
CHAPTER 6

RISK ASSESSMENT AND CONSEQUENCE ANALYSIS**6.1 INTRODUCTION**

Hydrocarbons operations are generally hazardous in nature by virtue of intrinsic chemical properties of hydrocarbons or their temperature or pressure of operation or a combination of these. Fire, explosion, hazardous release or a combination of these are the hazards associated with hydrocarbons operations. These have resulted in the development of more comprehensive, systematic and sophisticated methods of **Safety Engineering**, such as, **Hazard Analysis** and **Risk Assessment** to improve upon the integrity, reliability and safety of hydrocarbons operations.

The primary emphasis in safety engineering is to reduce risk to human life and environment. The broad tools attempt to minimize the chances of accidents occurring. Yet, there always exists, no matter how remote, that small probability of a major accident occurring. If the accident involves hydrocarbons in sufficient large quantities, the consequences may be serious to the project, to surrounding area and the population therein.

Risk assessment for crude oil storage and handling operations is discussed briefly in this chapter because the same will be carried out at the STF at Naoholia. Furthermore, risk associated with crude oil dehydration, and crude oil storage in large quantity will also be discussed in this chapter because the same will occur at STF development project installation.

6.2 IDENTIFICATION OF HAZARDS IN CRUDE OIL PRODUCTION, STORAGE AND TRANSPORT OPERATIONS

Various hazards associated with crude oil storage and handling operations are briefly described in following sub-sections.

6.2.1 Minor Oil Spill

A minor oil spill is confined within a limited area of STF development project installation. The conditions which can result in minor oil spill are oil spillage from leaking valves, lines and storage tanks.

6.2.2 Major Oil Spill

Significant crude oil inventories will be maintained at STF development project installation and a major spill can, therefore, arise as a result of storage tank failure. Many thousand liters could be leaked in a few minutes which, however, will be contained inside dyke wall area. But these major leakages are detected immediately and could be minimized by stopping feed pump feeding storage tank and emptying out the crude oil by pumping to another safe storage tank if cause of tank failure cannot be rectified quickly.

Provided that ignition does not take place, appropriate measures must be implemented quickly to transfer the leaked quantity of crude oil to a safe storage tank if cause of tank failure can not be rectified quickly. If ignition

occurs, then major fire is likely which will have an adverse impact on the installation, surrounding area and the population therein.

6.3 FIRE FIGHTING FACILITIES FOR STF DEVELOPMENT PROJECT

Crude oil storage and handling facilities at STF development project installation have inherent risk of fire and explosion hazards due to inflammable and explosive nature of crude oil. Fire Protection System will be provided at each installation as per TAC, OISD-117 and 189 Standards. All the hazardous area will be covered by water/foam monitors and hydrants with fire water pipeline network pressurized at 7 kg/cm². The system will include the following for fire fighting facilities:

- Hydrant system
- Water Spray System
- Foam Pourer System
- Automatic Fire Detection and Alarm system, etc.

Based on the total water requirement for the Fire Fighting System, following major Facilities are envisaged at STF development project installation at Naoholia in TNJ area:

- Two numbers of Fire Water tanks/ Ponds of suitable capacity.
- Adequate numbers of Diesel Engine driven Fire Pumps of suitable capacity.
- Two numbers Electric Motor driven Jockey Pumps of suitable capacity.

6.4 MEDICAL FACILITIES

Eventhough chances of accident occurring during operation of STF development project for storage and quality control of crude oil are negligible since observation of necessary safety requirements will be strictly followed and excellent track record of OIL in this respect. However, first aid would be made available at STF development project installation and a 24 hour standby vehicle (ambulance) would also be available at the nearby OIL's own full fledged Hospital presently functioning round the clock at Duliajan township for quick transfer of any injured personnel to the hospital, in case an accident occurs and medical emergency arises. Prior arrangements will also be made with the civil hospitals at Tinsukia and Dibrugarh to look after the injured persons in case of medical emergency during operation of STF development project.

6.5 QUANTATIVE RISK ASSESSMENT

Quantitative risk assessment (QRA) is a formal systemized approach for hazards identification and ranking. The final rating number provides a relative ranking of the hazards. Fire and Explosion Index (F&EI) is an important technique employed for hazards identification process. Consequence analysis then quantifies the vulnerable zone for a conceived incident. Once vulnerable zone is identified for an incident, measures can be formulated to eliminate or reduce damage to plant and potential injury to personnel.

