M. Tech. Dissertation Report

on

FIRE HAZARD ANALYSIS OF POWER PLANT IN RAJSHREE SUGARS AND CHEMICALS LTD.

Submitted by

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In partial fulfilment for the award of the degree of

Master of Technology

in

Health, Safety & Environment

Under the guidance of

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BONAFIDE CERTIFICATE

Certified this titled "**Fire Hazard Analysis of Power Plant in Rajshree Sugars and Chemicals Ltd**" is the bonafide work of **Dileepan GS (R080213013)** who carried out the work under my supervision. Certified further that to the best of my knowledge the work reported herein does not form part of any other thesis or dissertation on the basis of which a degree was conferred on an earlier occasion on this or any other candidate.

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This M. Tech. dissertation entitled "**Fire Hazard Analysis of Power Plant in Rajshree Sugars and Chemicals Ltd**" prepared by **Dileepan GS (Roll No. R080213013)** is approved for submission for the degree of **Master of Technology in Health, Safety and Environment** at **University of Petroleum and Energy Studies**.

Associate Vice President

Date: 01/04/2015

Place: Villupuram

Declaration

I hereby declare that the work entitled "**Fire Hazard Analysis of Power Plant in Rajshree Sugars and Chemicals Ltd**" is submitted in partial fulfilment of the requirement for the award of the degree in **M. Tech – Health, Safety and Environment** at **University of Petroleum and Energy Studies**, is a record of the my own work carried out by me during the academic year 2014 - 2015 under the supervision and guidance of, Mr. Presanjit Mondal, Assistant Professor, Department of Health, Safety and Environment, University of Petroleum and Energy Studies. The extent and source of information are derived from the existing literature and have been indicated through the dissertation. The matter embodied in this work is original and has not been submitted for the award of any other degree, either in this or any other University.

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Dileepan GS

Date:

Abstract

It is essential to understand the fire hazard to reduce the risk and for fire protection decision making. A fire hazard analysis (FHA) carried out here is a tool to understand fire hazards. The overall hazard of a process or facility can be determined. A FHA is an important tool of a risk assessment and can also be used as a separate hazard evaluation tool. Thus fire hazard analysis was carried out on a 35MW power plant considering various scenarios. The results of the FHA was used to identify the potential impacts of fire.

Fire hazard analysis shows that the fire hazard is negligible or very less in power plant as there are no flammable substance present except boiler area. The feed which is bagasse gets ignited only when the temperature goes above 400°C. So LPG is used for ignition. Thus boiler zone LPG is the major fire hazard. So LPG jet fire calculations were carried out. Recommendations were given based on the fire hazard analysis.

***Keywords**:* Fire Hazard Analysis (FHA), Jet fire, Fire Impact.

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List of Abbreviations

FHA	- Fire Hazard Analysis
TCD	- Tonnes of cane Crushed per Day
TPH	- Tonnes per hour
TG	- Turbine Generation
RPM	- Rotations per Minute
P	- Pressure (Pa)
v	- Specific volume of the gas
k	- Isentropic expansion factor
M	- Mass flow rate (kg/s)
C_d	- Coefficient of discharge
A_h	- Area of hole (m^2)
ρ	- Density of the gas (kg/m^3)
Q	- Heat release rate (kW)
Δh_c	- Heat of combustion (kJ/kg)
$\dot{m}$	- Mass flow rate (kg/s)
Q_r	- Heat radiated from the fire (kW)
R	- Distance from point source to target (m)
x_r	- Radiative fraction
q''	- Incident heat flux per unit surface area of a target (kW/m^2)
$\dot{m}''$	- Mass burning rate (kg/m^2s)
D	- Diameter of the fire (m)

Chapter 1
Introduction

1.1. General

Understanding fire hazards is essential to risk reduction and fire protection decision-making. A fire hazard analysis (FHA) is a tool used to understand fire hazards. The process of quantifying the fire hazard is typically motivated by the need to determine the overall hazard of a process or facility or to have a decision-making tool for fire protection systems. FHA is an important element of a risk assessment and can also be used as a standalone hazard evaluation tool.

A process hazard analysis is required to identify likely fire scenarios that are carried forward to the FHA. FHA provides the tools to characterize the hazards and evaluate consequences. The results are incorporated into an overall risk assessment.

1.2. Scope

This work is applicable to Co-Generation plant of Rajshree sugars and chemicals limited, Villupuram for the improvement of fire protection.

1.3. Aim

The aim of the project is to analyse the fire hazard in the power plant present in sugar mill. To fulfil the aim, the objectives are:

1. To study the fire protection facilities present in Co-Generation Plant of Rajshree Sugars and chemicals ltd.
2. To perform FHA to find the radiation impact on near-by equipment.
3. To provide suggestions and recommendations based on the analysis.

1.4. About the company

- Rajshree Sugars & Chemicals Limited was incorporated in the year 1985. Unit - I with a capacity of 2,500 TCD (Tonnes of cane Crushed per Day), commenced operations in January 1990 at Varadaraj Nagar in Theni District of Tamil Nadu
- RSCL acquired South India sugar Ltd, Villupuram District, Tamil Nadu in the year 2002 and it was subsequently merged with Rajshree Sugars & Chemicals

Limited as Unit–II. The present capacity of Unit - II is 5000 TCD. With RSCL's expertise, the unit has become one of the most efficient sugar plants in South India

Chapter 2

Literature survey

A FHA is used to document the inventory of flammable or combustible material, calculate the potential magnitude of the fire and determine the probable impact of the fire on personnel, equipment, the community and the environment. FHA can be performed on proposed or existing designs. Based on the fire impact, the fire losses can be estimated.

The FHA accomplishes three objectives:

- Provides an understanding of the hazards
- Enables the specification of performance-based fire protection
- Forms part of an overall risk assessment

The benefits of conducting an FHA includes:

- An inventory of fire hazards, including quantities
- A comprehensive understanding of the fire hazard
- An estimate of the potential impact of a fire on personnel, equipment, the community and the environment
- Development of a list of appropriate mitigation options

Process fires are very similar whether they occur outside or in enclosed buildings. The major differences are that products of combustion (toxic fumes, smokes, CO and CO_2) build-up in an enclosure very quickly and can incapacitate personnel and hinder escape. Depending on the location and size of the fire, personnel will not have much time (less than one minute) to escape the building. It is important that life safety issues can be handled by following the applicable building codes, Life Safety Codes and NFPA 101.

