

SAFETY PERFORMANCE ASSESMENT OF HAZARDOUS CHEMICAL FACILITIES IN BANGLADESH USING INDEXING APPROACH

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Abstract

This paper presents evaluation of safety performance of three hazardous facilities based on current safety practice by measuring their safety weighted hazard indices (SWeHI) of multifarious units of chemical process and what can be done to avoid any potential accidents in context of Bangladesh. Assessing hazard potential over safety procurement is a key indicator of how well a facility is prepared to reduce its vulnerability. The risks associated with hazardous facilities are always greater in a country like Bangladesh as the safety issues are not often been prioritized by its key stakeholders. In recent years, there were number of deadly accidents occurred in the chemical industries and storage warehouses which resulted multiple fatalities and significant property damage. The accident could be avoided using proper safety protocols in those facilities. Here safety performance of three facilities was assessed based on survey data. These facilities deal with flammable, explosive and toxic chemicals. This index is on the basis of fire & explosions properties and toxic release properties as well as the safety precautions against it. It helps professionals to identify the overall hazard potential and distinguish less protected units from other well operated units. The paper features on an approximate yet workable assessment of risks at a low cost and based on the current safety practices.

Keywords: Hazard index, Ranking, Risk assessment, Hazardous Chemical, Safety Performance

1. Introduction

Accidents have occurred in the chemical process industries since the industrial revolution. Because of the expanding variety of goods manufactured by chemical process industries, it has become increasingly usual for these businesses to employ reactors, conduits, and storage tanks in which hazardous compounds are handled at increased pressure. Accidents in such units can occur as a result of material failure, operational errors, or external disturbance. [1] The incidence and severity of these incidents have grown dramatically during the previous few decades. Process safety engineering is critical in limiting the occurrence of unanticipated hazardous releases and other catastrophes at chemical plants. [2] So now here in a country like Bangladesh, measuring potential risks and finding plausible solution to address the risk are very important. [3]

The first stage in any risk assessment approach is to identify hazards, which answers the question, "What could go wrong?" This is critical since unrecognized risks are readily underestimated. Only then may suitable safety precautions be implemented.

Identifying hazards is easy to say but difficult to perform, and it is growing more complex as technology advances. Identification of defects in complicated chemical processes without systematic investigations is undoubtedly difficult, since many risks are not always evident, particularly in the chemical process business. The risk and safety performance evaluations in chemical processes are a massive undertaking encompassing multiple phases ranging from basic hazard identification to the construction of believable accident scenarios and the preparation of solutions to prevent accidents or reduce damages. All of this necessitates significant time and financial investments. This work used an indices-based technique to measure the safety performance of a hazardous industry in order to provide an approximate yet workable risk assessment at significantly lower costs. In the past, indices have been reported for swift risk assessment- such as Dow fire and explosion index, Dow chemical exposure index, Mond fire index, Safety weighted Hazard index (SWeHI), Multivariate Hazard Analysis and ranking system (HIRA).

Dow's Index is a quantitative risk analysis method that has been used for hazard identification at plant level. This method was introduced by the

Dow Chemical Company for fire and explosion hazard analysis. The potential occurrence of fire and explosion can be estimated by using the Dow Index for determining the insurance costs of the explosion and fire. [4]

The Dow CEI is a measure of the relative acute toxicity risks. It may be used for initial process hazard analysis (PHA), calculation of a distribution ranking index (DRI), and in emergency response planning. [5] The Mond FETI index is a relatively simple technique, including a complete methodology to calculate the total risk of a given process. It does not require highly qualified experts to administer and its calculations are not time consuming. The FETI is the only index that considers all safety parameters and is able to select the most critical parts of the process. It is able to calculate the values of damages and other losses using day outage, property damage, replacement value and value of lost production [6] firefighting equipment, toxic release controls, etc., have not been incorporated. The index measures damage indices. It does not focus on the safety steps that already are there to prevent or fight accidents when occurs.