6.5.1 FIRE AND EXPLOSION INDEX & TOXICITY INDEX

Rapid ranking of hazard of an entire plant, if it is small, or a portion of it, if it is large, is often done to obtain a quick assessment of degree of the risk involved. The **Dow Fire and Explosion Index (F&EI)** and **Toxicity Index (TI)** are the most popular methods for **Rapid Hazard Ranking**. These are based on a formal systematized approach, mostly independent of judgemental factors, for determining the relative magnitude of the hazards in an installation using hazardous (flammable, explosive and toxic) materials.

The steps involved in the determination of the F&EI and TI are:

- Selection of a pertinent process unit
- Determination of the Material Factor (MF)
- Determination of the Toxicity Factor (Th)
- Determination of the Supplement to Maximum Allowable Concentration (Ts)
- Determination of the General Process Hazard Factor (GPH)
- Determination of the Special Process Hazard Factor (SPH)
- Determination of the F&EI value
- Determination of the TI value
- Determination of the Exposure Area

6.5.1.1 Hazardous Material Identification Methodology

From the preliminary appraisal of Material Safety Data Sheet, it is observed that both crude oil and natural gas are flammable and hazardous. Furthermore, large quantities of crude oil will be stored in storage tanks at STF. In view of hazards associated with very large storage inventory of crude oil in storage tanks at STF, F&EI and TI values have been computed for crude oil storage tanks at STF.

In general, the higher is the value of material factor (MF), the more flammable and explosive is the material. Similarly, higher values of toxicity factor (Th) and supplement to maximum allowable concentration (Ts) indicate higher toxicity of the material. The tabulated values of MF, Th and Ts are given in Dows Fire and Explosion Index Hazard Classification Guide. For compounds not listed in Dow reference, MF can be computed from the knowledge of **flammability** and **reactivity** classification, Th can be computed from the knowledge of the **National Fire Protection Association (NFPA) Index** and Ts can be obtained from the knowledge of **maximum allowable concentration (MAC) values**. The MF, Th and Ts values are respectively 16, 0 and 50 for crude oil and 21, 0 and 50 for natural gas.

General process hazards (GPH) are computed by adding the penalties applied for the various process factors.

Special process hazards (SPH) are computed by adding the penalties applied for the process and natural factors.

Both General process hazards and Special process hazards corresponding to various process and natural factors are used with MF to compute F&EI value and with Th and Ts to compute TI value.

6.5.1.2 F&EI Computation

F&EI value computed for crude oil storage at STF from GPH and SPH values using the following formula are given in **Table 6.1**:

$$\text{F\&EI} = \text{MF} \times [1 + \text{GPH (total)}] \times [1 + \text{SPH (total)}]$$

6.5.1.3 Toxicity Index (TI)

Toxicity index (TI) is computed from **toxicity factor (Th)** and **supplement to maximum allowable concentrations (Ts)** using the following relationship:

$$\text{TI} = (\text{Th} + \text{Ts}) \times [1 + \text{GPH (total)} + \text{SPH (total)}] / 100$$

Table 6.1 also gives the toxicity index (TI) value for crude oil storage considered most hazardous at STF operational area.

6.5.1.4 HAZARDS RANKING

Table 6.2 gives the hazard ranking based on F&EI values and also on toxicity index values. **Table 6.1** shows that the F&EI value is 79.36 and TI value is 1.85 for storage of crude oil in large quantity at STF and, therefore, STF area has **Moderate Hazard Potential** based on F&EI and **Low Hazard Potential** based on TI.

It may, however, be noted that hazards ranking (light, moderate, intermediate, heavy and severe) is based solely on potential and is basically used to improve upon the integrity, reliability and safety of crude oil storage and handling facilities by making requisite improvements in design of storage and handling facilities, by evolving completely safe operating procedures and by maintaining good safety standards. It is, therefore, quite possible that a crude oil storage installation which may have **moderate hazard potential** may be **completely safe in actual operation** as a result of conscious efforts by OIL management by ensuring safe design and operating procedures for minimizing the chances of occurrence of hazardous incidents.

6.5.2 CONSEQUENCE ANALYSIS

Consequence analysis quantifies vulnerable zone for a conceived incident and once the vulnerable zone is identified for an incident, measures can be proposed to eliminate damage to plant and potential injury to personnel. Consequence analysis for crude oil storage at STF has been carried out. The chosen scenario for consequence analysis is:

- Rupture of one of the nozzle of crude oil storage tank at STF.