Another difference is that, heat will build-up within an enclosure and the temperature on equipment and structures will increase quicker. The effects of both products of combustion and heat will be impacted by the venting that occurs in the building.

In table 2.1, the research work on fire hazard analysis, fire protection assessment, fire investigation, etc have been discussed.

Table – 2.1 A few research works on fire hazard assessment, fire investigation etc.

S. No.	Author & Year	Topic/Study Aspect	Objective	Methodology	Findings	Conclusion
1.	Author: Jaewook Kwon Year: 2014	Assessment of fire protection systems	To assess the level of protection afforded by stage active fire protection measures	Computational fluid dynamics has been utilized to examine fire conditions	The sprinkler activation times were not much sensitive. It was observed that opening of the stage roof vents by means of rate-of-rise heat detectors precede the activation of sprinkler	The assessment was carried out and recommendations were given.
2.	Authors: Qing Dong, Fei You, Shi-qiang Hu Year: 2014	Investigation of Fire Protection Status	To investigate the fire protection status of facilities present in historical sites of China	Field Investigation covering various aspects of fire protection	Fire protection equipment present and the monuments and their efficiency were calculated.	Fire risk is possessed by : wood component, internal Extensive distribution of combustible, partial high fire load, deficiency of fire separation distance, suppression difficulties caused by location site,

						lacking of fire fighting pipe network, unreasonable fire detector etc.
3.	Authors: Abdulaziz A.Alarifi, JimDave Year: 2014	Effects of fire-fighting on a fully developed compartment fire	To study and evaluate the effects and consequences of fire-fighting operations on the main characteristics of a fully-developed compartment fire	Testing building, fire load calculations, Instrumentation and fire fighting approach	It presents data and evaluation of the conditions to which fire-fighters are exposed. A typical room enclosure was used with ventilation through a corridor to the front access door. The fire load was wooden pallets. Flashover was reached and the fire became fully developed before the involvement of the fire-fighting team. The progress of the fire-fighters through the corridor and the main room was monitored and the effect of short, medium and long water pulses on either the hot gas layer or the fire seat was determined in terms of the compartment temperature, heat release	The fire fighting team was exposed to extreme conditions, heat fluxes in excess of 35 kW/m^2 and temperatures of the order of 250ºC even at crouching level.

					rates, oxygen levels and toxics pieces concentrations.	
4.	Authors: Jeong Hwan Kim, Du Chan Kim, Year : 2013	A study on methods for fire load application with passive fire protection effects	To develop guidelines for the Quantitative Risk Assessment (QRA) of FPSO installations, with a focus on top sides and equipment that are subject to fires	The design loads for gas explosions are equivalent to overpressure, drag forces and Pressure impulses and those for fire are equivalent to temperature and heat doses.	Fire load application methods considering with or without the effect of PFP are well established.	The modelling method of PFP using temperature dependent Thermal conductivity and specific heat is very useful in prediction of temperature development through insulation materials.

Chapter 3

Methodology

3. 1. Study of production process

Cane after weighed is taken through preparatory cane devices like leveller, fibrize/mincer, etc. In the preparatory cane devices, cane is cut and the cells in cane are opened without the extraction of juice and ready for crushing in the milling tandem.

During the crushing in milling tandem water through meter at 60ºC to 70ºC is added in the last two mills for maximum extraction of sugar from the cane. The water addition is known as Imbibition. The ratio of sugar extraction in mills to sugar in cane is known as mill extraction. The residue obtained after crushing is called bagasse which is used as fuel in Boilers for producing steam.

A part of dry saturated, superheated steam obtained from boilers is used for power generation in turbo alternators for generation of electricity and the rest is used in mill turbines for driving mill rollers. The exhaust steam coming out from turbo alternators and the mill turbines after de-superheating is ideal for use in heat exchangers called juice heaters, Evaporators and vacuum pans in sugar manufacture.

The juice obtained from the mills is weighed and in the first stage heated to around 65ºC - 70ºC and treated with lime of 6 ºBeryllium and dry sulphur di-oxide to about pH 7.0. During this treatment Calcium Hydroxide reacts with phosphate present in the juice forming tri calcium phosphate which is having a property of occluding the impurities and absorbing much of colouring matters existing in the juice. The Sulphur di-oxide combines with Calcium forming calcium sulphite which absorbs colouring compounds as well as other impurities. The Sulphur di-oxide added also has a definite bleaching effect. In the second stage the treated juice is heated to boiling point 103ºC to accelerate and complete the reactions. After this it is sent to continuous settler called clarifier where it is allowed to settle. The clear supernatant liquid called clear juice is taken out and sent to evaporators for further concentration.

The muddy juice at the bottom is taken out and sent to vacuum filters for filtration. The filtrate obtained from filters is taken back to process while the mud is thrown out to be used as manure by the ryots. During the evaporation the clear juice of 12 Brix concentration is evaporated in multiple effect evaporators to about 60 Brix concentration which is called as syrup.

This syrup is again treated with sulphur dioxide to around pH 5.0 for better bleaching to obtain good quality of sugar. The vapours obtained from first and second bodies are used in heat exchangers.

Crystallization takes place in vacuum pans. Pan boiling is carried out in three stages called A, B and C boiling. This is for maximum exhaustion of sucrose in syrup to crystals. The material obtained after boiling is called as A, B and C massecuite respectively. These massecuites are cooled in crystallizers for further extraction of sugar into crystals. The next stage is separation of mother liquor in centrifugals. The separated mother liquor is called as molasses from A and B massecuites is again sent to pans for further extraction of sugar into crystals. The last mother liquor separated from C massecuite called final molasses is weighed and sent to steel molasses storage as a bi-product to be disposed to distilleries, cattle feed units etc. The final product obtained from “A” massecuite called white sugar is dried, graded, weighed, bagged, stitched and marked as per Indian sugar standard and sent to gudown for storage. The entire process flow is explained in the Figure 3.1 – Process Flow Diagram.