SWeHI aims at providing a 'single frame' view of the industry, or the desired process units, the hazards posed by it under a given set of external forcing factors (ranging from meteorology to social upheavals). It simultaneously integrates this information with the safety measures as they are and as they ought to be.

2. Background

Studies on the safety performance of the energy industry are still rare in Bangladesh. However, the indexing methodology is a far more trustworthy means of evaluating safety in any hazardous site and has been utilized previously. Previously, a few works were completed to analyze the safety performance and fire risk hazard assessments of the fertilizer industries or chemical warehouses or textile sectors, as accidents in these sectors are relatively prevalent in the nation.

A prior study was undertaken to identify the relative hazard index for all of Shahjalal Fertilizer Company limited's key ammonia process units and compute the hazard area for a possible hazardous leak of the ammonia storage tank. With certain constraints and limitations, numerous indices were widely employed for evaluating various units of a chemical process industry based on the dangers they pose of the unintentional risk of fires, explosions, or hazardous discharge. SWeHI was chosen as a trusted index to evaluate. [10]

Again, in other work indexing method were used before to investigate the amount of fire hazard risk

linked with the cohabitation of chemical warehouses and residential units in Dhaka, Bangladesh's capital city. The idea is to analyze fire hazard risk for this sort of land use mix using a fire hazard risk index designed specifically for this application. The authors recommend developing a fire hazard risk index to determine the risk level in their study. [11]

3. Methodology

The Safety Weighted Hazard Index (SWeHI) proposes a methodical, thorough, yet simple-to-implement approach. SWeHI represents the radius of the area under moderate hazard due to the given unit considering the chemicals, operating conditions, environmental setting. SWeHI is the summation of FEDI and TDI divided by Safety Index. In mathematical terms: [7]

$$\text{SWeHI} = f(\text{FEDI}, \text{TDI}, \text{Safety Index}) \quad (1)$$

3.1. The Fire and Explosion Damage Index (FEDI)

For developing FEDI various units of plant are classified as storage units, units involving physical operation etc. In case of spontaneous combustion of hazardous chemicals, the pressure rises inside the vessel or storage tank and if the container fails, fire will spread to the other combustible materials of its surrounding which will eventually cause severe explosion and damage. [8] FEDI is computed by calculating damage potential. [7] Management priorities can be identified as well the losses estimated by this method can serve as a basis

$$\text{FEDI} = 4.76 (\text{Damage Potential})^{1/3} \quad (2)$$

Damage potential is a function of energy factors and penalties. It has got three energy factors; one account for chemical energy and two accounts for physical energy. Penalties depend on various parameters. The storage part of following facilities is calculated in this paper. Penalties depend on temperature properties, pressure properties, location of nearest hazardous unit, capacity, characteristics of chemical etc. FEDI hazard rankings are provided in Table.1 [available in the support document]. [9]

3.2. The Toxicity Damage Index (TDI)

This index is derived using transport phenomena and empirical models based on quantity of chemicals, physical state of chemicals, and the toxicity of chemicals, the operating conditions, and the site characteristics.

TDI is a function of G factor and penalties. The G factor is quantified as:

$$G=P \times m \quad (3)$$

The value of P is dependent on the release conditions and m is anticipated release rate in kg/s. The value of P depends of state of chemical and NFPA ranking. [9] Penalties depend on temperature characteristics, pressure characteristics, vapor density, toxicity of chemical etc. TDI hazard rankings are provided in Table. 2 [available in support document].[9]

3.3. Safety Credit

Safety credits are calculated using the following formula,

$$\text{Safety Index} = 0.15(1+cr1) (1+cr2) \dots (1+crN) \quad (4)$$

Here, N is the number of credit parameters. cr1, cr2 are the individual parameters for calculating safety index. These parameters are on the basis of safety actions that are taken, controlling devices, reliability as well as human characteristic. SWeHI hazard rankings are provided in Table 3 [available in support document].[7]

4. Case Studies

4.1 Plant A

Plant A is a 52.4 MW HFO based power plant situated on the bank of river Isamati in Munshigonj district. The plant has storage capacity of 7,000 MT HFO. It has one large storage tank with capacity of 5000 MT, a settling tank of 500 MT and a service tank of 500 MT for HFO storage. The plant started its operation from 2015 and total 110 employees work in the facility. The plant is not accessible by roads and needs to cross river by boats.

