UNIVERSIDADE EDUARDO MONDLANE

FACULTY OF ENGINEERING

CHEMICAL ENGINEERING DEPARTMENT

MASTER IN HYDROCARBON PROCESSING ENGINEERING

ENHANCING THE EFFICIENCY OF FUEL GAS CONSUMPTION IN A NATURAL GAS PROCESSING FACILITY

A Dissertation by

Elisée ITANGISHAKA

MAPUTO

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DECLARATION OF DOCUMENT ORIGINALITY

I declare that this dissertation has never been submitted to obtain any degree or in any other context and is the result of my own individual work. This dissertation is presented in partial fulfillment of the requirements for the degree of Master of Science in Hydrocarbon Processing Engineering, from the Universidade Eduardo Mondlane.

Submitted by:

Elisée ITANGISHAKA

DEDICATION

This thesis is dedicated to my late parents for their endless love, unconditional support and encouragement.

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First and foremost, all thanks go to the Almighty God.

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ABSTRACT

Today natural gas has been attracting significant attention by the world since its combustion release small amount of greenhouse gases compared to other fossil fuel. Natural gas is a mixture of heavy and light hydrocarbon with small amount of impurities but mainly composed by Methane. The separation of desirable product and byproduct take place in a gas processing plant or facility. During these activities not all processed gas is exported to the consumer rather a considerable amount of natural gas is typically consumed by natural gas processing plants in order to power gas turbines for the generation of electricity and mechanical power within the facility. Worldwide energy efficiency in industry plays key roles in improving energy security, environmental sustainability and economic performance. Hence, in this thesis the main aim was to enhance the efficiency fuel gas consumption through installation of a compressor booster to control the suction pressure of the low-pressure compressor and the study has been conducted based on a case study in a gas processing facility. A protype of gas compression at gas processing plant was built and its flowsheet model has been designed and simulate in Aspen HYSYS. The fuel gas consumption data for the gas plant main fuel gas user (LP and HP compressor and gas turbine generator) has been collected. Parametric studies were performed and variables like pressure, flowrate, work, pressure ratio and fuel gas quantity were analyzed on both sides (simulation and collected data). The collected data analysis results were shown that LP compressor unit was the main contributor to the total fuel gas consumption and excess total fuel gas consumption respectively where it is consuming ~ 9500GJ/day and ~ 3000GJ/day fuel gas respectively. The analysis of simulated results as well as of the collected ones have indicated that a high compression ratio above ~3 the driving force to excess of fuel gas consumption and the use of small compressor as a booster significantly enhance the efficient of fuel gas since it reduced the fuel gas flow rate 430.7 Kgmol/h up to 400.5kgmol/h.

Keywords: Natural gas, Natural gas processing facility, fuel efficiency, enhancing, fuel gas.

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LIST OF ABREVIATIONS

CH_4	Methane
CNG	Compressed Natural gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPF	Central Processing Facility
Gtg	Gas turbine generator
GTL	Gas to Liquid
H_2	Hydrogen
H_2S	Hydrogen sulphide
HPC	High pressure compressor
LNG	Liquefied natural gas
LPC	Low pressure compressor
MJ	Megajoule
NO_x	Nitrogen Oxides
Ppmv	Part per million by volume
SO_2	Sulphur Dioxide
SOP	Standard operating procedure
USD	United states dollar

Chapter 1

INTRODUCTION

1.1 Overview

Natural gas processing plant have been used for decades to extract and treat raw gas and transport large quantities of natural gas across long distances by means of different phase of equipment's or unit operation as illustrated in the figure 1 (where DM-2001 and DM-2002 stands for production separator drums, unit 30's is low pressure compressor unit, unit 40's is dehydration unit, unit 50's is dewpoint control unit, DM-2005 is slug catcher while unit 70's is stabilization unit) and described in section 1.2. According to Popli et.al (2012) Within a natural gas processing plants, a substantial amount of natural gas is commonly utilized to operate gas facility equipment such as compressors gas turbines enabling the generation of electricity and mechanical power on-site which results in a significant fuel gas consumption. Therefore, optimization of fuel consumption plays an important role in the operating costs of the facility (Alireza & Shirazi, 2020).

