AN INDUSTRIAL TRAINING REPORT ON

RELIANCE INDUSTRIES LIMITED

JAMNAGAR, GUJARAT

In partial fulfilment for the Award of

B. Tech – Mechanical Engineering

Offered by

IIT ROPAR

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Index

1. Introduction

1.1 Reliance Jamnagar Refinery

Reliance Industries Limited, founded by Mr. Dhirubai Ambani is a privately owned conglomerate that operates in petrochemical production and refining, textile, retail, marketing, telecommunications, and other industries. It was the first privately owned Indian company to enter the Fortune 500. Headquarters are in Mumbai. The company's petrochemical, refining, and oil and gas-related operations form the core of its business; other divisions of the company include cloth, retail, telecommunications, and special economic zone (SEZ) development. In 2012–13, it earned 76% of its revenue from refining, 19% from petrochemicals, 2% from oil & gas and 3% from other segments.

1.2 Reliance Energy Sector

Reliance is now one of the largest Oil & Gas Exploration and Production players in India with a balanced domestic conventional and unconventional hydrocarbons portfolio. Today, Reliance is among the first companies globally to adopt an Oil-to- Chemicals strategy to produce the chemical building blocks of a circular economy and integrate it with sustainable downstream derivatives, useful chemicals, and new materials. With its commitment to a clean and sustainable future, Reliance is taking steps to meet its net-zero carbon goals by 2035.

Reliance includes world-class refining and petrochemicals manufacturing assets located at Jamnagar, Hazira, Dahej, Nagothane, Vadodara, Patalganga, Silvassa, Barabanki and Hoshiarpur as well as in Malaysia at Nilai, Melaca, and Kuantan. With the largest refinery at Jamnagar, Gujarat.

1.3 Jamnagar Manufacturing Division(JMD)

Jamnagar refinery is the largest and the most complex single-site refinery in the world with 1.4 million barrels per day (MMBPD) crude processing capacity and a complexity index of 21.1 – the highest in the world. It was commissioned in the year 1999. The Jamnagar Manufacturing Division boasts an impressive refining capacity, capable of processing crude oil into a wide range of valuable petroleum products. The complex has a combined refining capacity of 1.24 million barrels per day (BPD).

It houses the world's largest refining and petrochemical units, including the Fluid Catalytic Cracker (FCC), Coker, Alkylation, Paraxylene, Polypropylene, and the iconic ROGC (Refinery Off-Gas Cracker) with an unmatched ethylene capacity of 1.7 million metric tonnes per annum. JMD has successfully processed over 216 grades of crude oil sourced globally, showcasing its adaptability to market demands.

Beyond its sheer capacity, JMD reflects Reliance's philosophy of excellence and innovation. It is not just a refinery — it's a symbol of industrial prowess, technological leadership, and strategic foresight, placing India firmly on the global energy map.

1.3.1 Sites of JMD

JMD consists of 6 sites:

- DTA (Domestic Tariff Area)
- SEZ (Special Economic Zone)
- C2 Complex
- OM & SH (Oil Moving and Solid Handling)
- PCG (Petcoke Gasification)
- IIR (Isoprene Isobutylene Rubber)

In Jamnagar, there are two refineries, **Domestic Tariff Area** (DTA) and **Special Economic Zone** (SEZ). DTA has a capacity of 650 KBPSD and SEZ refinery has a capacity of 950 KBPSD for processing. The two refineries are divided based on the supply of the products from each refinery, the products from DTA are supplied within INDIA while all products from SEZ are reserved for export purpose.**C2 Complex** deals with the derivatives of ethane and ethylenes.

OM & SH: Refinery also has marine facility, which is common to both DTA and SEZ refinery, which is India's largest private port with state-of-the-art facilities and environmental protection system. Marine operation is conducted in Eco - friendly way, heralding the way the ports are to be operated. The largest **petcoke gasifier** in the world designed to run on both coal and petcoke is present, which is giving the flexibility to optimize based on raw material cost. The petcoke gasification units allow to extract the full-value from barrels of crude oil processed, converting the bottom of the barrel into high-value energy.

Reliance Industries Ltd and Sibur have forged a partnership to seize the opportunities within the robustly growing synthetic rubber industry. This joint venture is South Asia's first butyl (**IIR**) and halogenated butyl rubber production facility at Jamnagar, India with a world scale capacity of 120,000 metric tonnes per annum.

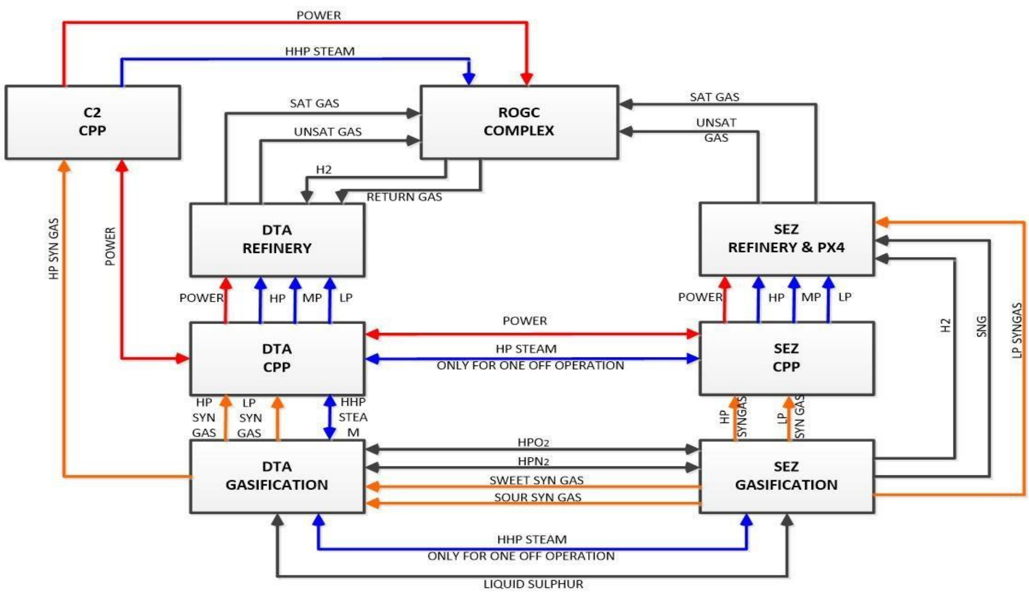


Fig 1. JMD Overview Block Diagram

1.3.2 Raw Materials

Crude oil is procured from all over the world and transported through very large crude containers (VLCC). Crude is off loaded via SPM (single Point Mooring) to crude tanks at the Marine Tank Farm (MTF). After enough settling and water removal/ Pre-treatment, suitable crude blend is prepared at MTF as per market requirement and refinery operation. Then it is pumped to the Crude oil tanks in SEZ-RTF, from there to crude units.

1.3.3 Products

The Jamnagar Manufacturing Division produces a comprehensive range of petroleum products to meet domestic and international market demands. This includes **gasoline (Motor sprit BS 4, RBPB), diesel, aviation turbine fuel, liquefied petroleum gas (LPG), naphtha, petrochemical feedstock (LLDPE, LDPE, Orthoxylene , Para xylene, Benzene), and various specialty chemicals (methyl Tetra Butyl Ether).** Reliance has established a strong reputation for delivering high-quality products that adhere to stringent global standards.

