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Comprehensive Hazard Identification and Safety Evaluation for Shahjalal Fertilizer Industry Limited

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ABSTRACT
The objective of the paper was to identify the relative hazard index for all the main ammonia process units of Shahjalal Fertilizer Company limited and calculate hazard area for probable toxic release of the ammonia storage tank. Various indices were extensively used for ranking various units of a chemical process industry on the basis of the hazards they pose of the accidental probability of fires, explosions or toxic release with some restrictions and limitation. So, a new, user-friendly tool for swift yet comprehensive hazard identification and safety evaluation index called Safety Weighted Hazard Index (SWeHI) was introduced for representation of overall comprehensive hazard identification and safety evaluation factors SFCL plant. The Dow chemical exposure index (CEI) was also calculated for the process units handling flammable and toxic materials respectively. The hazard area of the ammonia storage tank for probable toxic release with the atmospheric conditions data of the plant location was also determined using ALOHA software and CEI value. The SWeHI ranking was between 1.74 (NG loading) and 10.61 (primary reformer).

Keywords: hazards, SWeHI, Dow CEI.

1. Introduction

Industrial safety is important as it safeguards human life, especially in high risk industries like ammonia-urea plant operating under high pressure and temperature. The first step in any risk assessment procedure for industrial safety involves hazard identification, or answering the question: what can go wrong [1]? However, hazard identification is easier said than done, and it is becoming more difficult as the complexity and variety of the technologies which pose risk continually increases. Some key facts are needed to understand the process of making a chemical safety assessment. The communication system and tasks within the supply chain are related to the chemical safety assessment [2]. The roots of the hazards, as well as the strategies for reducing them, lie in the man-machine management system that runs any chemical plant and it is not always easy to discover the weaknesses in such a system. The hazards are rarely obvious, or accessible to simple visual inspection, [3] but it is very important to evaluate safety of the plant and surrounding lives and properties. In this paper, hazard identification and safety evaluation for the ammonia process plant of Shahjalal Fertilizer Industry Limited is presented. The best possible indices for the purpose are used for ranking and hazard area for accidental toxic release (ammonia release) such, SWeHI as SWeHI method [4] and Dow fire and explosion index (FEI) [5], Dow chemical exposure index (CEI) [6]. ALOHA software was also used for simulating the hazard area with environmental conditions [7].

The safety measures in industries such as use of pressure valves, flare systems, venting systems, alarms, and emergency shutdowns are to be designed for development of unusual situations during operation at the design stage of any industrial project. It is very important in case of approval of plant design, legal documents and installment of insurance. These are called means of inherently safer design [8-11]. In spite of that there remains some factors like model inaccuracy, human error, sensitivity of the process etc., which may cause failure of safety systems and accidents. That's why to ensure safety the process industry periodically needs the attention of safety audits [12]. But, how should it be measured that a plant has risk or is sufficiently safer? This is where safety indices come. Different kinds of safety indices are there to rank the safety of process or equipments of any industry, such as Dow fire and explosion index, Dow chemical exposure index, the Mond fire, explosion and toxicity index [13,14], the IFAL index [15], the mortality index [16], HIRA method [17], SWeHI method, extras. There are some safety indices that provides few rapid ranking techniques and databases such as the substance hazard index [18] and the NFPA ranking [19, 20], but they have different applicative sides. Each of them is used for different purpose.

The available indices, including the well-known Dow and Mond indices, and HIRA rank chemical process units mainly works in terms of the hazardous substances and operating conditions associated with the concerned units or process equipment. Most of them do not count in existing safety measures and human communication. Though Dow and Mond indices do consider some factors such as `offsetting index values' in the case of the Mond Index and `credits factor' in the case of the Dow index to account for the safety measures existing or planned in the unit [21, 22] but much greater rigorous, accuracy, and precision are needed in quantifying the impact of safety measures on the values of the hazard indices. Besides they are used for different purpose with different calculative method.

The Dow FEI relies on the calculation of a fire and explosion index which is then used to determine fire protection measures and, in combination with a damage