The plant is basically detached from other plants situated in that area since it is kind of located in an island. The plant is a bit congested as the power plant and storage area are located close. In the storage area the storage tank, service tank and settling tank are located. Each of the tank can be considered as a hazardous unit. The distance gap between them are about 6-7 meters which is actually very congested. The plant has got no emergency water tanks for emergency fire extinguishing purpose. The plant has got no fire walls. The plant is 30-40 minutes away from nearest fire service office and hospital. No smoke detector or fire alarms are located in the storage zone or in the main plant zone. Workers and employees are provided with enough walkie talkies. Enough portable fire extinguishers are available. Workers are moderately trained. Annual

safety conference is not arranged. Primary first aid service is available in the plant.

The plant stores pretty large quantity of flammable/combustible hydrocarbon as primary fuel. The failure of these tanks has potential to create large fire and destroy the whole facility. Though walkie-talkies are provided but if in case the fire somehow remains unnoticeable. It will lead to a huge disaster. A good communication facility will not help in that case. The buildings are so close to each other that it can spread in the whole facility within half an hour. Fire risk management and hazard evaluation program has not been established in the facility. The plant is not accessible by roads, fire service vehicle won't be able to reach the plant during any emergency. Large number of containers are randomly stored around the plant area. Containing dangerous goods and transportation pipeline are not clearly marked and protected. There is no containment for others tank such settling tank, service tank. Any spillage can contaminate the soil and spread around which can connect the drainage linked to the river.

4.1.1 Property Analysis

Now since the plant mainly deals with HFO. After identifying the risk, the next step is to measure it. And also, in order to calculate FEDI and TDI it's necessary to know its properties. Properties of HFO is given in Table 4 [available in the support document]. Considering all values, FEDI and TDI for the plant has been calculated. These are respectively 65072.7 and 0.118. Therefore, Plant A is extremely hazardous in terms of FEDI and not hazardous in terms of TDI.

4.1.2 Credit Analysis

To minimize the risk, the industry makes sure some safety features. As the industry is isolated some emergency resource planning by consulting with neighborhood industry is not possible. Only mode of communications is by phone and manual. Individuals are not well aware of their responsibility at emergency as there is no professional safety worker. They have first aid facilities but no easy way to the nearby hospital. For disaster management plan workers are not involved, fire fighting devices are enough for controlling small hazard, training program is conducted 6-7 times in a year which is enough, duty of individuals is not monitored, their security guards are also involved in disaster management. For damage control they have fire extinguishers and water supply only. Emergency shut-down system and safety vents are for the time of emergency control.

They have analog temperature, pressure, level and flow control as controlling devices. Process operation is partially automated and human interaction is often required. But no detecting devices are available here and there is still no record of any equipment failure before. According to their safety facilities some credit values are calculated and with these values overall safety factor is also calculated as SWeHI rules.

Credit parameters for Plant A

For plant A, available credit parameters can be considered as following numerical values according to their facilities, equipment and effectiveness. [7] Emergency resource planning- 1.9, Disaster management plan- 1.9, Other damage control measures- 0.45, Process control system- 2.3, Installation of detected device-0, Emergency control measures- 0.95, Human error prevention- 2.1, Equipment reliability- 0.1. All these safety credits provide an overall safety factor of 211.63 which leads to a SWeHI value of 307.47. So, it can be rated as extremely hazardous.