2. C2 Complex

The C2 Complex at Reliance's Jamnagar Manufacturing Division stands as a core component of the company's visionary Oil-to-Chemicals (O2C) strategy. Developed under the ambitious J3 Expansion Program, it symbolizes vertical integration, operational excellence, and sustainable industrial transformation.

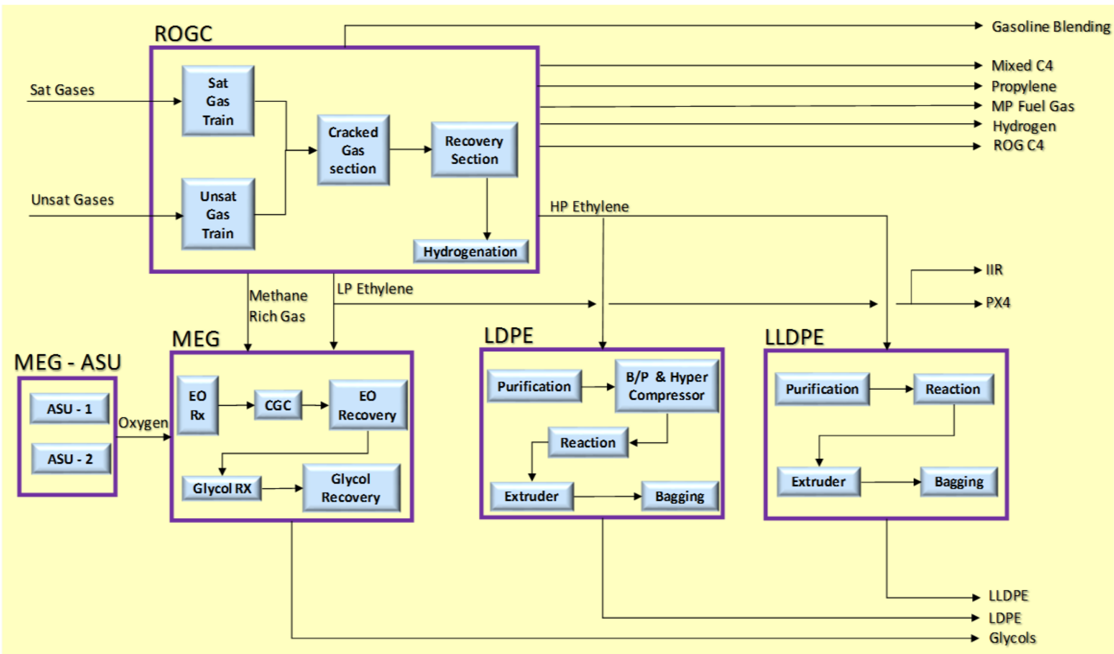


Fig 2. C2 Complex Block Diagram

Major Units and Capabilities: The heart of the C2 Complex is the Refinery Off- Gas Cracker (ROGC) — one of the world's largest and most advanced units. It converts low-value refinery off-gases into high-value petrochemicals like ethylene and propylene, which are foundational to modern manufacturing. Complementing the **ROGC** are **LDPE** and **LLDPE** plants, and Monoethylene Glycol (**MEG**) facilities, including MEG-ASU, which ensure a seamless flow of intermediate chemicals for downstream applications. Supporting infrastructure includes C2

Utilities, a dedicated Captive Power Plant (CPP) ensuring uninterrupted operations, and a cutting-edge Effluent Treatment Plant (ETP) serving the IIR and HIIR units, reflecting the complex's commitment to environmental stewardship.

Sustainability at core the C2 Complex leads in sustainable practices: Treated effluent is reused for cooling tower makeup, horticulture, and greenbelt development, promoting circular water management. Waste heat recovery and energy-efficient operations significantly reduce emissions, aligning with global climate goals. Strategic Output and Importance The ethylene and propylene produced are crucial for: Plastics Synthetic fibers Performance chemicals These outputs directly feed RIL's downstream polymer and chemical units, bolstering its position as a global petrochemical leader. The C2 Complex not only maximizes value from by-products but also embodies Reliance's forward-looking approach to integrated, sustainable, and highmargin chemical production.

2.1 Refinery Off Gas Complex(ROGC)

The Refinery Off Gas Cracker (ROGC) is a dedicated processing unit used to recover valuable hydrocarbon components like ethylene, propylene, ethane, propane, and butane from refinery off-gas streams. Previously, these off-gases have been used as low-value fuel gas. But the ROGC brings huge value by processing these streams into high-purity polymer-grade ethylene and propylene, as well as other significant by-products, thus increasing the overall economic efficiency of the refinery. The ethane and propane that are recovered from these off-gas streams are utilized as feedstocks to the cracking process, which then generates about 180 TPH of ethylene and 16 TPH of propylene.

The ROGC feed comes mainly from two of Jamnagar's refinery complexes: the DTA refinery and the SEZ refinery. These feeds are saturated gas streams, unsaturated gas streams, and an external supply of propane that serves as backup when one of the refineries off-gas sources is not available. Saturated gases consist of off-gas streams from a number of units including the aromatics complex, crude distillation unit (CDU), and hydro-treaters in the DTA refinery and platformer, CDU, and hydro-treater units in the SEZ refinery. Unsaturated gases, on the other hand, come from the fluid catalytic cracking (FCC) unit and the Coker unit that have higher olefin concentrations. All these feed streams are individually processed to maximize energy efficiency and component recovery. The ROGC is organized in three different trains of separation:

- Saturated gas processing train
- Unsaturated gas processing train
- Crack gas train

2.2 Monoethylene Glycol(MEG)

The Monoethylene Glycol (MEG) Plant at Reliance's Jamnagar complex is a key part of the J3 program, producing Monoethylene Glycol (MEG) and Diethylene Glycol (DEG) through the catalytic oxidation of ethylene and hydrolysis of ethylene oxide. The process involves formation of ethylene oxide (EO) over a silver catalyst, removal of byproduct CO_2 using a hot potassium carbonate process, conversion of EO with water to produce glycols, and final purification to meet product specifications. With a capacity of 550 KTA ethylene oxide equivalent, the plant can deliver 708.7 KTA of MEG and 49.6 KTA of DEG. These products find wide applications in polyester fibers, PET resins, antifreeze formulations, and other industrial uses.

Supporting this unit, the Air Separation Unit (ASU) provides high-purity oxygen (≥99.8%) to the MEG plant and nitrogen (≥99.9%) to the C2 complex. The ASU process involves air compression, cooling, purification, and cryogenic distillation, followed by compression of oxygen and nitrogen for delivery. With two trains of 840 TPD oxygen capacity each, the ASU ensures a continuous and reliable gas supply. Additionally, its flexible operation allows production of liquid oxygen (LOX) and liquid nitrogen (LIN), with oxygen primarily used in EO production and nitrogen serving as an inert gas in multiple processes.

2.3 LDPE and LLDPE

The Low-Density Polyethylene (LDPE) plant is designed to produce high-quality polymer using the Basell Lupotech TS high-pressure tubular reactor process. Ethylene, along with small quantities of co-monomers such as propane, n-butane, and propylene, is first purified in the purification columns to remove any impurities. The purified feed is then passed through a series of compressors. The booster and primary compressors increase the pressure before it enters the hyper compressor, which raises the pressure to very high levels necessary for the free-radical polymerization reaction.