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factor, to derive the base maximum probable property damage [10]. Obviously, it is used for flammable materials, specially gas and liquid [22].
The Mond index and Dow CEI are used for exposure ranking of toxic materials [11-13]. They have fairly similar calculation procedures. Dow CEI is relative ranking system where the Mond index gives a briefer view of the damage [21].
The IFAL index is too complex for manual calculation and used both to calculate damage due to accidents of major units of a process plant. It used to be the primarily for insurance assessment purposes [23].
This the mortality index is a measure of the lethality which is computed on the basis of the number of deaths per ton of material involved [15].
HIRA method is more systematic, comprehensive and reliable than previous index systems. It provides more brief data on safety matters. Some calculations were done according to this method.
SWeHI provides a `single frame' view of the industry or the desired process unit the hazards posed by it under a given set of external forcing factors. It simultaneously integrates this HAZOP information with the safety measures to represent the radius of the hazard area under moderate hazard (50% probability of fatality/ damage) due to the operation to installed safety feathers. It also accounts for the environmental setting. It accounts for almost all factors of the process industry [17]. It a complete and easy index to rank relative hazardous units of a process industry including all possible risk factors. In this paper, SWeHI was calculated for main units of ammonia plant of SFCL. For NG loading, primary reformer, secondary reformer, ammonia storage tank and ammonia reactor were calculated to be 1.74, 10.61, 4.32, 7.12 and 2.59. The numbers indicate if the units are low, moderate or highly hazardous. The CEI and hazard area was also calculated for ammonia storage tank under SFCL environmental condition as it can greatly affect the human health surrounding the area.

2. Methodology

For ammonia plant of Shahjalal Fertilizer Industry limited hazardous units of industry can be classified in two groups-

a) Fire Hazards
b) Toxic Hazards

For fire hazards, Dow fire explosion index (FEI) is calculated and for toxic release, Dow chemical exposure indexes (CEI) are calculated only for ammonia storage tank due to frequent accident in this unit. Primary and secondary reformer have the highest probability of fire explosion. At the same time, ammonia storage tank and ammonia reactor have the probability of toxic release of ammonia and CEI (chemical exposure index) have been calculated. This is also been simulated by ALOHA software to show the affected hazard area of toxic release of storage tank at plant's average atmospheric condition. For hazard ranking SWeHI method is used.

2.1 SWeHI method
The SWeHI methodology was collected from reference 4. In mathematical term of SWeHI is represented as,

$$SWeHI = B/A \qquad (1)$$

Where, B is the quantitative measure of the damage that may be caused by a unit. It is measured in terms of area under 50% probability of damage, A represents the credits due to control measures and safety arrangements made to counter the undesirable situations.

$$B = B1 + B2 \qquad (2)$$

B1 represents damage due to fire and explosion, while B2 considers damage due to toxic release.

2.1.1 B1 methodology
B1 has different a methodology for storage units; units involving physical operations such as heat transfer, mass transfer, phase change, pumping and compression; units involving chemical reactions; transportation units and other hazardous units such as furnaces, boilers, direct-fired heat exchangers, extraa.
For the storage tank, there were three energy factors to be calculated, F1 (only for chemical energy release), F2 and F3. Their corresponding equation are given below-

$$F1= 0.1M \times H_c /K \qquad (3)$$

$$F2 = 1.304 \times 10^{-3} \times PP \times V \qquad (4)$$

$$F3=1.0 \times 10^{-3} \times (1/ T+273) \times (PP-VP)^2 \times V \qquad (5)$$

The impact of pressure (presented by F2 and F3) were quantified as follows,

$$F = F2+F3 \quad \text{(if VP > AP and PP > VP)} \qquad (6)$$

$$\text{or, } F=F2 \qquad (7)$$

$$\text{or, } F=F3 \text{ (if AP > VP and PP > AP)} \qquad (8)$$

So, total Hazard potential $=(F1\times pn1+F\times pn2) \times pn3\times pn4\times pn5\times pn6\times pn7\times pn8$ (9)
Here pn1-pn8 are penalty factors. They represent the impact of temperature, pressure, distance, quantity in ton, flammable and/or reactive characteristics of a chemical, the density of the units at the site, external factors such as earthquake and vulnerability of the surroundings accordingly. They are calculated according their potential risk due to temperature, pressure, distance extra with probabilistic analysis of HIRA method [4].
For units involving physical units, hazard potential can be calculated using equation 9, but penalty calculation will be different.
For, units involving chemical reactions (for ammonia reactor), new factors must be calculated, F4 is energy factor for reaction energy.

$F4= M \times H_r /K$ (10)

The nature of the reactions is presented as pn9 and related to the probability of `side reactions' or `runaway reactions' is represented as pn10 [4]. So,

hazard potential = (F1×pn1+F×pn2) + F4×pn9×pn10× pn3×pn4×pn5×pn6×pn7×pn8 (11)

For other hazardous units B1 can be calculated as

Hazard potential= F1 × pn1 × pn2 × pn3 × pn4 × pn5 × pn6 × pn7 × pn8 (12)

All the hazard potential mentioned above can be represented by B1 (as they are for flammable material).