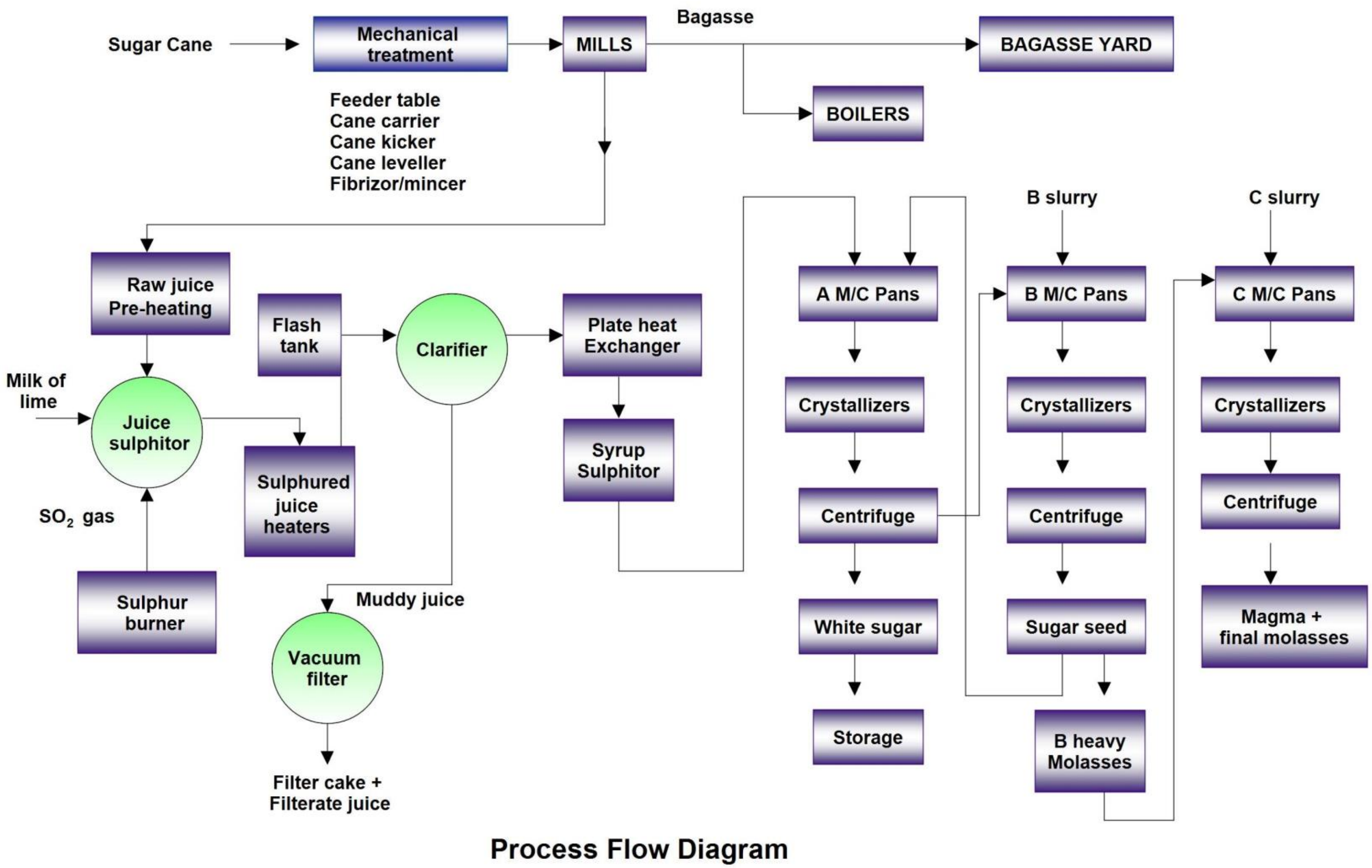

Figure 3.1 – Process Flow Diagram

3.2 Study of power plant and fire protection facilities

3.2.1 Co-Generation plant

- The Co – generation plant has a production capacity of 35 MW
- Bagasse is fed at a rate of 50 TPH along with stoichiometric air rate of 190 TPH
- Bagasse is fed with help of seven belt conveyers and one stack conveyer
- The bagasse and air are fed into the boiler which has a capacity to handle 100 TPH of bagasse
- The boiler operates at a pressure of 90 atmosphere and a temperature of 540±5 °C
- The high pressure steam generated from the boiler is fed into the 35 MW Turbine Generator (TG) set
- There are 15 stages in the TG set. First stage reduce one third of the temperature and pressure of the steam which is converted into electrical energy. The consecutive stages of turbine reduces pressure and temperature to minimum value
- The steam from the TG set is taken out from three stages
    - First stream is taken at 3 atmosphere pressure is fed to evaporator and de-aerator then it goes to boiler feed water tank
    - Second stream is taken at 9 atmosphere pressure and sent to HP heater which is fed back to boiler
    - Third stream is taken to air cooled condenser and then to plate heat exchangers
- A raw of 25 TPH is treated in Water treatment plant before sending to boiler feed water tank
- LPG gas is used for ignition of the boiler. The Co–Generation plant is shut down during rainy seasons and then started during off rain seasons
- Bagasse Requirement
    - 5.25 ton of steam is required to produce 1 MW of electricity
    - 1 ton of bagasse produces 2.5 ton of steam
- The excess of bagasse is stored in bagasse yard. The Co-Generation process flow diagram and the equipment layout is shown in the Figure 3.2 and Figure 3.3 respectively