In contrast, the Linear Low-Density Polyethylene (LLDPE) plant operates at much lower pressures compared to LDPE. Ethylene is copolymerized with alpha-olefins such as butene, hexene, or octene in the presence of advanced catalyst systems like Ziegler–Natta or metallocene catalysts. Depending on the technology (Unipol, Innovene, or Lupotech-F), the reaction may take place in a slurry, solution, or gas-phase reactor. The linear molecular structure with controlled short-chain branching gives LLDPE excellent toughness, tensile strength, and puncture resistance compared to LDPE. After polymerization, the material undergoes extrusion, pelletizing, and storage in silos similar to the LDPE plant.

Together, the LDPE and LLDPE plants provide a broad spectrum of polyethylene grades. LDPE is mainly utilized for food packaging, squeeze bottles, and cable insulation due to its softness and clarity, while LLDPE is preferred for stretch films, heavy-duty bags, pipes, and geo - membranes where higher mechanical strength is required. Both plants complement each other in meeting diverse market demands, ensuring flexibility and durability across applications.

3. Project

Study Project On ROGC Furnace , ID Fan and its Reliability Issues

Abstract

The Refinery Off-Gas Cracker (ROGC) furnace is a critical component in the ethylene production unit at Reliance Industries Limited, ensuring efficient cracking of hydrocarbon feedstocks into valuable olefins. This study project focuses on understanding the **working principle, operational significance, and performance optimization** of the ROGC furnace. Detailed analysis was carried out on the **coil revamping process** to enhance heat transfer efficiency and minimize coke formation. The project further emphasizes the **operation and maintenance of the Induced Draft (ID) fan**, which plays a vital role in maintaining furnace draft and overall process stability. Reliability issues associated with both the furnace and ID fan were identified and examined through performance data and maintenance records. The study concludes with a set of **recommendations and open actions** aimed at improving equipment reliability, optimizing operational efficiency, and ensuring long-term sustainability of furnace operations.

3.1 Introduction

The Refinery Off-Gas Cracker (ROGC) unit at Reliance Industries Limited represents a key technological advancement in India's petrochemical sector, enabling the conversion of refinery off-gases into high-value petrochemical feedstocks such as ethylene, propylene, and butadiene. The ROGC furnace serves as the **heart of this cracking unit**, where the endothermic pyrolysis reactions take place under carefully controlled temperature and residence time conditions. Its performance directly influences the overall efficiency, yield, and reliability of the ethylene production process.

In modern refining and petrochemical operations, furnace reliability and thermal efficiency are of paramount importance. The ROGC furnace operates under severe thermal and mechanical conditions, making it susceptible to challenges such as **tube coking, hot spots, and draft instability**. These factors not only impact product yield but also increase energy consumption and maintenance frequency. Consequently, continuous monitoring, revamping of coil design, and optimization of draft control systems have become essential to ensure sustained performance.

A crucial auxiliary system supporting furnace operation is the **Induced Draft (ID) fan**, responsible for maintaining the required negative pressure and ensuring proper flue gas evacuation. Any malfunction or degradation in the ID fan can lead to unstable combustion, inefficient heat transfer, and even unplanned shutdowns. Therefore, understanding its operation, preventive maintenance, and reliability behavior is vital for safe and efficient furnace performance.

3.2 Objectives

1. **To understand the working principle and functional importance of the ROGC furnace**
2. **To analyse the coil revamping process**, focusing on improvements in heat transfer, reduction in coke formation, and enhancement of furnace run length.
3. **To study the operation and maintenance practices of the Induced Draft (ID) fan**,
4. **To identify and evaluate reliability issues** associated with the furnace and ID fan,
5. **To propose corrective and preventive measures** aimed at minimizing downtime, improving reliability indices, and extending equipment life.

4. Furnace Working Principle & Importance

4.1 Introduction

A furnace is a thermal device used to generate heat by burning fuel or using electricity. It transfers the generated heat to a process material, fluid, or feedstock for industrial purposes such as heating, melting, or chemical reactions.

Basic Working Principle

- **Fuel Combustion**: Fuel (e.g., natural gas) burns with air in burners, generating high-temperature flue gases.
- **Heat Transfer**: Heat is transferred to the target material either directly or through heat exchangers.
- **Exhaust Removal:** Flue gases are discharged via chimneys or stacks, often aided by an Induced Draft (ID) fan.

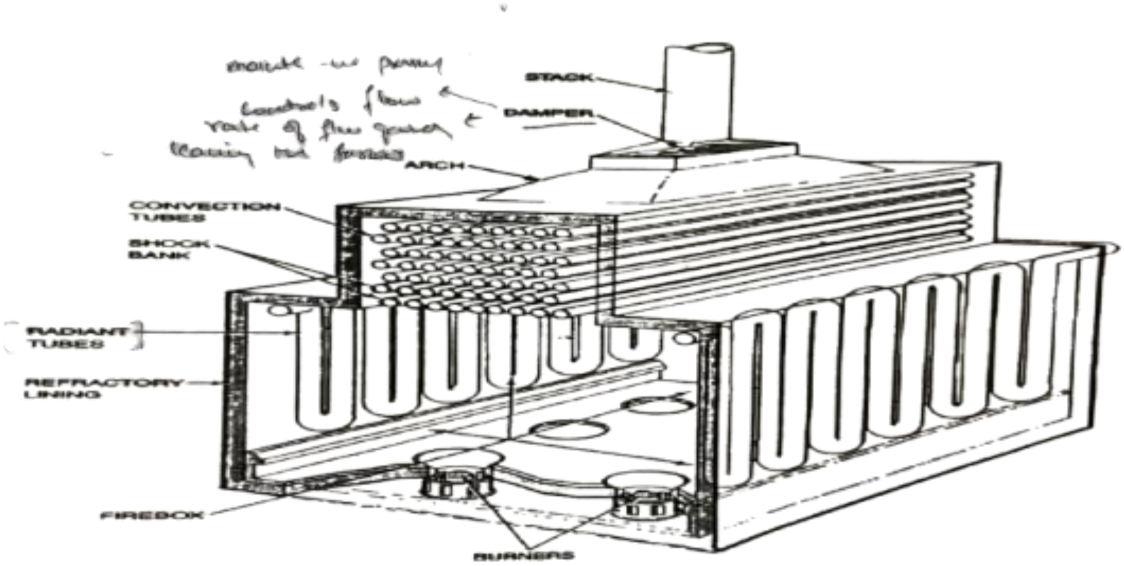
4.2 Furnace in ROGC Cracker Unit

In a Refinery Off-Gas Cracker (ROGC), the furnace is the core component responsible for thermal cracking of hydrocarbon feedstock into valuable petrochemicals like ethylene, propylene, and butadiene.

4.2.1 Furnace Components

1) Furnace Shell
2) Radiant Section
3) Convection Section
4) Refractory

5) Burners
6) Stack
7) Induced Fan



1. **Furnace Shell :**

Furnace Shell is made of Carbon Steel plates 6mm thick as casing material . It is designed to **contain the heat, support insulation, and house the internal process systems** while ensuring mechanical stability and safety. Maximum Temperature CS can withstand is 440 degree C.