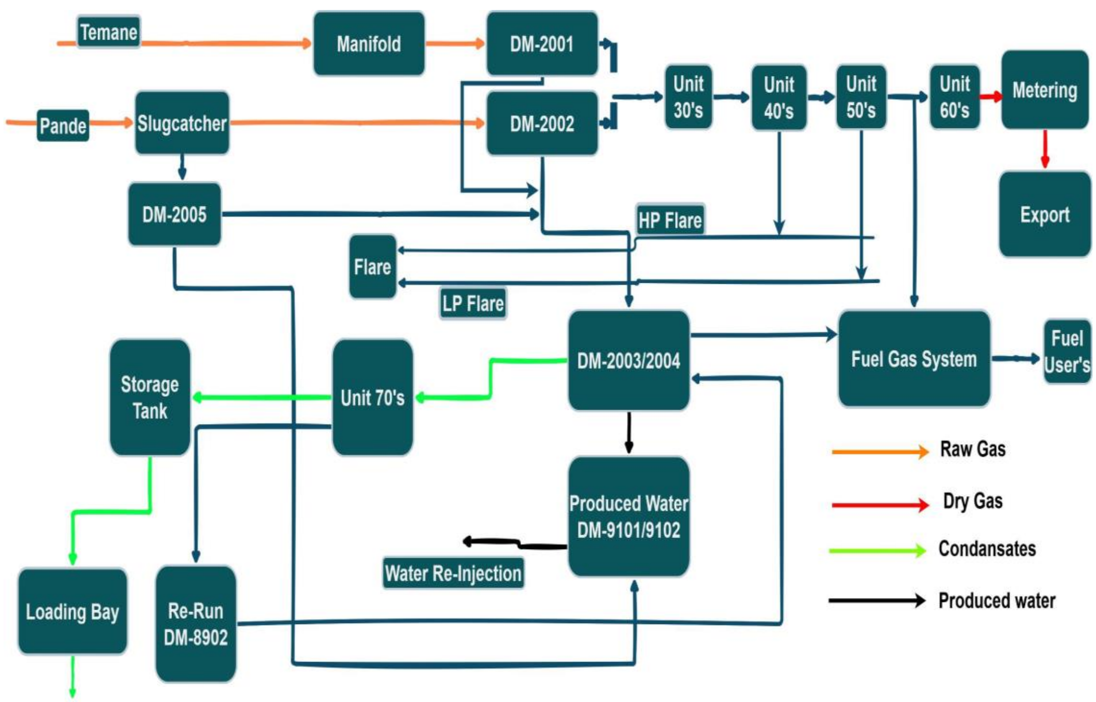

Figure 1: Schematic diagram represents the general gas processing units

The gas plant has a fuel gas system unit to use in fuel gas distribute to the fuel gas users in the facility as it shown in figure 2 (where GTG stands for gas turbine generators, HP and LP are high pressure and low pressure respectively). The fuel gas system is composed by a high- and low-pressure fuel header since fuel gas is consumed at different pressure. The high-pressure fuel header is to supply the fuel gas to high pressure fuel gas user at ~ 2000kpa. On the other hand, low pressure fuel header is to deliver fuel gas to low fuel gas user at ~ 500kpa.