From the value of SWeHI we can easily say that the plant is poorly protected. First of all, it doesn't ensure the safety of employees and workers as there is no emergency escape option. On firefighting team for outside cannot enter into the plant if any explosion occurs as there is no road available. Moreover, the firefighting system of the plant is very weak. So at least a small bridge or foot over bridge must be built as soon as possible for life safety in the worst-case scenario.

4.2 Plant B

Plant B is a storage and lube oil manufacturing plant located in Narayanganj district. The plant has storage capacity of 380 MT of Base oil. The daily production capacity is approximately 20-27 tons of finish products. The facility also has storage of bulk flammable materials in plastic tanks and finish products in their facilities. The plant started its operation from 2015 and total 40 employees work in the facility. Base oil is imported and transported to the facility using oil tanker by roads.

The plant is located in a moderately populated area. Plant is surrounded by local houses. The plant has 6 base oil storage tanks. Those are situated very close to each other. Moreover, these tanks are surrounded by drums where more oils are preserved. There is a dormitory for employees only about 12 meters away from the base oil tanks. These are flammable materials. Some are stored in plastic vessels. The main building is located about 25 meters away from base storage tanks. Main building consists of blending, packaging units and office.

Blending oil consists of 4 tanks. And packaging is done under the same roof. There is quality testing lab in the same building. First aid and portable fire extinguishers are available. Nearest hospital and firefighting units are around 45-55 minutes away from the plant. The plant is actually located in a lane so it is hard for any firefighting unit to enter while emergency.

The plant stores pretty large quantity of flammable/combustible hydrocarbon lubricant oil. The plant stores large quantity of flammable/combustible hydrocarbon for production of lubricating oil. A series of storage tanks has been built with quite congested area. No containment was there due to the ongoing expansion works. The failure of these tanks has potential to create large fire and destroy the whole facility. Fire risk management and hazard evaluation program has not been properly established in the facility. The plant only entrance is connected to main road with narrow road, if entrance is blocked by the fire; the fire emergency service vehicle won't be able to reach the plant. Large numbers of containers are randomly stored around the plant area here and there. The pipelines in the loading/unloading area are not clearly marked. Human error may lead to overflow a tank. No separation and containment exist in the production units or reactors. Spillage of combustible liquid may occur and spread all over the area due to any failure of these units or its pipeline or human error. No separation exists in the production line and package line. In case of fire, it can damage the whole facility. 1000-liter plastic bulk containers are used to store large quantity of combustible chemicals and close to the office buildings. In case of fire, these can easily melt and provide fuel create large fire which may destroy the whole facility.

4.2.1 Property Analysis

Now since the plant mainly deals with lubricant oil. After identifying the risk, the next step is to measure it. And also, in order to calculate FEDI and TDI it's necessary to know its properties. Properties of lube oil are given in Table 5 [available in the support document]. Considering all values, FEDI and TDI for the plant has been calculated. These are respectively 45330 and 0.109. Here FEDI value is too much high as heat of combustion of base oil is high and the plant is too much congested compare to the quantity of chemical to be handled. Therefore, Plant B is extremely hazardous in terms of FEDI and not hazardous in terms of TDI.

4.2.2 Credit Analysis

To minimize the risk, the industry makes sure some safety features. As a part of emergency

resource planning the industry has made quite good mutual understanding with neighboring society, for any emergency they communicate only by phone or manually, they have first aid facility and nearby hospital is not so far. In the case of disaster management plan workers are involved only, technical professionals are trained minimum two times in a year, but duty of each individual is not displayed and properly monitored and no social group is involved. For damage control water spray system is available, water in different pipeline and fire extinguishers are available but no water blanket or fire arrestor. Analog temperature, level and flow controllers are available for process control. Process operation is moderate, requires human interaction. In case of emergency, emergency shut down and safety vents are available, but there is no interlock.

According to their safety facilities some credit values are calculated and with these values overall safety factor is also calculated as SWeHI rules.