Key Functions of the Furnace Shell

1. **Structural Support**
   - Provides a **rigid frame** to support burners, coils, refractory, insulation, and ducting.
   - Withstands **thermal expansion** and mechanical loads during operation.

2. **Heat Containment**
   - Acts as a barrier to prevent **heat losses** to the environment.
   - Typically covered internally with **refractory lining and insulation**.

2. **Radiant Section :**

The portion of the heater in which the heat is transferred to the tubes primarily by radiation . The **radiation section** of a furnace, also known as the **radiant zone**, is the hottest part of the furnace and plays a critical role in heat transfer, especially in fired heaters like those used in Refinery Off-Gas Cracker (ROGC) furnaces. The radiation section is primarily responsible for transferring heat to the process fluid by **thermal radiation** from high-temperature flame and combustion gases. This is where the **majority of heat transfer** takes place**Floating Head:**

Key Components

- **Radiant Coils**: Tubes carrying hydrocarbon feed are placed in the radiant section to absorb heat through radiation. These are typically made of high-temperature resistants Ni, Cr Alloys . There are total 40 no's W coil which consist 160 no's of Tubes per Furnace .

  The flow pass thru a **Critical flow Nozzle** , the flow is a function of upstream pressure only and is not affected by the downstream pressure , even though the pressure drop vary in the radiant coils due to uneven coking , the flow to all coils remains equal .

  Coils are freely suspended with the help of constant spring supports at the inlet feeder to the 1st pass and 180 degree return bend between the second and third tubes of the each coil . Spring supports are attached from the top of the shell .

- **Burners**: Located at the floor (floor-fired) or sidewalls (side-fired), they provide the heat source by combusting fuel in presence of air . There are total 96 burners (2rows /elevations x 24 No's each side walls). We are using GLSF-8 burners in our process.

GLSF-8 burners are **low-NOx, floor-fired burners** widely used in **Refinery Off- Gas Cracker (ROGC) furnaces** due to their high efficiency, stable flame characteristics, and environmentally compliant design. They are engineered to handle **hydrocarbon-rich refinery off-gas** as fuel and are crucial in supplying controlled radiant heat to initiate cracking reactions in the furnace coils.

- **Radiant Walls**: Insulated walls and roof lined with **refractory bricks** that reflect radiant heat and protect the structure. Radiant walls are lined with a combination of 4 layers of Superwool plus blokes and one layer insulation brick (JM-26 ,JM-28) on the hot face anchored to the casing . Total thickness of the wall lining is 328mm , 200kg/m3.Radiant Floor are lined with Brick Lining – JM23 bricks , Isolmos450 brick .Total thickness of floor lining is 356mm .

  Refractory is used in furnaces to:

❖ **Insulate** and reduce heat loss, improving thermal efficiency.
❖ **Protect** the furnace structure from high temperatures and flame.
❖ **Withstand** thermal shock and chemical attack from flue gases.
❖ **Enhance safety** by keeping the outer surface cool.

3. Convection Section

The **convection section** of an ROGC (Refinery Off-Gas Cracker) furnace is located above the radiation section and plays a crucial role in improving the overall thermal efficiency of the furnace. Its primary function is to recover heat from the hot flue gases exiting the radiant chamber. This recovered heat is used to preheat the hydrocarbon feed, dilution steam, and sometimes combustion air before they enter the radiant section. The section consists of a series of convection coils arranged in tube banks through which these process streams flow. Baffles are used to guide the flue gases over the coils, ensuring efficient heat transfer. By utilizing the otherwise wasted flue gas heat, the convection section significantly reduces fuel consumption and lowers flue gas temperature before it exits the stack, contributing to higher furnace efficiency.

After radiation section **7 banks** of tubes are housed in the vertical column called convection section of the Furnace.

1. **DM Section-** The DM (Demineralized) water section in an ROGC furnace system supplies high-purity water by removing dissolved salts and minerals. This water is mainly used for generating dilution steam, which helps reduce coke formation during cracking, and in steam-air decoking processes. Using DM water prevents scaling and corrosion in furnace coils and steam systems, ensuring efficient heat transfer and reliable operation

   Inlet Temp – 85 degree C

   Outlet Temp -105 degree C

2. **FPH section (Feed Preheater)**- The **FPH (Feed Preheater) section** in an ROGC furnace is part of the convection zone where the hydrocarbon feed is preheated using hot flue gases. It receives the feed at 55 degree C and at the outlet (225 degree C) the feed is mixed with the dilution steam coming from the hot section . Then the mixture (217 degree C) is sent to the HTC -1 for further heating .

3. **Economizer Section** - The **economizer section** in an ROGC furnace is used to recover residual heat from flue gases. It primarily **preheats boiler feed water** before it enters the steam drum or boiler, thereby reducing the energy required for steam generation. This improves the overall thermal efficiency of the furnace and helps in reducing fuel consumption.

   Inlet temp -220 degree C

   Outlet Temp -316 degree C

4. **HTC 1(Feed and Steam Preheater)-** Feed and Steam mixture from FPH at 217 degree C is further heated in HTC-1 to 455 degree C . Then it is directed to HTC-2 .

5. **HPSSH-1(High pressure Steam Superheater) -** Its primary function is to superheat high-pressure steam generated in the boiler by increasing its temperature without increasing its pressure. This superheated steam is then used for driving steam turbines, compressors, or for process heating in downstream units.

In the ROGC furnace, flue gases pass over the HPSSH-1 coils, transferring sensible heat to the saturated steam. This improves the thermal efficiency of the system and ensures dry, high-enthalpy steam, which is crucial for reliable operation of steam-driven equipment.

6. **HPSSH-2(High pressure Steam Superheater) -** It is typically the second stage of superheating in the convection section of an ROGC furnace. After the steam is partially superheated in HPSSH-1, it flows through HPSSH-2, where it is further heated using the hotter flue gases. This ensures the steam reaches the required final superheat temperature for efficient use in turbines, compressors, or other high-temperature process applications.

7. **HTC-2(Feed and Steam Preheater)-** Mixture is further heated to 681 degree C . After leaving the HTC -2 coil , 4 convection passes are split into 40 radiant coils inlet streams.

4. Stack:

The stack, also known as the chimney, is the final component in an ROGC furnace that safely discharges flue gases into the atmosphere after heat recovery in the convection section. It provides the necessary draft to pull combustion air into the burners and push exhaust gases through the furnace.

- ❖ Maintains **stable airflow** and **burner performance**.
- ❖ Prevents **backflow** of gases into the furnace.
- ❖ Ensures **compliance with air quality standards**.
- ❖ Plays a role in **plant safety** by venting toxic and hot gases away from personnel.

5. ID FAN:

The **Induced Draft (ID) fan** in an ROGC furnace plays a critical role in managing the flow of flue gases through the system. Located near the base of the stack, the ID fan pulls flue gases from the furnace, including the convection section, and pushes them out through the stack. This creates a **negative pressure** inside the furnace, ensuring a steady draft that promotes efficient combustion and stable furnace operation. By maintaining proper airflow, the ID fan supports consistent burner performance and helps in regulating furnace pressure, especially in large or high-efficiency units.
In addition to aiding combustion, the ID fan facilitates the movement of flue gases through emission control and monitoring systems, contributing to environmental compliance.