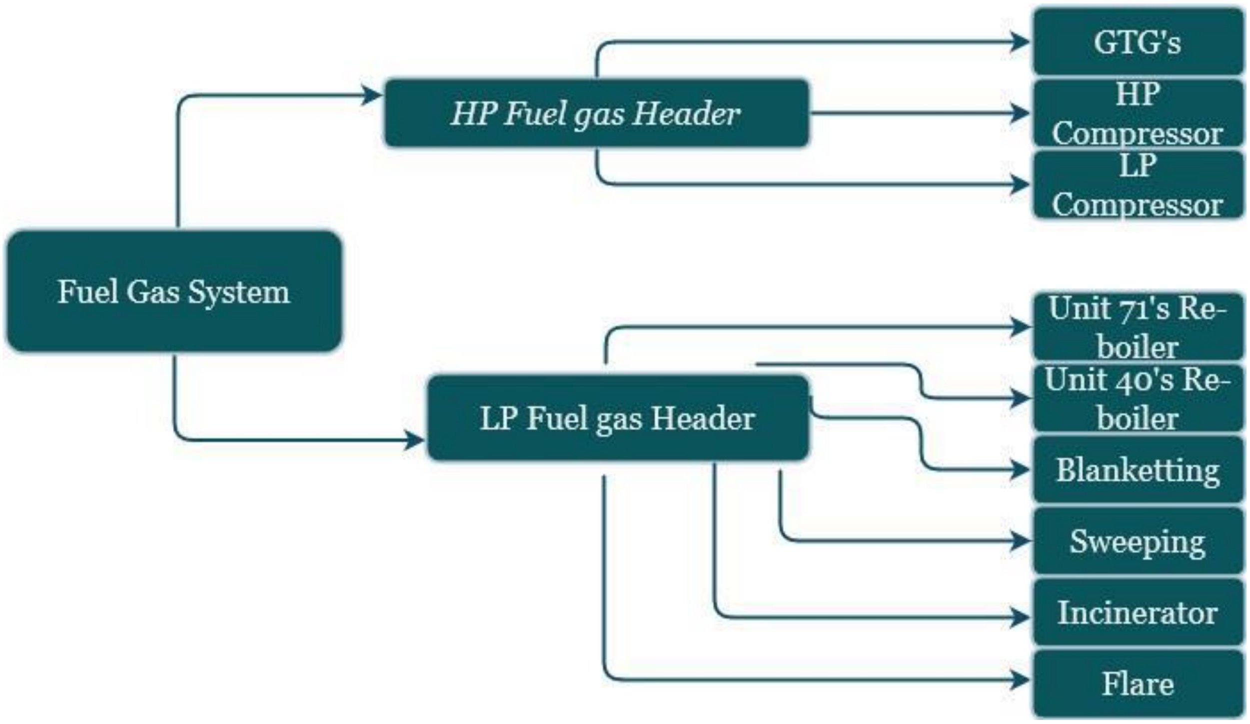

Figure 2: Natural gas processing facility fuel users

Generally, the excessive consumption of energy specifically fuel gas is not good since it causes hazard not only to the operating plant but also to the environment or the community in the surrounding of the plant facility. Therefore, for the propose of this dissertation evaluation has been done to enhance the efficient use of fuel gas in the plant and find the recommendation for the root cause of the high consumption of fuel gas above the limit.

1.2 Description of gas processing facility

Central Processing facility is among natural gas production and processing facilities located in different countries globally. These plants mostly produce three types of products: the dry gas or methane as the desired product, condensate (a mixture of low-density hydrocarbon) and produced water as non-desired products. To get set of the latter products, the raw gas from wells goes through several processing phases as shown in the Figure 1 and described below.

The raw natural gas comes from gas wells remotely located in different miles to the gas processing facility. It is received sometimes at the required operating pressure of the plant or not depending the gas pressure from wells. The raw gas received from wells far away gas processing facility is associated with a mixture of liquids called slug, composed with condensate (wet gas) and water. On the other hand, gas from wells nearby gas processing plant is routed directly to liquid separator since it received to the plant with little amount of slug and water in case these liquid goes to the processing system may leads to water presence and hydrates formation that normally create blockage and corrosion of the pipeline and equipment. To avoid this problem all the liquids that are coming with gas are separated from the raw gas using separator.

The raw natural gas comes from the wells at low pressure of 20 bar or below due to the decline of gas pressure at the reservoirs. However, to meet the operating pressure of the facility as recommended in the design of the plant facility, the gas is routed to the LPC, Low Pressure Compressors (Unit 30's), to increase the pressure of the gas from ~ 20 bar to ~ 60 bar (HPC suction pressure), in order to perform further natural gas process.

After boosting the gas pressure to around HPC suction pressure the gas is sent to the gas dehydration unit (unit 40's) to remove moisture available in the gas by using Tri-ethylene glycol (TEG) with hygroscopic nature, to prevent gas condensation. The Tri-ethylene glycol is heated to a high temperature and put through a condensing system, which removes the water as waste and reclaims the TEG for continuous reuse within the system.