Credit parameters for Plant B

For plant B available credit parameters can be considered as following numerical values according to their facilities, equipment and effectiveness. [7] Emergency resource planning- 2.5, Disaster management plan- 2.6, Other damage control measures- 0.75, Process control system- 1.4, Installation of detected device-0.5, Emergency control measures- 0.95, Human error prevention- 2.1, Equipment reliability- 1

All these safety credits provide an overall safety factor of 503.5 which leads to a SWeHI value of 89.96. So it can be rated as extremely hazardous. As the result shows that the plant is extremely hazardous although it deals with lubricant oil which is less dangerous. So, more safety practices and advanced devices are required to minimize hazard. Fire wall around the plant should be built as many people live by the side of the industry. Flammable chemicals stored outside of the plant should not be allowed.

4.3 Plant C

Plant C is a LPG bottling plant located in Palash, Ghorashal district by the side of Shitalakshya River. The plant has storage capacity of 550 MT of 85% LPG. The daily production capacity is approximately 230 MT of finish products. The plant started its operation from 2015 and total 200 employees work in the facility. LPG is imported mainly from MiddleEast, manufactured and transported to using LPG cylinders by roads and by barge though the river. The plant is located in a less populated area. There is a garments factory beside the plant. The plant has 3 barges. It also has two evacuation units.

As fire detection system the plant has 15 gas detectors, 7 flame detectors, 13 emergency shut-down buttons. Alarm system is also available in the plant. The plant has quite strong firefighting system. It has one large fire water tank of capacity of 1800 m³ water and two firefighting pump of capacity 430m³/h water flow. This system can fight against the unwanted fire up to 4 hours without any outside help. The firefighting system is also protected by 3 fire walls. In the filling station there are two domestic filling lines for different quantities and 36 filling scales. Filling capacity is 1800 pieces/hour. It also has industrial filling line of capacity 310 pieces/hour. There gas cylinders are ranged 5.5-45 kg. First aid facilities are available here and nearest hospital is only 0.5 km away from the plant. As it is located by road side firefighting team can easily enter at the moment of emergency.

The plant deals with large quantity of flammable LPG. In the plant storage tanks has been built with quite congested area but it has good fire detection and fighting system. In the case of barge there is only manual firefighting system. So an explosion can cause severe damage during transportation. There is some gas leakage in the filling station during gas filling in the cylinders and there are no gas detectors in that sector. The workers who are involved in carrying the cylinders to the nearby trucks are unprofessional and careless. As the cylinders are used to refill, some cylinders are not up to the mark. Valves in the plants are checked up once every ten years only. A garments factory is located just beside the plant area boundary, so any incident occurs in the garment's factory can affect the plant also.

4.3.1 Property Analysis

The plant is a manufacturing plant of LPG. After identifying the risk, the next step is to measure it. And also in order to calculate FEDI and TDI it's necessary to know its properties. Properties of LPG is given in Table 6[available in the support document]

Considering all values, FEDI and TDI for the plant has been calculated. These are respectively 11094.33 and 6.5. FEDI value is quite high here as LPG gases are very much combustible and also the plant storages are pretty much congested though well maintained. Therefore, plant C is extremely hazardous in terms of FEDI and not hazardous in terms of TDI.

4.3.2 Credit Analysis

To minimize the risk plant C makes sure some safety features. For emergency resource planning they have few modes of communication during emergency, individuals are quite aware of their

responsibility, hospital is nearby, fire drills are conducted often. In disaster management plan no neighboring industrial people are involved, firefighting devices are in sufficient quantity, technical professionals are properly trained, duty of each individuals is displayed and monitored, outside people are not involved that much. Water with separate pipe line and adequate quantity of fire extinguishing gases are available, but there is no flame arrestor. Temperature, pressure, level, flow controllers are present. The industry adopted sufficient amount of detecting devices throughout the plant except in the filling unit. Process operation is moderate and human interaction is required sometimes. There is no record of any equipment failure. According to their safety facilities some credit values are calculated and with these values overall safety factor is also calculated as SWeHI rules.