6. Furnace Boiler Loop:

In industrial and petrochemical applications such as the ROGC unit, the **furnace-boiler loop** plays a crucial role in energy integration and process efficiency. In this system, the furnace burns fuel—typically natural gas—to produce high-temperature flue gases. These hot gases pass through the convection and radiant sections of the furnace, where heat is transferred to coils containing **boiler feed water (BFW)**. As the water absorbs this heat, it converts into **high-pressure steam**.

Components of Furnace Boiler Loop

- **Transfer Line Exchangers (TLE's) :** Transfer Line Exchangers (TLE) in ROGC furnaces are designed as double tube heat exchangers to efficiently recover heat from the hot cracked gases exiting the radiant section. In this design, the hot process gas flows through the inner tubes while the boiler feedwater flows in the annular space between the inner and outer tubes, allowing effective heat transfer. This recovered heat is used to generate high-pressure steam, which improves the overall thermal efficiency of the furnace by reducing fuel consumption. Additionally, the TLE cools the cracked gases before they enter downstream separation and processing units, protecting sensitive equipment from thermal damage and extending its operational life.

- PTLE (Primary TLE)
- STLE (Secondary TLE)
- TTLE (Tertiary TLE)

- **Steam Drum :** It acts as a reservoir where water and steam separate after being heated in the boiler tubes, including those in the convection and radiation sections. The steam drum collects the saturated steam generated in the furnace coils and allows water to settle and recirculate back into the system. This separation ensures that only dry steam is sent to superheaters or process equipment, improving steam quality and preventing damage to turbines or other machinery.

5. Process Medium

1) Fuel Combustion and Flue Gas Generation (Radiant Section)

- Fuel (natural gas) is burned in the burners located in the radiant section.
- This generates **flue gases** at very high temperatures, typically around **1100 degree C**.
- These hot gases transfer intense **radiant heat** to the furnace coils containing the hydrocarbon feed.
- The radiant section is where the **main cracking reaction** occurs, as the hydrocarbon feed inside the coils is rapidly heated.

2) Process Medium Heating (Radiant Section)

- The **process medium**, a mixture of hydrocarbon feed and dilution steam, enters the furnace coils at about **300–500°C** after preheating.
- Inside the radiant section, it is heated quickly by the radiant heat from the flames and flue gases to the **cracking temperature range of 850–900°C**.
- This causes thermal cracking, breaking large hydrocarbons into smaller olefins and other products.

3) Preheating of Feed and Other Media (Convection Section)

- In the convection section, the flue gases pass over coils designed to recover their residual heat.
- The hydrocarbon feed is preheated here through the Feed Preheater (FPH) to raise its temperature from ambient to around 250 degree C , preparing it for cracking.
- Boiler feedwater is heated in the Economizer to increase efficiency in steam generation.
- High-pressure steam is further superheated in HPSSH-1 and HPSSH-2 by the flue gases to improve steam quality.
- The temperature of flue gases decreases as heat is transferred, typically dropping to around 115°C by the end of the convection section.

4) Heat Recovery in Transfer Line Exchanger (TLE)

- The hot cracked gases exiting the radiant coils (around **850–900°C**) enter the **Transfer Line Exchanger**.
- The TLE uses a **double tube heat exchangers** design to transfer heat from these gases to boiler feedwater, generating high-pressure steam.
- This step recovers a significant amount of thermal energy and cools the cracked gas before it proceeds to downstream separation units.

5) Flue Gas Discharge

- After passing through the convection section and TLE, the cooled flue gases are drawn out by the **Induced Draft (ID) fan**.
- The ID fan maintains negative pressure, ensuring smooth gas flow through the furnace and preventing backflow.
- Finally, the gases are discharged into the atmosphere via the **stack**, where they are safely released at a height that promotes dispersion and minimizes environmental impact.

The cracked product, a mixture of lighter hydrocarbons, steam, and unconverted feed, is rapidly cooled (quenched) to stop further reactions and prevent coke formation. It then enters the **quench tower** or **cooler**, where it is cooled using water or oil quenching.

After cooling, the cracked gas undergoes **separation and purification** in downstream units such as:

- **Primary fractionators** to separate hydrogen, methane, ethylene, propylene, and heavier hydrocarbons.
- **Compression and drying units** to remove impurities and prepare the product for further processing.
- **Polymer-grade purification** processes if the olefins are destined for polymer production.

The ultimate goal is to recover high-purity olefins and valuable byproducts while safely managing unconverted hydrocarbons and byproducts.

6. Coil Revamping

1. Existing Coil Configuration

In ROGC plant , total 6 main furnaces are having with Kubota make coils . The metallurgy of these coils are stated below :-

Parameter	Inlet	#1	#2	#3	#4	Outlet
Material	18Cr10NiNb	25Cr35NiNb MA	25Cr35NiNb MA	35Cr45NiNb MA	35Cr45NiNb MA	20Cr33NiNb
ID × MSW (mm)	90 × 7.0	90 × 7.0	90 × 7.0	100 × 7.0	100 × 7.0 / 100 × 8.0	100 × 8.0
DT (°C)	780	1080	1080	1115	1115	910
DP (kg/cm^2g)	6.5	4.0	3.9	3.6	3.3	3.3
TMT (SOR) (°C)	966	976	992	1002	—	—
TMT (EOR) (°C)	1011	1042	1065	1092	—	—

2. Need For Revamping

As we are dealing with high temperature as 1100degree C in radiation section . This causes radiant coils to undergo some defects such as:-

- -Sagging and Bowing
- -Oxidation and scaling
- -Bulging and Creep
- -Corrosion
- -Carburization

Carburization - Carburizing or carburization is a heat treatment process in which iron or steel absorbs carbon while the metal is heated in the presence of a carbon-bearing material, such as charcoal or carbon monoxide i.e Carbon migrates into crystal structure of coil.

- This results in loss of ductility

- Carburization occurs at elevated temperature.
- Due to which there is a change in carbon content along the thickness. The depth until which there is a change in carbon content is called the depth of carburization which is generally measured by finding the magnetic permeability.
- Heater tubes are replaced after 50% depth of carburization because after 50% the tube becomes highly brittle.

So ,the radiant coil carburization has significantly increased from 14 % (Jan 2020) to > 70 %(Oct 2022) in span of 2.5 years . This damage was evident in all 4th pass tube .

Significant bulging is observed in majority of the 4th pass tube .

Sr. No.	Furnace	Make	Commissioning Date	Progressive % Carburization (Max.)				
				2018	2019	2020	2021	2022
1	F010001	Kubota	Sep-17	0.00			18.44	33.14
2	F010002	Kubota	Sep-17	0.00		18.44		44.21
3	F010003	Kubota	Sep-17	0.00		10.50	14.02	
4	F010004	Kubota	Sep-17	0.00		9.40		
5	F010005	Kubota	Sep-17		0.00	15.14	27.80	
6	F010006	Kubota	Sep-17		4.60	14.00		>50

3. Revamp Methodologies

Maximum life of the radiant coils was estimated as 8-9 years in 2020-21. Post inspection in Sept-Oct 2022, it is revised to 5-6 Years considering the higher throughput 49 TPH to 56 TPH operation. Typically, other RIL Gas cracker radiant coils replacement was carried out in 5-6years of life.
Aluminium containing (HT-E Al alloy) coil is found to be beneficial over Bare coil in the NPV (Net present value) analysis. In the NP analysis, the Aluminium coil life of 7-8 yrs. considered due to reduced coking & carburization tendency and the Bare coil life of 5 yrs. considered as we may operate the furnace at higher severity post DBN.