To protect the compressor from damage during operation, filters or scrubbers that are able to remove very fine particulates (both solid and liquid) from the feed gas are required upstream of the compressor. Also, high pressure discharge gas from the compressor (LPC) may contain some free liquid water and liquid hydrocarbons which need to be removed by installing appropriate filter coalescers or gas scrubbers downstream of the compressor (HPC).

As gas processing plant delivered produced natural ga to the customer using pipeline to avoid two phase formation during natural gas transportation natural gas dew point is corrected before routed to the compressor for transportation. The dewpoint correction is done by chilling the gas using liquid propane and the heavier hydrocarbons condense and are separated from the lighter ones. Some of the dew point corrected gas remain locally or exported out of the country. the external export take place using a High-Pressure Compressors (HPC) to around 125 bars in a pipeline (Gas processing plant SOP's).

As aforementioned above the facility produces a byproduct called condensate (free of water) which within the temperature of 25°-30°C range and pressure of 30 bar is routed to the Condensate Stabilization Unit to remove the vapor or Off gas (C_1 to C_4). After stabilization the condensate is routed to the condensate storage tank and loading bay where it is taken for selling to the customer (refining plant) which utilizes it as feedstock for the petrochemical production. The main target of stabilizing the condensate is to control gas stabilization and ensure that it is stored and transported safely and avoid accidents during transportation, as the condensate are naturally more volatile (Gas processing plant SOP's).

In case a defect or error in the facility happens during gas processing or pretreatment the liquid is route to the re-run drum from where the liquid sent again to the liquid separator drum for reseparation. In addition, for the integrity of the plant flare is always alive to burn the gas that may cause hazard to the facility (Gas processing plant SOP's).

1.3 Research Problem

The natural gas processing facility is responsible for the production, processing, and transportation of natural gas. Despite these processes, not all of the produced natural gas is able to reach consumers due to various factors. Though a portion of gas is typically taken and utilized as a source of energy or fuel by the gas processing facility to run some of the plant equipment's and/or powering the plant. The excessive use of natural gas as a fuel poses a significant challenge as it not only raises operational expenses but also serves as a source of environmental harm, this are the big problem to gas processing facility and to environment as well. It is crucial to address the issue of surpassing the limit of natural gas consumption in processing facilities to mitigate operational costs increase, promote environmental sustainability, and enhance overall efficiency. By reducing the consumption of fuel gas in these facilities, a positive impact can be made on both financial and environmental aspects.

1.4 Research Objectives

1.4.1 General objective:

- To enhance the efficiency of fuel gas usage in a natural gas processing facility.

1.4.2 Specific of objective:

- To design and simulate a flowsheet model for natural gas compression process via three stages
- To analyze data from a gas processing plant and identify the unit operation with high fuel gas consumption above the limit.
- To compare simulation and data analysis result and identify the root cause of high fuel gas consumption.

1.5 Motivation, contribution and Significance

Gas processing facilities, which play a vital role in the natural gas supply chain, are essential for purifying raw natural gas extracted from the wellhead. These facilities are designed to eliminate impurities and contaminants from the gas stream, ensuring that the final product meets the strict quality standards necessary for both consumption and industrial applications. However, the significant energy consumption associated with the operation of gas turbines and fired heaters in these plants leads to substantial carbon emissions, making them notable contributors to greenhouse gas (GHG) emissions within the industry (Choudhary, Srivastava, & De, 2018).

The emphasis on energy efficiency has become a key focus in the global sustainability agenda, particularly in industries like oil and gas. Improving energy efficiency not only helps in reducing operational costs but also plays a crucial role in minimizing the environmental impact of these facilities. Gas treatment plants, with their high energy demands, present a unique challenge in terms of optimizing energy consumption and reducing emissions. Addressing these challenges requires innovative solutions that can effectively identify areas for improvement and implement strategies to enhance overall efficiency (Brookes, 1990).

By conducting a thorough evaluation of energy usage patterns and emission sources within gas treatment plants, opportunities for optimization can be identified and leveraged to enhance sustainability. Implementing energy-efficient technologies, optimizing process operations, and exploring alternative energy sources are some of the strategies that can be employed to improve the overall energy performance of these facilities. The pursuit of energy optimization and emissions reduction in gas treatment plants is not only essential for meeting regulatory requirements but also for demonstrating a commitment to environmental stewardship and sustainable practices in the oil and gas industry (El-Eishy, Abdelalim, & Aboul-Fotouh, 2023).