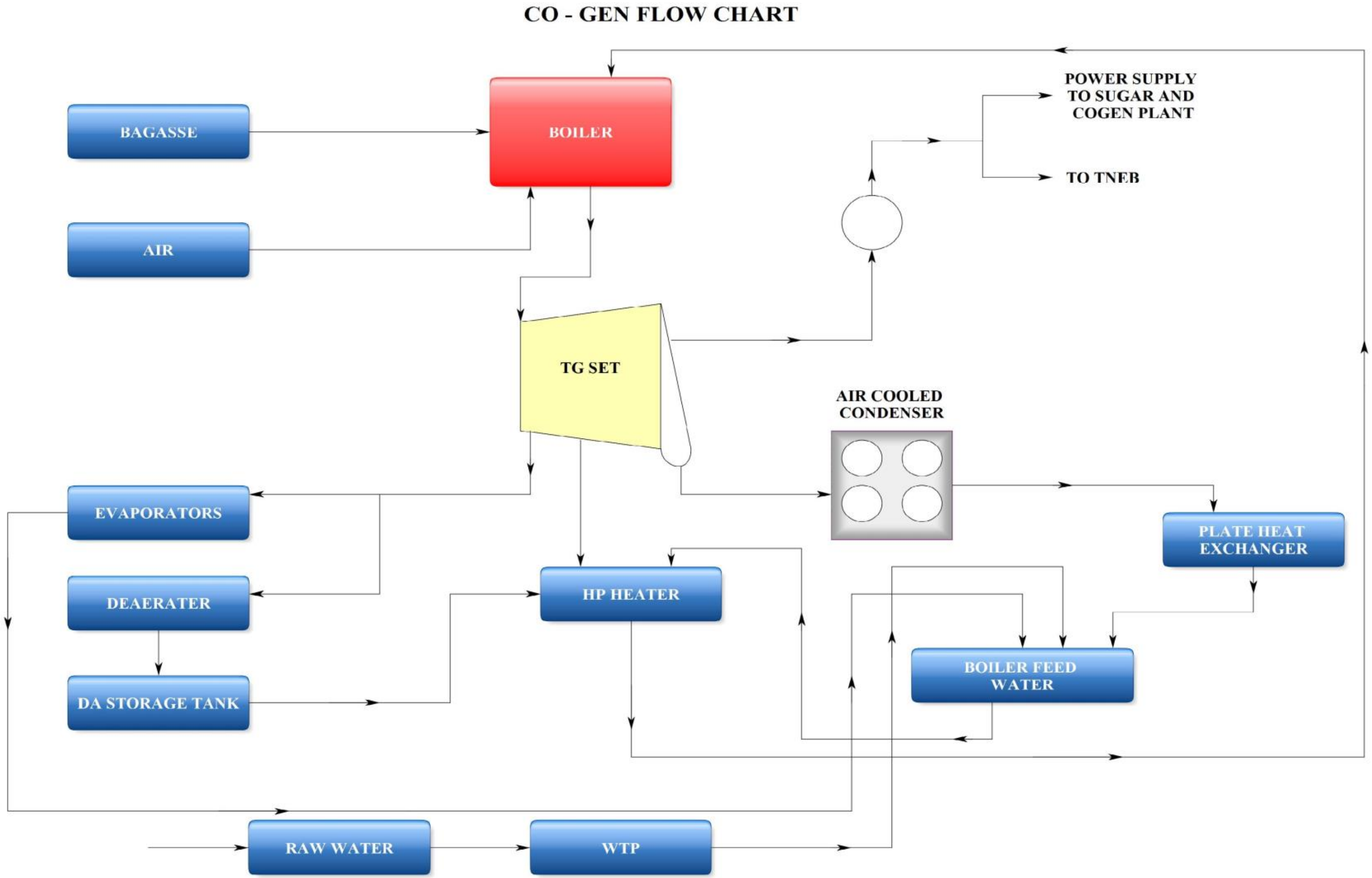

Figure 3.2 – Co-Generation Process Flow Diagram

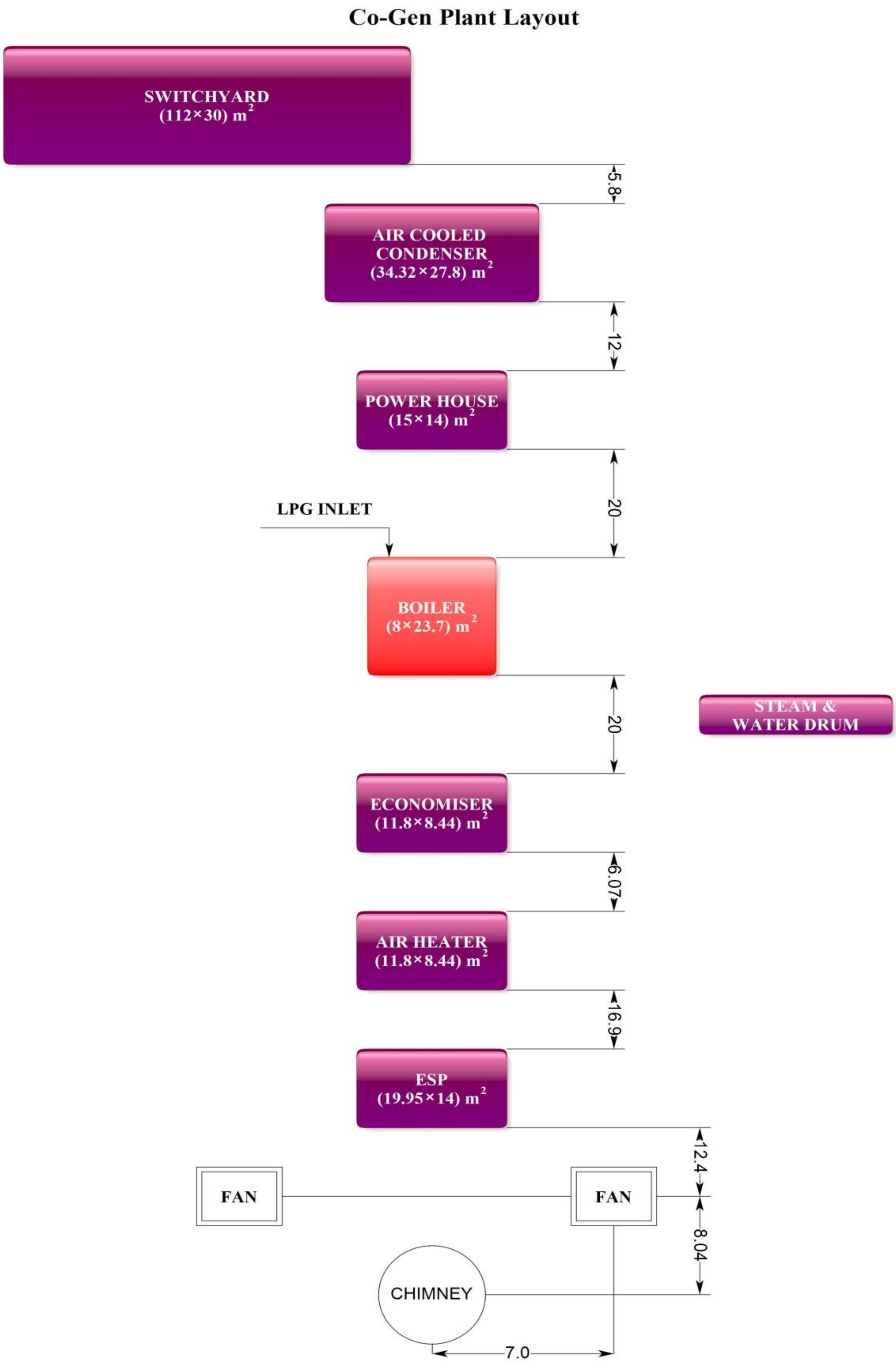

Figure 3.3 – Co-Generation Equipment Layout

3.2.2 Fire protection facilities available

The active fire protection is supported by two main pumps and one jockey pump which pumps water from a reservoir of 2,500 m^3.

The fire water line is maintained at a pressure of 7.5 kg/cm^2. When the pressure goes below 6 kg/cm^2, the jockey pump starts to maintain the pressure. If the pressure goes below 4 kg/cm^2 then the jockey pump automatically cuts out and the main pump starts. The plant pump details are given in the Table 3.1

Table 3.1 – Fire-fighting Pump Details

Specifications	**Pump – 1**	**Pump – 2**	**Jockey Pump**
Total Head (m)	88	88	90
Discharge (m^3/hr)	171	171	11
Pump Input (kW)	53.47	53.47	8.19
Size (mm)	125 × 100	125 × 100	50 × 25
Speed (RPM)	1450	1450	2900
Prime Mover Rating (kW)	67	67	11

There are 25 Hydrant points and 5 water monitor points surround every part of the power plant. Each equipment like boiler, economiser, etc are provided with automatic sprinkler system.

3.3 Fire hazard analysis

All equipment except boiler pose only negligible or low fire hazard. But boiler uses LPG for ignition during start-up which poses very high fire hazard. Thus jet fire hazard analysis is carried out for the boiler LPG gas. The detailed jet fire calculation is discussed below. The steps in the jet fire calculation is shown in figure 3.4.

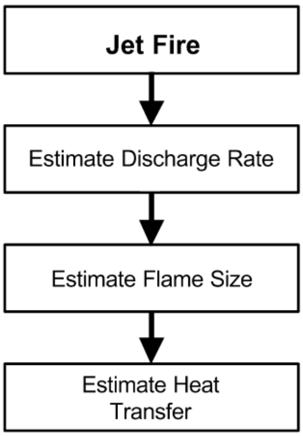

Figure 3.4 - Steps in Calculation

3.3.1 Estimating discharge rates

The initial release rate of hydrocarbon gas through a hole to the atmosphere depends on the pressure inside the equipment, the shape/size of the hole and the molecular weight of the gas.

For a small hole in the containment, there are two possible release conditions:

1. Adiabatic, if the pressure drop across the orifice is large.
2. Isothermal, if the pressure drop is small.

The adiabatic condition is the most common in accident cases. The process is treated as an isentropic free expansion of an ideal gas using the equation of state:

$$P \times v^{k} = constant \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.1)}$$

Where,

P	- Pressure
v	- Specific volume of the gas
k	- Isentropic expansion factor

Isentropic expansion factor is equal to the ratio of specific heats for pure isentropic, but in practice pure isentropic is not achieved, hence k is less than γ.

Assuming, flow on a horizontal axis and using a coefficient of discharge to account for friction at the orifice, the mass flow rate of an ideal gas through a thin hole in the containment wall is:

$$M = C_d \times \rho_{ambient} \times A_h \sqrt{\frac{2 \times P_{process}}{\rho_{process}} \times \frac{k}{k-1} \times \left[1 - \left(\frac{P_{ambient}}{P_{process}}\right)^{(k-1)/k}\right]} \text{ …..…. } (3.2)$$

Where,

M - Mass flow rate (kg/s)

P - Pressure (Pa)

C_d - Coefficient of discharge, typically 0.85 for gas releases

A_h - Area of hole (m^2)

ρ - Density of the gas (kg/m^3)

If the pressure ratio is above a critical value given below, the exiting mass flow is limited to a critical maximum value. This is sonic or choked flow:

$$\left(\frac{P_{ambient}}{P_{process}}\right)_{critical} = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} \text{ …………………….. } (3.3)$$

$$M_{max} = C_d \times A_h \times \sqrt{\left[P_{process} \times \rho_{process} \times k \times \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}\right]} \text{ …. } (3.4)$$

3.3.2 Jet flame size

Once the fuel flow rate is determined, the heat release rate is calculated as:

$$Q = \dot{m} \times \Delta h_c \text{ ……………………………………... } (3.5)$$

Where,

Q - Heat release rate (kW)

Δh_c - Heat of combustion (kJ/kg)

$\dot{m}$ - Mass flow rate (kg/s)

In relatively still air, the flame length, L (m), of most jet flames can be estimated as:

$$L = 0.2 \times Q^{2/5} \text{ …………………………………….. } (3.6)$$

The base of the jet flame is usually not attached to the release point, due to the high velocity and richness of the fuel near the heat source. This lift off distance has been measured on flares to be 20% of jet length.