4. Impact on Furnace Performance

1. **Reduced Coking Tendency:**
    - Aluminum forms a stable alumina (Al_2O_3) layer on the coil surface.
    - This layer is smooth, dense, and has low catalytic activity, thus reducing coke formation.
    - Lower coking means longer continuous run time between decoking operations.
2. **Reduced Coking Tendency:**

- Carburization (carbon diffusion into the metal) weakens the coil over time.
- The alumina layer acts as a diffusion barrier, reducing carburization, thereby preserving the mechanical strength of the alloy longer.

3. **Improved Oxidation Resistance:**
   - The protective alumina layer resists high-temperature oxidation better than the oxide layers on bare coils (typically Fe-based or Cr-based oxides).

4. **Longer Service Life:**

- HT-E Al coil: 7–8 years
- Bare coil: ~5 years
- Fewer replacements reduce long-term capital and shutdown costs.

5. **Reduced Decoking Frequency:**

- Less coke means fewer shutdowns and shorter downtime.
- This improves furnace availability and throughput, enhancing profitability.

7. ID Fan Operation and Maintenance

7.1. Role of Induced Draft(ID) Fans in furnaces

The **Induced Draft (ID) fan** plays a vital role in the operation of industrial furnaces by maintaining **proper airflow and pressure control** within the combustion chamber. Positioned near the flue gas exit (usually at the stack), the ID fan **draws hot combustion gases** through the furnace and expels them into the atmosphere via the chimney or stack. This creates a **negative pressure** inside the furnace, ensuring that combustion gases flow smoothly and preventing any leakage of hot gases into the surrounding environment. In cracking furnaces, such as those in ROGC units, the ID fan helps optimize heat transfer by ensuring uniform flue gas flow over the convection and radiant coils, thereby improving thermal efficiency and maintaining safe operating conditions. It is also essential for controlling emissions and aiding in effective heat recovery through heat exchangers or steam generation sections.

7.2. Operating Principles

The **Induced Draft (ID) fan** operates on the principle of **creating negative pressure** within a furnace or boiler system to draw flue gases through the combustion chamber and exhaust them out through the stack. It is typically installed at the **outlet of the flue gas path**, near the chimney.

The fan works by rotating impellers or blades at high speeds, which reduces the static pressure at the furnace outlet. This causes the **combustion gases to flow** from the high-pressure zone inside the furnace to the low-pressure zone created by the fan. The movement of air and gases is governed by **Bernoulli's principle** and **centrifugal force**, depending on the type of fan used (axial or centrifugal).

By regulating the fan speed (often via a Variable Frequency Drive – VFD), the draft level can be controlled precisely. This ensures **efficient combustion**, **complete removal of flue gases**, and **safe furnace operation**. The ID fan also plays a role in maintaining the **air-fuel ratio**, optimizing heat transfer, and minimizing heat losses through leaks.

7.3. Maintenance Procedure

<u>Disassembly of ID Fan</u>

- **Coupling Disassembly**
  - Isolate the fan from the drive system and ensure proper lock-out and tag-out (LOTO) procedures are followed.
  - Inspect and record the **bolt and disc shim condition** before removal.
  - Check and note the **DBSE (Distance Between Shaft Ends)** to ensure proper alignment during reassembly.
  - Carefully loosen and remove coupling bolts to avoid damage to the disc packs.
  - Clean coupling surfaces and store the components properly for inspection.
- **Dismantling the Seal Housing**
  - Remove the seal cover and dismantle the seal housing assembly.
  - Inspect **seal rings, gaskets, and labyrinth seals** for wear, cracks, or deformation.
  - Check the **seal housing bore condition** and clean it thoroughly.
  - Record any abnormalities for corrective maintenance.
- **Fan Bearing Removal**
  - Remove bearing covers and unbolt the bearing housings carefully.
  - Check **bearing housing seal condition** for leakage or damage.
  - Inspect the **bearing fitment, lubrication condition, and oil quality** (if oil-lubricated).
  - Examine **all bolt threads, nut, and washer conditions** for signs of wear or corrosion.
  - Tag the bearings for location identification if they are to be reused.
- **Dismantle Fan Top Cover**
  - Remove the top cover or casing carefully to avoid distortion.
  - Inspect the **inner surface for deposits, erosion, or cracks**.
  - Clean the interior surface using approved cleaning methods.
- **Shaft Runout Check**
  - Mount a dial indicator and measure **shaft runout** to determine any bending or misalignment.
  - Record readings at multiple points along the shaft length.
  - Compare measured values with allowable tolerances as per design standards.
- **Shaft Diameter Check and Inspection**
  - Measure **shaft diameter** at bearing seating, coupling ends, and impeller mounting locations.
  - Check for **wear, scoring, or ovality**.

- Inspect keyways, threads, and surfaces for signs of fatigue or corrosion.
- Ensure the shaft dimensions are within acceptable limits before proceeding with reassembly.

Assembly of ID Fan

Pre-Assembly Checks

- Ensure all fan components, bolts, nuts, and washers are thoroughly **cleaned and inspected** before assembly.
- Verify that **seal housing, bearings, and shaft** have passed dimensional and surface condition checks.
- Confirm that all components are **free from burrs, corrosion, and foreign material**.
- Check that **gaskets, O-rings, and seals** are new or in reusable condition as per standard maintenance practices.

Shaft Installation

- Carefully place the **fan shaft** into position using suitable lifting tools to prevent bending or surface damage.
- Apply a thin layer of **anti-seize compound or lubricant** on the bearing seats and coupling ends.
- Ensure the shaft is correctly aligned with the bearing housing bores and centered properly.

Bearing Assembly

- Mount the bearings onto the shaft using the appropriate heating and fitting techniques (e.g., induction heater for shrink-fit).
- Check **bearing axial and radial clearance** as per manufacturer specifications.
- Secure the bearing housings onto the pedestal and torque all bolts to the specified value.
- Apply the recommended **grease or lubrication oil** to the bearings.
- Reinstall bearing housing covers and verify **seal ring positioning** and tightness.

Seal Housing Assembly

- Reassemble the **seal housing** onto the fan shaft.
- Fit new **seal rings and gaskets** if required.
- Ensure proper alignment between the seal housing and bearing housing.
- Check for smooth shaft rotation to confirm no rubbing or misalignment.

Coupling Assembly

- Align the fan shaft with the drive shaft using dial indicators or laser alignment tools.
- Check and adjust the **DBSE (Distance Between Shaft Ends)** according to design values.
- Install the **coupling bolts and disc shims** carefully, ensuring even torque tightening.
- Verify angular and parallel alignment within permissible limits.
- Rotate the assembly manually to check for smooth operation.