Estimation of vulnerability zone of such an incident plays an important role in preparing a realistic emergency plan. Only credible consequence of leakage of stabilized crude oil at STF will be the pool fire within bunded area.

The thermal radiation modelling is based on correlation of Thomas and various other relations available in "Guidelines for Chemical Process Quantitative Risk Analysis", published by Centre for Chemical Process Safety, American Institute of Chemical Engineers, New York (USA).

Wind speed of 1.0 m/s has been assumed during the fire to consider worst meteorological condition and has been selected based on recommendation in the above reference.

6.5.2.1 Damage Criteria For Thermal Radiation

In order to apprehend the damage produced by various scenarios, it is appropriate to discuss the physiological/physical effects of thermal radiation intensities. The thermal radiation due to pool fire usually results in burn on the human body. Furthermore, inanimate objects like equipment, piping, cable, etc. may also be affected and also need to be evaluated for damages. **Tables 6.3 and 6.4** give tolerable intensities and damages to various objects.

6.5.2.2 Pool Fire in STF Area

Rupture of nozzle (dia 100 mm) of crude oil tank at STF containing stabilized crude will result in leakage of crude oil which will spread within bunded/dyked area and will be filled with released crude oil. Since the minimum open cup flash point of stabilized crude is expected to be more than 32°C (maximum temperature likely in tank farm area), formation of explosive vapour cloud from pool is ruled out and only pool fire of spilled crude oil is likely if ignition source is available. The consequence analysis calculations in this scenario include:

- Effective pool area,
- Combustion rate on ignition of pool,
- Heat radiation distance to 15 kW/m², 12.7 kW/m², 10 kW/m², 3 kW/m² and 1 kW/m².
- **Release Consequence**

The computed results of consequence analysis are as follows:

Parameters	Crude Oil Tank
Release Rate	38.10 kg/s
Release Quantity	23510 kg
Effective Pool area	230 m ²
Combustion Rate	23.52 kg/s
Heat Radiation Distance from Pool Boundary (m) for Different Radiation Intensity (kW/m²)	
• For 15 kW/m ²	15.0 m
• For 12.7 kW/m ²	16.5 m
• For 10 kW/m ²	19.0 m
• For 3 kW/m ²	43.0 m
• For safe limit of 1 kW/m ²	77.5 m

The consequence analysis results indicate that the safe distance from tank farm pool (bund periphery) for fire radiation intensity defined as the distance to

1 kW/m² heat level, extends from 77.5 m from pool boundary and **distances upto 77.5 m around tank farm pool boundary (bund periphery) are considered as vulnerable zone.**

6.5.2.3 Frequency of Occurrence of Accident Scenario

Frequency of occurrence of incident is important in risk analysis. Safe operating procedures, proper maintenance and safety precaution reduce the frequency of occurrence of such incident. The data sources referred for failure frequency is E&P Forum (Oil Industry International Exploration & Production Forum) frequency data base from TNO and failure frequency data from the Rajmond Report (COVO study). The frequency occurrences for various scenarios are given below:

Sl. No.	Scenarios	Frequency of Occurrence
1.	Catastrophic failure of largest nozzle connection in crude oil tank	1 x 10 ⁻⁶ per tank per year
	Probability of Ignition	
	• Immediate Ignition	0.065
	• Delayed Ignition	0.065
	• No Ignition	0.87
2.	Catastrophic failure of Tank	6.7 x 10 ⁻⁷ per tank per year

Catastrophic failure of either a crude oil storage tank or that of its largest nozzle connection will, therefore, have a combine frequency of occurrence of 1.67 x 10⁻⁶ per tank per year or alternately once in every 5,98,800 years for each tank. Since number of crude oil storage tanks at STF is 6, the probability of such catastrophic failures will be once in 99,800 years at STF at Naoholia. Therefore, probability of catastrophic failure of either a crude oil storage tank or its largest nozzle connection at any of the STF development project installation appears to be quite remote. It may, however, be noted that even though the probability of catastrophic failure of storage tank or its largest nozzle connection is found to be remote but the probability of their minor failure (hole and leak) will be relatively more which may result in minor oil spill. Furthermore, possibility of leakage of crude oil can be much more due to sabotage at STF.

Safety precaution, proper maintenance of equipments and risk mitigation measures adopted in storage and handling of inflammable materials will reduce the probability of occurrence of hazardous incident. Strict security surveillance will reduce the possibility of sabotage at STF.