2.1.2 B2 methodology

The estimation of B2 was done with one core factor, named as the `G factor', and several penalties. The G factor was accounted for the accidental release of super-heated liquid from the unit, the release of gases would directly lead to dispersion in the atmosphere and causing build-up of lethal toxic load and liquefied gases having two-phase release. All are responsible for toxic release disasters. The G factor is represented by,

G= S × m (13)

m is the anticipated mass release rate of materials present in the unit and S is dependent on the physical state of the materials of the unit. It is calculated through the NFPA ranking shown in table 1.

Table 1 NFPA rank for evaluating S

NFPA rank	Liquefied gas	Gas	Ref
4	8.0	13.40	
3	0.80	1.34	20
2	0.40	0.67	
1	0.10	0.25	

After calculating G, B2 was calculated by equation 14 where a=25.35 and b = 0.425.

$B2 = a\times (G \times pnr1 \times pnr2 \times pnr3 \times pnr4 \times pnr5 \times pn6 \times pn7)^b$ (14)

pnr1-pnr5 are penalty factor represented operating temperature, operating pressure, vapor density, toxicity of the chemical that are being handled, and site characteristics and soil type [20,24-26]. They were calculated differently. Some of their values were fixed based on the characteristics of the unit.

2.1.3 A methodology

Hazard control index, A represents present credits for the safety arrangements planned or exist on the unit as numbers.

A = 0.15× (1+ cr1)(1+ cr2)(1+cr3)(1+cr3)(1+cr4)(1+ cr5)(1+cr6)(1+ cr7)(1+cr8) (15)

cr1-cr8 are credits for safety measurements already exist in the unit or emergency response system (ERS). They were calculated specifically for SFCL plant. cr1 stands for ERS; cr2 for disaster management plan (DMP); cr3 for other damage control measures; cr4 for general control system like temperature, pressure, level control; cr5 for installation of detecting devices; cr6 for emergency control systems like interlock; cr7 are for general human characteristics and probable human errors and cr8 for quantification of credit for equipment reliability [4, 27-31]. Most of the information regarding credit calculation for SFCL, were collected personally from some of the employees of SFCL and students of BUET who were internee of SFCL. Some data was also collected from the literature review [32,33]. Most of the calculation was proceeded with statistical data and probabilistic equations in plotted graph [4].

After calculating B and A, SWeHI numbers were arranged. The ranking was done accordingly fig 1.

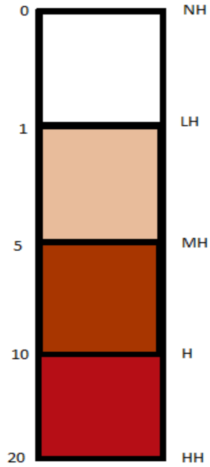

Fig.1 SWeHI Hazard Ranking where HH: Highly Hazardous, H: Hazardous, MH: Moderately Hazardous, LH: Less Hazardous

2.2 Dow CEI

The Chemical Exposure Index (CEI) provides a simple method of rating the relative acute health hazard potential to people in neighboring plants or communities from possible chemical release incidents. For ammonia storage tank, CEI was calculated. It can be expressed by the equation,

$CEI= 655.1 \times\sqrt{(AQ/ERPG\text{-}2)}$ (16)

Where, AQ is airborne quantity (kg/sec), ERPG-2 value (mg/m3) [The value is taken from AIHA guideline]. ERPG is abbreviation of emergency response system guideline. [34] It is fixed for a toxic material ERPG are same for the operating pressure and temperature. If the gas releases from the storage tank,

$$AQ = 4.751 \times 10^{-6} \times D^2 P_a \times \sqrt{\{MW/(T+273)\}} \quad (17)$$

Where, P_a absolute pressure, MW molecular weight of the ammonia, D diameter of the probable hole of the storage tank in millimeter. For ammonia storage tank liquid ammonia may release and then vaporize in atmospheric conditions. So equation will be,

$$AQ = 5\, F_v \times L + 9.0 \times 10^{-4} \times A^{0.95}\, \{MW \times P_v/(T+273)\} \quad (18)$$

$$F_v = (C_p/H_v) \times (T_s - T_b) \quad (19)$$

$$L = 9.44 \times 10^7 \times D^2 \rho_l \times \sqrt{(1000 P_g/\, \rho_l)} + 9.8h \quad (20)$$

The symbols have their usual meaning. [35, 36]

2.3 Hazard area using Aloha Software

ALOHA which is elaborated as Areal Locations of Hazardous Atmospheres, is the hazard modeling software program for the CAMEO software suite. It is used widely to plan for and respond to chemical/hazardous materials emergencies. Details about a real or potential chemical/hazardous materials release can be entered into ALOHA for generating threat zone (hazard area) estimated for various types of hazards. This software can also be used for modeling hazard area for toxic gas clouds, flammable gas clouds, Boiling Liquid Expanding Vapor Explosions (BLEVEs), jet fires and vapor cloud explosions. The estimated hazard area are shown on a grid in ALOHA. The red threat zone represents the worst hazard level; the orange and yellow threat zones represent areas of decreasing hazards [37, 38].