Credit parameters for Plant C:

For plant C available credit parameters can be considered as following numerical values according to their facilities, equipment and effectiveness. [7] Emergency resource planning- 2.4, Disaster management plan- 3.1, Other damage control measures- 1.6, Process control system- 2.3, Installation of detected device- 1.8, Emergency control measures- 1.4, Human error prevention- 2.1, Equipment reliability- 1

Again, these safety credits provide an overall safety factor of 2541.4 which leads to a SWeHI value of 4.365. So it can be rated as moderately hazardous. Though the plant area ensures satisfactory safety facilities but filling area and barge are not well protected. Therefore, safety features like gas detector for filling area and potable firefighting equipment for barge should be included. Fire arrestor is not available to prevent the plant from outside hazard effect. Moreover, the control room in the plant can't control the plant automatically, so more advance technology should be included to make the less hazardous plant to not hazardous.

5. Findings and Recommendations

Analyzing the data of damage indices and credit factors, final comparison of the safety performance on the basis of SWeHI values between these three plants are given in Table 7.

So, it can be easily mentioned that plant A and B are too much hazardous compared to plant C after implying SWeHI indexing method.

There are actually no strict safety regulations that are needed to follow to get a license to set up a plant in Bangladesh. And being a developing country, it is not possible to maintain as the other developed

countries are doing. There can be budget, cultural, technical, political issues. So, it is quite necessary to set up some feasible acts which can lessen the risks without disturbing the mentioned facts.

Table 7:

Comparison of safety performances between plant A, Plant B and Plant C.

Plant	A	B	C
FEDI	65072	45329	11094
TDI	0.12	0.12	6.50
Overall Safety Factor	211.63	503.84	2541.45
SWeHI	307.47	89.967	4.365
Rating	Extremely Hazardous	Extremely Hazardous	Moderate

The indices actually set a relation between what hazards are actually posing and how much the authority is concerned to minimize the risks. Now plant A, B and C basically deals with storage facilities of explosive and toxic chemicals. The analysis is clearly showing three different pictures. All of three are dealing with dangerous chemicals. But plant A and B's indices are high. Plant C is posing an index which is quite reasonable. Definitely, not taking enough measures is a huge cause. This was a general picture but actually there are lots of plants out there. Of course, the infrastructure is huge issue. But constructions which are already done cannot be undone. So, talking about changing infrastructure will not be a good suggestion. Analyzing overall scenario some feasible recommendations are formulated here which can be considered for improving overall safety performance of the process plants.

Emergency resource planning:

Emergency resource planning involves coordination between the different layers of management within an industry, service agencies such as trauma centers and fire brigades, and the neighboring industries are likely to be affected. If the plant is situated somewhere in remote area like plant alpha, in that case, the authority must be in good terms with local defense forces. So that in case of emergency situations, safety of human resources can be ensured.

Detection devices:

Early discovery of inaccuracy can greatly minimize the likelihood of an event occurring. Smoke detectors and fire alarms should be installed at all relevant locations. Their precision should be checked. Employee education and training are required. So that in the event of an emergency or a technical failure, personnel can confirm the risks and take appropriate action. This is known as manual detection. Manual detection should be implemented.

A good communication facility within the plant is required for this.

Emergency exits planning:

Authorities must be ready for the worst-case situation. Failures, both technical and manual, can occur at any time. Fire barriers and fire doors are widely accessible these days. These facilities must be put in place for the worst-case scenarios.

Disaster management plan:

The disaster management plan is another hazard control measure that is generally developed by forecasting an accident, assessing its harmful consequences, and estimating the steps necessary to mitigate the consequences.

Emergency control measures:

As per the old proverb prevention is better than cure, emergency control systems are very significant. Emergency shutdown, interlocks, showers, safety vents devices are essential. In case of worst-case scenario if safety relief devices, rupture disks or this kind of facilities fails, emergency lockdown or shutdown can save the plant from accidents.