For a jet fire close to obstacles but not impinging on them, the flame shape will be similar to free-field predictions but the radiation field will be distorted. A simple judgmental representation of the effects of obstacles on the radiation zones is described below:

- Solid obstacles such as walls on enclosed spaces are considered impervious to thermal radiation, and are assumed not to affect the radiation zones outside them
- Partial obstacles such as process equipment or decks on open sided modules are approximated by reducing the radiation zones as given in the table 3.2

Table 3.2 – Variation in Radiation Level

Actual Value	Reduced Value
37.5 kW/m^2	12.5 kW/m^2
12.5 kW/m^2	5 kW/m^2
5 kW/m^2	2 kW/m^2

When a jet fire has decayed to a pressure of 10 psig the fire is assumed to have effectively ceased. This pressure is close to the transition pressure from sonic to subsonic flow. When a jet fire event has decayed to this level, its magnitude and exposure potential are considered to have reached a threshold level below which no significant further damage can occur (i.e., no escalation potential) and active fire-fighting measures can effectively bring the fire under control.

3.3.3 Heat transfer

To calculate the incident heat flux per unit surface area on a target, q", at a distance R from the point source, the following equations apply:

$$q'' = \frac{Q_r \cos\theta}{4\pi R^2} \quad \text{………………………………………... (3.7)}$$

$$Q_r = x_r \times Q \quad \text{……………………………………..… (3.8)}$$

Where,

Q - Heat release rate (kW)

Q_r - Heat radiated from the fire (kW)

R - Distance from point source to target (m)

x_r - Radiative fraction

q'' - Incident heat flux per unit surface area of a target (kW/m^2)

$$\cos\theta = 1 \quad \text{for } U^* \leq 1$$

$$\cos\theta = \frac{1}{\sqrt{U^*}} \quad \text{for } U^* > 1$$

$$U^* = \frac{U_w}{\sqrt[3]{\frac{g\,\dot{m}''D}{\rho v}}} \quad \text{………………………………….. (3.9)}$$

Where,

$\dot{m}''$ - Mass burning rate (kg/m^2s)

The radiative fraction is the fraction of heat that is radiated from the fire plume. It can be estimated using

$$X_r = 0.21 - 0.0034D \quad \text{……………………………. (3.10)}$$

Where,

X_r - Radiative fraction

D - Diameter of the fire (m)

The radiative fraction, X_r, generally ranges from 0.2 to 0.4. This range reflects differences in fuel properties, with values of 0.2 for hydrocarbon fuels with one carbon atom (e.g., C1 for methane) to values of 0.4 for hydrocarbons with five or more carbon atoms

3.4 Jet fire calculation – scenario 1

In this scenario Jet fire calculations are carried out assuming that the gas release area is very small (25 mm^2).

Data:

C_d = 0.85

A_h = 25×10^{-6} m^2

k @ 1.6MPa = $\frac{142.5}{100.2}$ = 1.422

ΔH_c = 49.9 MW/kg

$\dot{m}''$ = 0.11 kg/m^{2}s

U_w = 6 m/s

D = 1 m

R = 20 m

Parameter	**Ambient**	**Process**
Density (kg/m^3)	557	2.21
Pressure (Pa)	0.53×10^6	1.65×10^6

i. Estimating Discharge Rate

$$M = C_d \times \rho_{ambient} \times A_h \sqrt{\frac{2 \times P_{process}}{\rho_{process}} \times \frac{k}{k-1} \times \left[1 - \left(\frac{P_{ambient}}{P_{process}}\right)^{(k-1)/k}\right]}$$

M = 14.19 kg/s

The pressure ratio value is found to be below the critical value.

ii. Jet Flame Size

$$Q = \dot{m} \times \Delta h_c$$

Q = 708.081 MW

$$L = 0.2 \times Q^{2/5}$$

L = 43.75 m

iii. Heat Transfer

$$q'' = \frac{Q_r \cos\theta}{4\pi R^2}$$

$$Q_r = x_r \times Q$$

$$\cos\theta = 1 \quad \text{for } U^* \leq 1$$

$$\cos\theta = \frac{1}{\sqrt{U*}} \quad \text{for } U^* > 1$$

$$U* = \frac{U_w}{\sqrt[3]{\frac{g\,\dot{m}''D}{\rho v}}}$$

U* = 8.61 m

⇨ $\cos\theta = \frac{1}{\sqrt{U*}}$

$\cos\theta = 0.34$

Therefore, $\boldsymbol{q'' = 14.36}$ **kW/m²**

Thus the result obtained is, if any gas releases from an area of **25 mm^2** and catches fire, the jet flame reaches up to a height of **43.75 meters** and the incident heat flux per unit surface area of any target which is 20 meters away is **14.36 kW/m^2**.

3.5 Jet fire calculation – scenario 2

In this scenario jet fire calculations are carried out assuming that the gas release area is medium (100 mm^2).

Data:

C_d	= 0.85
A_h	= 1×10^{-4} m^2
k @ 1.6 MPa	= (142.5/100.8) = 1.422
ΔH_c	= 49.9 MW/kg
$\dot{m}''$	= 0.11 kg/m^2s
U_w	= 6 m/s
D	= 3 m
R	= 20 m

Parameter	Ambient	Process
Density (kg/m^3)	557	2.21
Pressure (Pa)	0.53×10^6	1.65×10^6

i. **Estimating Discharge Rate**

$$M = C_d \times \rho_{ambient} \times A_h \sqrt{\frac{2 \times P_{process}}{\rho_{process}} \times \frac{k}{k-1} \times \left[1 - \left(\frac{P_{ambient}}{P_{process}}\right)^{(k-1)/k}\right]}$$

M = 56.73 kg/s

The pressure ratio value is found to be below the critical value.

ii. **Jet Flame Size**

$$Q = \dot{m} \times \Delta h_c$$

Q = 2830.827 MW

$$L = 0.2 \times Q^{2/5}$$

L = 76.17 m

iii. Heat Transfer

$$q'' = \frac{Q_r \cos\theta}{4\pi R^2}$$

$$Q_r = x_r \times Q$$

$$\cos\theta = 1 \quad \text{for } U^* \leq 1$$

$$\cos\theta = \frac{1}{\sqrt{U*}} \quad \text{for } U^* > 1$$

$$U* = \frac{U_w}{\sqrt[3]{\frac{g\,\dot{m}''D}{\rho v}}}$$

U* = 5.28 m

⇨ $\cos\theta = \frac{1}{\sqrt{U*}}$

$\cos\theta$ = 0.435

Therefore, **q″ = 73.82 kW/m²**

Thus the result obtained is, if any gas releases from an area of **100 mm²** and catches fire, the jet flame reaches up to a height of **76.17 meters** and the incident heat flux per unit surface area of any target which is 20meters away is **73.82 kW/m²**.