3. Results and Discussion

The results found from the calculation is expressed below.

3.1 SWeHI Ranking

Table 2 SWeHI ranking for main units of ammonia section of SFCL

Units	B1	B2	B	A	SWeHI =B/A	Rank
NG loading	202.55	13.34	202.55	116.20	1.74	LH
Primary reformer	669.47	5.56	669.47	101.36	10.61	HH
Units	B1	B2	B	A	SWeHI =B/A	Rank
Secondary reformer	397.90	105.22	397.90	108.06	4.32	MH
Ammonia Storage Tank	255.18	296.27	296.27	115.29	7.12	H
Ammonia Reactor	112.64	138.64	138.64	110.2	2.59	LH

3.2 CEI value

After calculation using excel, CEI value for ammonia storage has been found 89.9. This indicates that it is moderately toxic but it only depends on operating temperature and pressure. So, nothing else can be predicted from this analysis.

3.3 ALOHA software

In ALOHA, for SFCL average environmental condition for the ammonia storage tank, two kinds of hazard area were simulated; one for toxic vapor release and another for blast area of a vapor cloud. The simulated area shows that how much area will be mostly affected if any accident takes place

3.3.1 Toxic area of vapor cloud

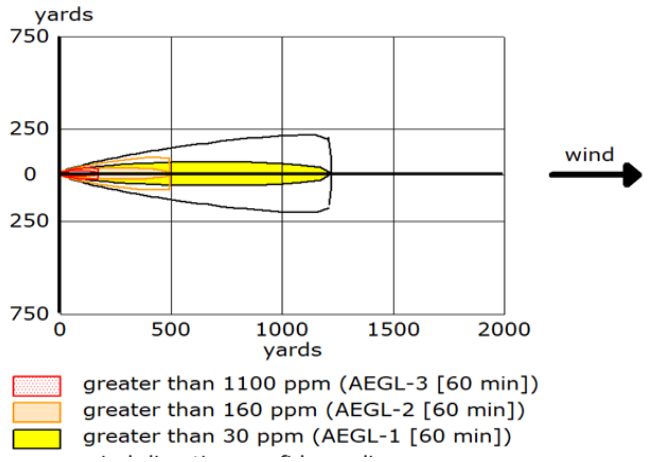

Fig.2 Hazard area calculation of ammonia storage tank for toxic release

3.3.2 Blast area of vapor cloud

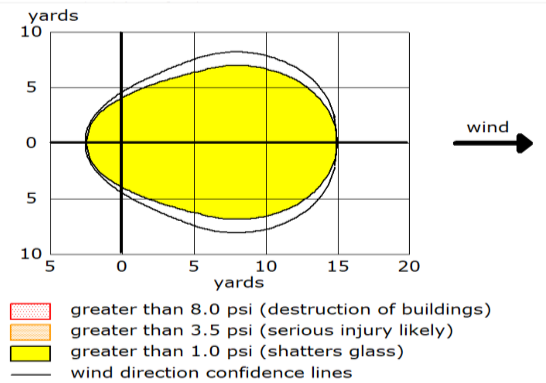

Fig.3 Hazard area calculation of ammonia storage tank for blast area of vapor cloud

4. Conclusion

To identify the hazard of SFCL through an index (SWeHI) for assessing hazards in chemical process industries. As there are locals around the plant, CEI and

ALOHA software simulation were also used (as mostly used) for Ammonia storage tank. The purpose of the study was to acknowledge the SWeHI method for the contribution of safety measures in its final hazard assessment score with greater rigor, accuracy, and precision than that achieved in the prevailing indices. The SWeHI has also been based on more systematic and reliable methods for hazard identification as it considers a larger number of parameters for hazard quantification. It is so complete, simple and rigorous that it can help in insurance procedure too. A 'snap-shot picture' of ammonia process units of SFCL is presented through indices. In near future, the SFCL authority can use the data for further safety measures.

NOMENCLATURE

cr	Credit factor
pn	penalties for damage index estimation
pnr	penalties for toxic damage index estimation
PP	processing pressure, kPa
T	temperature, ˚C
TP	transportation pressure, kPa
V	volume of the chemical, cu m
Fv	Flash fraction
Pv	Vapor Pressure
pl	Liquid Pressure

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