Education and Safety Training:

Annual training programs for employees, operators and workers should be introduced on how to deal with hazardous chemicals, job specific trainings, basic awareness training and what to do when emergency situation comes.

6. Conclusion

Industrial safety management is very crucial to the continued existence of any industry. This is because when accident occurs often in an industry, such industry can fold up. Hence, it is paramount for every industry to follow and maintain certain rule to prevent accidents. Beside a better infrastructure and design, it is also required to have adequate safety operational practices, proper controlling devices as well as qualified safety professionals to minimize the risk associated with the hazards. The proposed recommendation and finding in this work could serve as an assessment criterion during the approval and license renewal for hazardous establishments.

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Supporting Document

Table 1: Hazard ranking according to FEDI[1]

FEDI	Hazard characterization
<20	No Hazard
20-100	Less Hazard
101-200	Moderate
201-400	Hazardous
401-500	Highly Hazardous
>500	Extremely Hazardous

Table 2: Hazard ranking according to TDI[1]

TDI	Hazard characterization
<5	No Hazard
6-50	Less Hazard
51-200	Moderate
201-500	Hazardous
501-700	Highly Hazardous
>700	Extremely Hazardous

Table 3: Hazard ranking according to SWeHI[2]

SWeHI	Hazard characterization
0	No Hazard
0-1	Less Hazard
2-5	Moderate
6-10	Hazardous
11-20	Highly Hazardous
>20	Extremely Hazardous

Table 4: Properties of HFO [3][4][5]

Chemical Properties	Numerical Values
Heat of Combustion, H _c (kJ/mol)	3.95×10 ⁸
Atmospheric Pressure, AP(kPa)	101.32
Process Pressure, PP(kPa)	101.32
Vapor Pressure, VP(kPa)	0.99
Volume of vessel, V(m ³)	568.4
Ambient Temp(C)	25
Process Temp, T (C)	25
Flash Point(C)	115
Fire Point(C)	125
Auto Ignition Temp(C)	302
Chemical quantity (Ton)	611.7
NF(NFPA ranking For Flammability)	2
NR(NFPA ranking For Reactivity)	0
NH(NFPA ranking For health hazard)	2
Air density (kg/m ³)	1

Table 5: Properties of Lube oil [6][7]

Chemical Properties	Numerical Values
Heat of combustion, H _c (J/mol)	9.36×10 ⁷
Constant, K	3.148
Atmospheric Pressure, AP(kPa)	101.32
Process Pressure, PP(kPa)	101.32
Vapor Pressure, VP(kPa)	0.00001
Volume of vessel, V(m ³)	109
Ambient Temp(°C)	25
Process Temp (°C)	25
Flash Point(°C)	187
Fire Point(°C)	197
Auto Ignition Temp(°C)	237
Distance From nearest hazardous unit(m)	3
Chemical quantity (Ton)	418
NF(NFPA ranking For Flammability)	1
NR(NFPA ranking For Reactivity)	0
NH(NFPA ranking For health hazard)	0
% space occupied by the unit in an area of 30m rad from unit	10
Air Density(Kg/m ³)	1.2

Table 6: Properties of LPG [8]

Chemical Properties	Numerical Values
Heat of combustion, H _c (kJ/mol)	1.04×10 ⁶
Atmospheric Pressure, AP(kPa)	101.32
Process Pressure, PP(kPa)	405
Vapor Pressure, VP(kPa)	637
Volume of vessel, V(m ³)	127
Ambient Temp(°C)	25
Process Temp (°C)	25
Flash Point(°C)	-76
Fire Point(°C)	-65
Auto Ignition Temp(°C)	380
Chemical quantity (Ton)	230
NF(NFPA ranking For Flammability)	4
NR(NFPA ranking For Reactivity)	0
NH(NFPA ranking For health hazard)	1
Air density (kg/m ³)	1.2

References:

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