://doi.org/10.30564/nmms.v1i1.515.

[20] N.R. Council, Acute Exposure Guideline Levels for Selected Airborne Chemicals: Volume 3. Book. Vol. 3. National Academies Press, 2003.