3.6 Jet fire calculation – scenario 3

In this scenario jet fire calculations are carried out assuming that the gas release area is extremely large ($250mm^2$).

Data:

C_d = 0.85

A_h = 250×10^{-6} m^2

k @ 1.6MPa = $\frac{142.5}{100.2}$ = 1.422

ΔH_c = 49.9 MW/kg

$\dot{m}''$ = 0.11 kg/m^2s

U_w = 6 m/s

D = 3 m

R = 20 m

Parameter	Ambient	Process
Density (kg/m^3)	557	2.21
Pressure (Pa)	0.53×10^6	1.65×10^6

i. **Estimating Discharge Rate**

$$M = C_d \times \rho_{ambient} \times A_h \sqrt{\frac{2 \times P_{process}}{\rho_{process}} \times \frac{k}{k-1} \times \left[1 - \left(\frac{P_{ambient}}{P_{process}}\right)^{(k-1)/k}\right]}$$

M = 141 kg/s

The pressure ratio value is found to be below the critical value.

ii. **Jet Flame Size**

$$Q = \dot{m} \times \Delta h_c$$

Q = 7083.8 MW

$$L = 0.2 \times Q^{2/5}$$

L = 109 m

iii. Heat Transfer

$$q'' = \frac{Q_r \cos\theta}{4\pi R^2}$$

$$Q_r = x_r \times Q$$

$$\cos\theta = 1 \quad \text{for } U^* \leq 1$$

$$\cos\theta = \frac{1}{\sqrt{U*}} \quad \text{for } U^* > 1$$

$$U* = \frac{U_w}{\sqrt[3]{\frac{g\,\dot{m}''D}{\rho v}}}$$

U* = 5.28 m

⇨ $\cos\theta = \frac{1}{\sqrt{U*}}$

$\cos\theta = 0.435$

Therefore, **q'' = 183.88 kW/m²**

Thus the result obtained is, if any gas releases from an area of **250 mm^2** and catches fire, the jet flame reaches up to a height of **141 meters** and the incident heat flux per unit surface area of any target which is 20meters away is **183.88 kW/m^2**.

Chapter 4

Result and discussions

Based upon the jet fire calculations the following impacts can be estimated:

4.1 Fire Impact to personnel

When there is a line-of-sight between a person and the flame, the main impact is thermal radiation. The effects are explained in table 4.1. The primary potential effects of thermal radiation are burns to exposed skin and ignition or melting of clothing.

Burns are classified in increasing degrees of severity:

- First degree – superficial burns giving a red, dry skin (similar to mild sunburn)
- Second degree – burns more than 0.1 mm deep, affecting the epidermis and forming blisters
- Third degree – burns more than 2 mm deep, affecting the dermis and nerve endings, resulting in a dry skin that has no feeling (major blistering)

Figure 4.1 shows the heat flux vs time to injury graph. The time taken for injury decreases as the heat flux increases. When the heat flux reaches to a value of 34 kW/m^2, the time taken for injury is negligible.

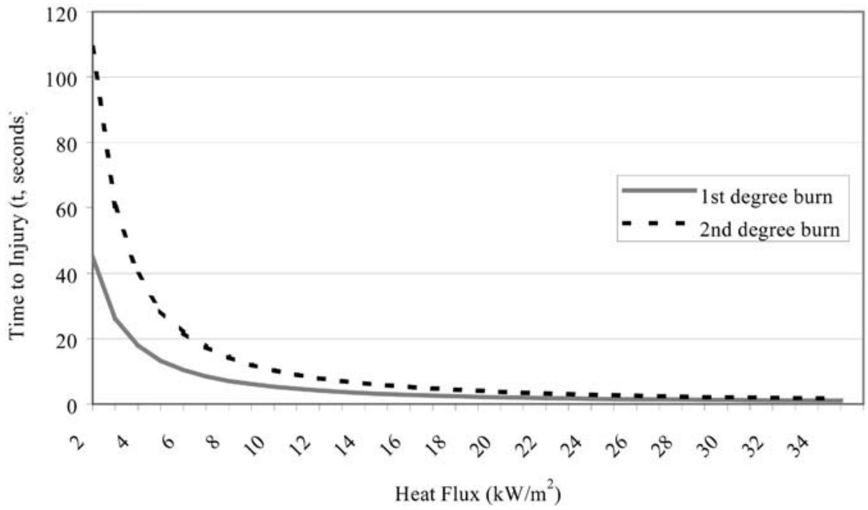

Figure 4.1 - Prediction of First- and Second-Degree Burns

Table 4.1 - Estimated Effects of Heat on Personnel

Incident Flux (kW/m^2)	Impact
37.5	100% lethality in 1 minute (Barry, 2002)
25	1% lethality in 10 seconds (Barry, 2002)
15.8	100% lethality in 1 minute, significant injury in 10 seconds (Barry, 2002)
12.3	1% lethality in 1 minute; first degree burns in 10 seconds (Barry, 2002)
6.3	Emergency actions lasting a minute can be performed by personnel without shielding, but with appropriate clothing
4.7	Emergency actions lasting several minute can be performed by personnel without shielding, but with appropriate clothing

4.2 Impact of fire on structures

Steel, aluminium, concrete, and other materials that form part of a process or building frame are subject to structural failure when exposed to fire. Bare metal elements are particularly susceptible to damage. A structural member under- goes any combination of three basic types of stress: compression, tension, and shear. The time to failure of the structural member will depend on the amount and type of heat flux (i.e., radiation, convection, or conduction), and the nature of the exposure (one-sided flame impingement, flame immersion, etc.). Cooling effects from suppression systems and effects of passive fire protection will reduce the impact. Examples for few materials with their failure temperature is given below.