6.5.2.4 Conclusions

Quantitative risk analysis presented above leads to following conclusions:

- Storage of crude oil in tank farm area has a computed F&EI value of 79.36 and indicates **moderate fire and explosion hazard.**
- Storage of crude oil have **low toxicity hazard** with computed TI value of 1.85.

- Safe distances for stationary persons not to cause any discomfort for exposure time upto 60 seconds will be 77.5 m from the boundary of pool fire in tank farm area of STF installation.

6.5.2.5 Recommendations for Risk Reduction

- Smoke sensors and thermal detectors should be installed at strategic locations including tank farm area and other vulnerable area at STF.
- Proper fire fighting system (hydrant and fire extinguishers) should be provided in tank farm area, power generator room, housing complex, etc at STF.
- Crude oil storage tanks at STF should be inter-connected so that in case of emergency crude oil from one could be quickly transferred to other.
- Proper deluge system has been provided to all crude oil storage tanks, emulsion treater to avoid cascading effect of fire.
- Developing of a properly designed peripheral green belt around STF area will help in preventing the spread of fire to other areas if accidental fire occurs in crude oil storage tanks.

Table 6.1

Determination of the Fire and Explosion Index and Toxicity Index of the Crude Oil

	Crude Oil in Tank Farm
MATERIAL FACTOR (MF)	16
GENERAL PROCESS HAZARDS (GPH)	Penalty Used
Exothermic Reactions (Condensation/Hydrolysis)	0
Endothermic Reactions	0
Material Handling and Transfer	0.50
Process Units within a Building	0
Centrifuging	0
Limited Access	0
Poor Drainage	0.10
Add: GPH(total)	0.60
[(1+GPH(total)) x Material Factor = sub-factor	25.6
SPECIAL PROCESS HAZARDS (SPH)	
Process Temperature (use highest penalty only)	
- above flash point	0.25
- above boiling point	0
- above auto ignition	0
Low Pressure (atmospheric/sub-atmospheric)	
- Hazard of Peroxide Formation	0
- Hydrogen Collection Systems	0
- Vacuum Distillation at less than 0.67 bar abs.	0
Operation in or near Flammable Range	
- Storage of Flammable Liquids and LPGs outdoor	0.50
- Reliance on Instrumentation and/or Air Purging to stay out Flammable Range	0
- Always in Flammable Range	0
Operating Pressure	0
Low Temperature	0
- Between 0 and -30 deg. C	0
- Below -30 deg. C	0
Quantity of Flammable Material	
- In Process	0
- Storage	1.15
Corrosion and Erosion	1.10
Leakage joints and packing	1.10
Add: SPH	2.10
[(1+SPH(total)) x sub-factor = F&EI	79.36
TOXICITY INDEX TI	
Toxicity Factor (Th)	0
(Ts)	50
(Ts + Th)	
----- x [(1 + GPH(total) + SPH(total)) =	
100	1.85
Toxicity Index TI	

- Note:**
1. The term “process” includes handling as well as storage.
 2. For a number of process hazard the penalty to be used is fixed and can be taken from the preceding column “penalty”.

Table 6.2**Hazard Ranking****I. Based on Dow Fire and Explosion Index (F & EI)**

F & EI Value	Hazard Ranking
1-60	Light
61-96	Moderate
97-127	Intermediate
128-158	Heavy
159-up	Severe

II. Based on Toxicity Index (TI)

TI Value	Hazard Ranking
< 6	Low
6 – 10	Moderate
10 – up	High

Table 6.3**Tolerable Radiation Intensities For Various Objects**

Object	Tolerable Radiation Intensity (kW/m²)
Drenched Tank	38
Special Buildings (No windows, fire proof doors)	25
Normal Buildings	14
Vegetation	10-12
Escape Route	6 (upto 30 seconds)
Personnel in Emergencies	6 (upto 30 seconds)
Plastic Cables	2
Stationary Personnel	1.5

Table 6.4

Damage Due to Incident Radiation Intensity	
Incident Radiation Intensity (kW/m²)	Type of Damage
62	Spontaneous ignition of wood
38	Sufficient to cause damage to process equipment
25	Minimum energy required to ignite wood at infinitely long exposure (non piloted)
12.5	Minimum energy required for piloted ignition of wood, melting of plastic tubing, etc.
4.5	Sufficient to cause pain to personnel unable to reach cover within 20 seconds, blistering of skin (1 st degree burns) is likely.
1.5	Will cause no discomfort for exposure upto 60 seconds.