Chapter 2

LITERATURE REVIEW

2.1 Natural gas historical background

2.1.1 Natural gas

Natural gas (also called fossil gas, methane gas or simply gas) is a naturally occurring mixture of gaseous hydrocarbons and non-hydrocarbon. It is normally found and produced in the reservoirs (onshore or offshore as see in the figure 4) alone or sometimes with oil both contained in the pore spaces of the reservoir rock far away from the consumption regions and it is transported either by pipeline pressure or liquefied with ships and land vehicles from the origin to areas of demand. Some types of reservoirs allow the gas to move freely, making it easier to recover. Other reservoirs restrict the flow of gas and require special techniques to move the gas from the pores to a producing well (Alparslan et al., 2015).

Natural gas was firstly used in the 19th century for illumination of roads and public buildings but nowadays it's being used in almost all sectors, residential, industry, transport and others. The charts below illustrate natural gas consumption in Mozambique in 2018.

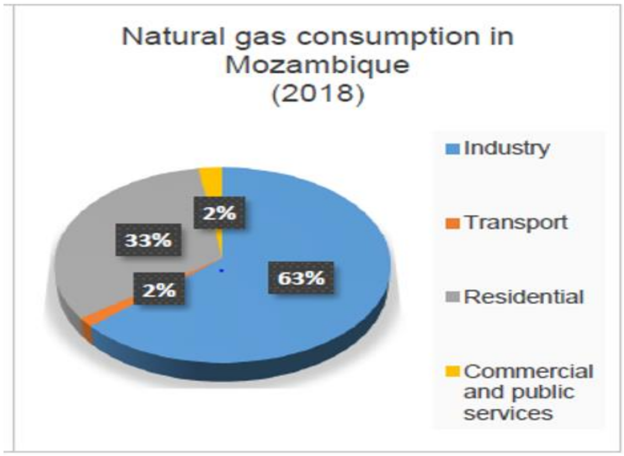

Figure 3: Natural gas consumption by sector in Mozambique (IEA, 2018)

Natural gas is a fossil fuel and non-renewable resource that is formed when layers of organic matter (primarily marine microorganisms) decompose under anaerobic conditions and are subjected to intense heat and pressure underground over millions of years. The energy that the decayed organisms originally obtained from the sun via photosynthesis is stored as chemical energy within the molecules of methane and other hydrocarbons (Neumann et al., 2015).

Natural gas can be extracted inside water or outside water (offshore) as shown by the figure 4. This means that infrastructure to extracted natural gas is situated in the middle of water while it is situated on land when it is extracted out of water or onshore.

Figure 4: Onshore and offshore petroleum platform (Rasmussen & Kurz, 2009)

2.1.2 Natural gas composition and heating value

Natural gas is a colorless and odorless mixture of hydrocarbon and non-hydrocarbon gases, primarily methane (CH_4), which makes up about 95 percent of the gas (see Table 1) (Liang et al., 2012).

Table 1: Chemical composition of natural gas (Bag, 2008)

Component	**Typical analysis, % by volume**	**Range, % by volume**
Methane	94.9	87-96
Ethane	2.5	1.8-5.1
Propane	0.2	0.1-1.5
Other hydrocarbons	0.1	0.04-0.7
Nitrogen	1.6	1.3-5.6
Carbon dioxide	0.7	0.1-1
Oxygen	0.07	0.01-0.1

Natural gas is measured in volumetric unit. It is composed of several combustible and non-combustible gases, each occurrence of natural gas has a different heating value, typically ranging between 30 and 40 megajoules (MJ) per cubic meter (Neumann el al., 2015).

2.2 Mode of natural gas transportation

The efficient and effective movement of natural gas from producing plants to consumers requires an extensive and elaborate transportation system. In many instances, natural gas produced from a particular well will have to travel a great distance to reach its point of use. The possible ways of transporting natural gas to markets are pipelines, liquefied natural gas, compressed natural gas, gas to solids (hydrate), gas to liquids, gas to wire and other gas to commodity methods (Rajnauth, Ayeni, & Barrufet, 2008). Therefore, of all the aforementioned natural gas transportation modes, this study is mostly related to pipelines as it moves gas from wells to export lines.