- Paint begins to soften 204°C (400°F)
- Zinc primer paint discolours to tan 232°C (450°F)
- Zinc primer discolours to brown 260°C (500°F)
- Normal paints discolour 310°C (600°F)

- Zinc primer paint scorches to black 371°C (700°F)
- Lube oil auto ignites 421°C (790°F)
- Stainless steel begins to discolour 427-482°C (800-900°F)
- Plywood auto ignites 482°C (900°F)
- Vinyl coating on wire auto ignites 482°C (900°F)
- Rubber hoses auto ignite 510°C (950°F)
- Aluminium alloys melt 610–660°C (1,125–1,215°F)
- Brass melts (instrument gauges) 900–1025°C (1,650–1,880°F)
- Copper melts 1,083°C (1,980°F)
- Cast iron melts 1,150–1,250°C (2,100–2,200°F)
- Carbon steel melts 1,520°C (2,760°F)
- Stainless steel melts 1,400-1,532°C (2,550-2,790°F)

Time taken for various type of fires to reach maximum temperature is shown in the figure 4.2.

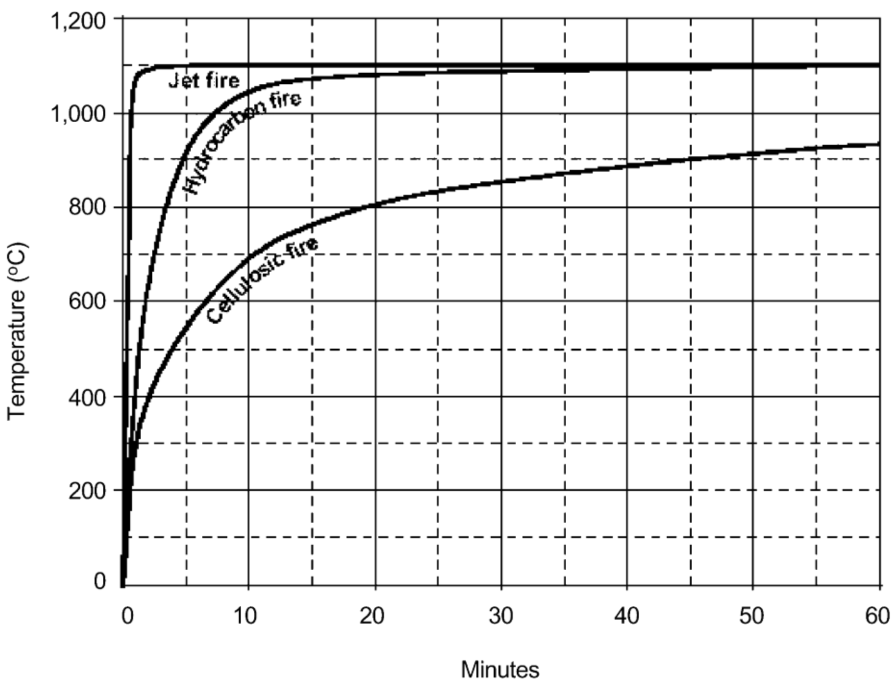

Figure 4.2 - Time–Temperature Curve for Fire Tests

Table 4.2 shows predicted failure time of steel elements for impinging fire and non-impinging fire.

Table 4.2 - Estimated Failure Time of Steel Elements

Component	Time to failure (minutes)	
	Impinging jet fire	Non impinging fire (37.5 kW/m^2 exposure)
25 mm steel pipe	5	No failure
7 mm steel plate (flame impingement on one side only)	2	13
305 mm web × 127 mm flange steel beam	3 – 4	13

4.3 Thermal Impact on Electrical Equipment

A heat flux of 25 kW/m^2 has been published as a general rule-of-thumb for damage to process equipment. Clearly, this excludes electrical and electronic equipment, which may fail to operate at much lower heat fluxes and resulting temperatures. For example, data on the thermal impact of fire on electrical equipment have been summarized for U.S. Navy applications. The following limits were derived from a literature evaluation:

- 50°C (122°F) for faults in operating electronic equipment.
- 150°C (302°F) for permanent damage to non-operating equipment.
- 250°C (482°F) for failure of standard Polyvinyl Chloride (PVC) cable.

Chapter 5

Summary and conclusion

5.1 Summary

- For the scenario 1, the gas release rate and the flame height is less when compared to scenario 2 and 3. The intensity of flux is also less. It may cause
- ✓ First degree burns
- ✓ Emergency action lasting a minute can be performed by personnel without shielding but with appropriate clothing
- For the scenario 2 and 3, the gas release rate is high resulting in huge flame and high intensity of flux. It causes
- ✓ Third degree burn in no time to personnel
- ✓ Causes 100 % lethality to personnel in less than a minute
- ✓ 25mm steel pipe fails in less than 5 minutes
- ✓ 7mm steel plate fails in less than 2 minutes
- ✓ 305 mm web × 127 mm flange steel beam fails in less than 3 minutes
- ✓ Causes severe damage to all surrounding process equipment
- ✓ Causes environmental pollution
- Gas detectors should be placed in the surrounding areas
- Leak detection system should be installed and the care should be taken that there is no crack or corrosion in the pipeline
- Periodic mock drills and trainings should be conducted
- Water from water monitors can reach a maximum height of 85m above ground. It is recommended to increase the operating pressure of fire water to reach maximum height desirable

5.2 Conclusion

1. The fire hazard analysis was carried for the 35MW power plant present in the Rajshree Sugars and Chemicals Ltd.
2. Fire hazard analysis shows that the fire hazard is negligible or very less in power plant as there are no flammable substance present except boiler area. The feed

which is bagasse gets ignited only when the temperature goes above 400°C. Thus boiler zone LPG is the major fire hazard.

3. Jet fire calculations were carried out for the LPG gas release considering various scenarios.
4. Recommendations for improved fire protection were given based on the jet fire calculations.

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