 Fan Casing and Cover Installation

- Reinstall the **fan top cover** and casing components.
- Check that all **fasteners are tightened uniformly** to avoid casing distortion.
- Inspect for proper alignment between impeller and casing to prevent rubbing.
- Ensure all **inspection covers and drain plugs** are securely closed.

 Final Checks and Testing

- Perform **shaft runout and vibration checks** after full assembly.
- Verify free rotation and absence of abnormal noise.
- Ensure all lubrication systems are functional and levels are adequate.
- Record all **clearance, torque, and alignment readings** for documentation.
- Conduct a **trial run** under supervision and monitor bearing temperature, vibration, and motor current.

8. Furnace and ID Fan Reliability Issues

Enhancing the reliability of cooling water service heat exchangers requires a combination of design improvements, operational controls, and material upgrades. Since these exchangers operate in harsh environments prone to corrosion, fouling, and erosion, mitigation strategies must target both the degradation mechanisms and the operating conditions that accelerate failure.

8.1 ID Fan Coupling Failure

An induced draft (ID) fan at Furnace-4 experienced a mechanical failure on September 26, 2024, resulting in a complete shutdown of the furnace. The issue was initially triggered by high draft conditions, later traced to a damaged coupling spacer. The investigation revealed that the root cause was torsional resonance induced through the variable frequency drive (VFD), leading to fatigue failure of the coupling bolts and spacer. This report details the incident chronology, technical analysis, root causes, and preventive recommendations.

Background

The ID fan in question facilitates the induced draft required for furnace operation and is driven by a VFD-controlled electric motor. This system allows for controlled airflow across the burner blocks, optimizing combustion and thermal efficiency.

The equipment specifications indicate a design mass flow rate of 2,32,295 kg/hr and a volume flow rate of 87.726 m^3/sec at a design temperature of 142°C and density of 0.78 kg/m^3.

The ID fan was operating normally until a high draft alarm(-2 (high, high)) appeared on the DCS system, leading to a full furnace shutdown. On inspection, the coupling spacer between the motor and fan was found damaged.

Problem Identification

At 05:30 hrs on September 26, 2024, a high draft alarm was registered for Furnace-4. One minute later, a total shutdown of the furnace occurred. Upon field inspection, damage to the ID fan coupling spacer was observed. This initiated a series of inspections, maintenance actions, and tests that revealed repeated abnormal vibrations and mechanical issues with the coupling system.

The problem evolved from spacer damage to more complex failures, including bolt shearing and fatigue cracks, necessitating motor replacement and consideration of the torsional harmonic interaction between the fan and motor.

Timeline of Events

- Sep 26, 2024: High draft alarm and furnace shutdown triggered at 05:30 hrs. Coupling damage was identified.
- Sep 27, 2024: Re-start of the ID fan with temporary spacer; furnace light-up began.
- Sep 28 – Oct 3, 2024: Multiple inspections revealed damaged bolts, misalignment, and spacer issues.
- Oct 4 – Oct 7, 2024: ID fan restarted with spare motor; repeated abnormal noise at 250 RPM led to another stop. Final restart occurred after installing a healthy coupling spacer and bolts.

Observations

- Spacer and bolts between the fan and motor coupling were found cracked and fatigued.
- Spacer inspections revealed spiral cracks and failures due to prolonged cyclic stress.
- Vibration analysis indicated that the fan was operating near a critical harmonic speed zone, specifically at 250 RPM.
- Campbell diagram analysis identified intersections at 697 RPM (2X harmonic) and at 348, 232, and 116 RPM (4X, 6X, 12X subharmonics), leading to amplified torsional excitation and bolt fatigue.

Mechanical Effects

- Coupling bolts experienced torsional fatigue due to prolonged operation within harmonic excitation zones.
- Spacer damage stemmed from repeated torque spikes and inadequate damping.
- Repeated noise during ramp-up and trials confirmed the presence of vibration resonance.

Root Cause Analysis

- Design Shortfalls: The coupling design did not account for sub-harmonic resonance zones.
- Fatigue Failure: Bolts failed under repetitive torsional loading due to harmonic excitation at 4X and 6X the operating speed.
- Environmental Factors: Although considered, no significant corrosion, contamination, or external degradation was found.
- Maintenance Practices: Procedures followed were consistent with OEM recommendations; however, failure modes due to torsional vibration were not anticipated.

Engineering Judgement and OEM consultation

- OEM (M/s Boldrocchi India Pvt. Ltd.) conducted a detailed harmonic analysis.
- Campbell diagram confirmed that resonance intersects at critical operational speeds.
- Both the operating motor (425 A FLC) and the spare (366 A FLC) were prone to this resonance.
- Recommendations included moving operations out of the 250–450 RPM range and installing torsionally resistant couplings.

Preventive Measures and Recommendations

- Hardware Upgrade:
  - Replace current disc pack coupling with rubber element or spider-type coupling that can absorb torsional vibration.
  - Use a coupling rated to avoid harmonic intersections in critical RPM ranges.
- Operational SOP Revision:
  - Ramp up ID fans quickly from 25 to above 450 RPM to avoid prolonged operation in resonance zone.
  - Avoid operating in ranges: 550–560 RPM, 660–700 RPM, 670–695 RPM.
- Field Measurements:
  - Conduct real-time torsional vibration measurement and adjust VFD tuning accordingly.
  - Validate damping properties of the newly installed coupling in the field.
- Spare Parts Check:
  - Ensure availability of torsionally resistant couplings in spare inventory.
  - Periodically inspect coupling bolts and spacers for early signs of fatigue.

Conclusion

The ID fan failure at J3 ROGC was ultimately linked to torsional vibration resonance within the sub-harmonic range, intensified by VFD operation. This led to fatigue failure of the coupling bolts and spacer. Long-term resolution requires both design upgrades and procedural changes. Operating fans outside of the identified torsional zones, installing vibration-resistant couplings, and continuous monitoring of vibration signals are critical to prevent recurrence.

8.2 ID Fan Motor Tripping Incident

Incident Overview

On June 14, 2024, the Induced Draft (ID) fan motor of Furnace #04 tripped due to an earth fault. This fan is essential for maintaining airflow inside the furnace, and its failure led to the activation of the furnace's cold standby shutdown mode.

System Background

The ID fan is powered by a Variable Speed Drive (VSD), which regulates the airflow by adjusting fan speed. During normal operations, this fan ensures stable combustion by maintaining proper draft using a control system. Any failure in the fan directly impacts furnace operations.

Issue Identified

After the motor tripped, insulation resistance (IR) checks were performed and showed zero resistance, confirming an earth fault. Although the power cables from the VSD panel and substation to the motor were found to be healthy, a detailed inspection of the motor terminal box revealed the actual problem.
One of the power cable lugs (R-phase) had overheated. The terminal nut securing the cable was found melted and detached. This caused the cable to come into contact with the motor body, leading to the earth fault. Minor overheating was also seen on the winding lead, but the motor winding itself was later confirmed to be in good condition**.**

Root Cause Analysis

The earth fault was primarily caused by:

1. Improper Tightness of Cable Lug Connection: A loose connection between the power cable lug and terminal created high electrical resistance, which generated localized heating.

2. Material Mismatch (Possible Contributing Factor): The power cable lug was made of aluminium, while the terminal link was brass. This combination can lead to electrolytic corrosion over time, increasing contact resistance and heat generation. However, no visible corrosion was found during inspection.

Corrective Actions Taken

- The faulty motor was replaced with a spare, tested motor.
- Proper alignment and re-termination of cables were completed.
- The system was tested through no-load and final load trials and handed back to operation after confirming normal performance.

Recommendations for preventions

- Use of Bimetallic Washers: Introduce bimetallic washers between aluminum lugs and brass terminals to prevent corrosion-related heating.

- Upgrade to Copper Cables: Explore replacing aluminum power cables with copper ones for better electrical contact and flexibility during termination.

- Ensure Proper Torque During Termination: All cable lugs must be tightened to the manufacturer's recommended torque values. This will now be part of the standard procedure.

- Regular Thermography Monitoring: Thermal imaging of all ID fan motors will be scheduled every 4 weeks to detect early signs of overheating in terminal boxes.

Conclusion

The root cause of the motor tripping was a high-resistance connection at the R-phase terminal of the motor. This was due to either loose termination or a poor-quality connection, which led to severe heating and eventual failure. Measures have now been taken to improve termination practices and monitor motor health regularly to prevent such incidents in the future.

8.3 Issue in ZS Line Valve

A basic valve is used to permit or restrain the flow of fluid or adjust the pressure in a system .

A complete control valve is a valve in which fluid flow must be manipulated and monitored . It is made of valve itself , an actuator or a valve control device .Actuator will provide the required force to open or close the valve.

Valve control device :-

- Keeps valve in proper operating condition
- Ensure proper positioning
- Interpret signals
- Manipulate responses

General Types of Valves

- **Ball Valves** - Valve with a spherical disc , the sphere has a hole in it which when it comes in line with the pipe it makes connection open .
- **Butterfly Valves** - Consists of disc attached to shaft with bearing used to felicitate rotation .
- **Globe Valves -** Globe valves are a type of linear motion valve primarily used to start, stop, and regulate flow in a pipeline
- **Plug Valves** - Plug valves are quarter-turn valves used to start or stop flow in pipelines

ZS Line Valve

Valve – Isolated Wedge valve

Vendor Name – L&T Valves

EQ No – VG8ARANC -20“

Metallurgy

Body	ASTM A336 GR F91
Stem	ASTM A182 GR F6A
Packing (Before the issue)	Graphite Rings With Corrosion Inhibitor
Gland	ASTM A276 TYPE 410

ASTM A276 TYPE 410 - Primarily composed of iron, with a minimum of 11.5% chromium and small amounts of other elements like carbon, manganese, and silicon. Shows good scaling resistance up to approximately 650°C (1200°F).

ASTM A182 GR F6A -ASTM A182 Grade F6A is a specification for forged or rolled alloy and stainless steel materials, specifically a 13% chromium martensitic stainless steel grade. It's commonly used for high-temperature applications, including flanges, fittings, valve bodies, fasteners, and other pressure parts.

Gland Packaging

Gland packing is a type of shaft seal, traditionally used in pumps, valves, and other rotating or reciprocating equipment, to prevent leakage between a moving part and its housing. It consists of compressible material, like braided or twisted fibers, that is compressed within a gland (a cavity or housing) to create a seal. The packing material is compressed within the gland to create a barrier against leakage.

TEADIT 2336

Teadit® 2236 valve packing is self-lubricating, non-hardening, dimensionally stable and resistant to gases and fluids as well as heat, pressure and chemicals. The TEADIT packing style 2236 is made from layers of flexible graphite tape plied into compact strands; each individual filament is reinforced with an Inconel wire jacket. This yarn is then treated in a special process and then braided to form a dense yet malleable packing, which is subsequently treated with lubricating agents to reduce stem friction and a corrosion inhibitor to prevent pitting.Teadit 2236 valve packing incorporates **PTFE** in its construction, utilizing it as a key component for its low-emission and high-performance properties

Temperature Limits		Pressure Limits	
Minimum	-400°F (-240°C)	Static	6526 psi (450 bar)
Maximum*	Atmosphere 850°F (455°C)		

ISSUE

Gland packing failure and stem corrosion incident got noticed during TA2023 .It is observed that damage is due to corrosion . It has only occurred in STEM and Stuffing Box at ID at gland packing contact region . Corrosion is attributed due to Fluorine attack .

PTFE fillers in TEADIT 2236 imparts low fugitive emission features . Fluorine is present in PTFE fillers which is the source for fluorine attack . So Fluorine generated from PTFE fillers in typical low fugitive emission type gland packaging when used in high temperature steam service .

SOLUTION

So the main problem we are facing is fluorine attack on stem and stuffing Box . So in order to eradicate low fugitive emission we will use TEADIT 2235 packing instead of TEADIT 2236 because it doesn't contain PTFE fillers which is the sole source of fluorine .And moreover this is the case of corrosion therefore changing the metallurgy of packing will solely going to fulfil the purpose . And the metallurgy of stem and gland remain unchanged .

TEADIT 2335

Packing Style 2235 is composed of layers of flexible graphite tape plied into compact strands; each filament is reinforced with an Inconel® wire jacket. The strands are then square braided to form a dense yet malleable packing. Additionally, it is also impregnated with a minimal amount of lubricating agents to reduce stem friction.

Style 2235 is self-lubricating, non-hardening, dimensionally stable and resistant to gases as well as heat, pressure and chemicals.

Temperature Limits		Pressure Limits	
Minimum	-400°F (-240°C)	Static	6500 psi (450 bar)
Maximum	842°F (450°C)		
Steam	1202°F (650°C)	pH	0-14*

9. Conclusion

The internship at Reliance Industries Limited, Jamnagar, provided an opportunity to study the consequence analysis of leaking cooling water service heat exchangers in the C2 and Rubber Complex. During the course of the project, I reviewed the design and function of shell-andtube exchangers, examined the major failure mechanisms such as corrosion, fouling, erosion, and stress corrosion cracking, and analyzed their operational, safety, and environmental implications.The work involved understanding the inspection techniques currently used in industry—ranging from visual checks and boroscopy to hydrotesting and advanced nondestructive examinations—and evaluating their role in detecting early signs of tube failure. Based on industry standards, particularly API RP 571, and plant-specific practices, I studied the root causes of exchanger leaks and assessed strategies to enhance equipment reliability.

The project also highlighted practical reliability improvement measures adopted at Reliance, including water chemistry control, periodic backflushing, use of sacrificial anodes, application of protective coatings, and upgrades to stainless steel and titanium tubes in critical exchangers. These measures, supported by design modifications and rigorous maintenance schedules, have significantly improved the performance of cooling water heat exchangers in the C2 and Rubber Complex.

In conclusion, the internship allowed me to connect theoretical knowledge with real-world engineering practices, gain exposure to industrial reliability management, and contribute to a structured analysis of exchanger failures and mitigation strategies. The insights obtained not only strengthened my technical understanding of degradation mechanisms but also emphasized the importance of preventive maintenance and consequence analysis in ensuring safe and reliable refinery operations.

10. Acknowledgement

I am extremely thankful to have undergone my internship at Reliance Industries Limited, Jamnagar Manufacturing Division. This experience provided me with invaluable industrial exposure, practical insights, and an opportunity to apply my academic knowledge in a realworld setting.

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2022MEB1343

4th Year Mechanical Engg.

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