2.2.1 Pipelines

For many years pipelines have been the most convenient way to transport natural gas. Today pipeline transportation still remains a significant mechanism for gas delivery to markets. The transportation system for natural gas consists of a complex network of pipelines, designed to quickly and efficiently transport natural gas from its origin, to areas of high natural gas demand. Compressor stations are positioned along the pipeline route to maintain an efficient gas transportation process. Pipelines can measure anywhere from 6 to 56 inches in diameter.

Pipelines are operated at pressures normally > 700 psig and this depends on the age of the pipeline and construction material used.

In general, natural gas pipelines can be classified in three categories depending on purpose:

(i) Gathering Pipelines: Group of smaller interconnected pipelines forming complex networks with the purpose of bringing the natural gas from several nearby wells to a treatment plant or processing facility. In this group, pipelines are usually short (couple of hundred meters) and with small diameters. Also, sub-sea pipelines for collecting product from deep water production platforms are considered gathering systems.

(ii) Transportation Pipelines: These are mainly long pipes with large diameters, moving products between cities, countries and even continents. These transportation networks include several compressor stations in gas lines.

(iii) Distribution Pipelines: Pipelines composed of several interconnected pipelines with small diameters, used to take the products to the final consumer. Feeder lines distribute gas to homes and businesses downstream. Pipelines at terminals for distributing products to tanks and storage facilities are included in this group.

2.2.2 Liquefied natural Gas LNG

Liquefied natural gas or LNG is natural gas that has been converted to liquid form for ease of storage or transport. LNG is gas cooled to temperature of about -162^{o}C and has a volume of 1/600 that of the gas at room temperature. LNG can be transported on land or by sea. It can be transported by specially designed cryogenic sea vessels (LNG vessels) or cryogenic road tankers. The liquefaction process removes oxygen, carbon dioxide, sulfur compounds and water. LNG is loaded onto ships and delivered to a regasification terminal, where the LNG is reheated and turned into gas. Regasification terminals are usually connected to a storage and pipeline distribution network to distribute natural gas to local distribution companies (LDCs) or Independent Power Plants (IPPs).

Pipeline-quality raw gas and processed natural gas must be transported from the source to the end user, industrial or residential. Except for the uncommon situation where the gas plant is dedicated to a single commercial customer. Transport of gas in pipelines is a very effective way of transporting energy over large distances. However, gas flowing in a pipe suffers from pressure losses that increase with flow velocity and the length of the pipe. Every 50 to 100 miles, a compressor station is necessary to recompress the gas and compensate for the pressure losses (Kidnay, & Parrish, 2006).

For natural gas, transportation and storage problems are more difficult than with other common fuels, such as coal and gasoline. Being a gas, it has low energy density at ambient temperatures and pressures. For an equal volume of these three fuels at ambient temperature and pressure, the energy content of gasoline is approximately 1,000 times greater than that of natural gas. The same volume of coal contains 700 times more energy as a fuel (Kidnay et al., 2006). These large differences in energy density highlight two major issues with natural gas. First, a relatively high pressure is required to increase the gas density and raise the energy content per unit volume so that the gas can be transported economically by pipeline (common pressures are approximately 800–1,500 psig (60–100 bar) (INGAA, 2009). Second, large quantities of natural gas cannot be stored in relatively simple and inexpensive aboveground facilities similar to those used for less volatile liquid petroleum products. Note that for methane, the primary component of natural gas, the critical temperature is –83°C, and, consequently, no amount of pressure can convert methane into a liquid at 15°C (Lee, 2017).

2.3 Natural gas compression technology

Natural gas compression is used in different aspects of the natural gas industry to increase gas pressure and reduce its volume for several advantages. It plays a major role in gas processing, as it moves gas from the field, through the gas plant, and into the sales gas line. The benefits of operating at higher pressures include the ability to transmit larger amount of gas through a given size of pipeline, lower transmission losses due to friction, and the capability to transmit gas over long distances without additional boosting stations (Margareth, 2017). However, the latter process is achieved via a compressor or compressor unit of a gas processing plant.

In gas compression, two basic types of compressors are used: reciprocating and centrifugal compressors. Reciprocating compressors are usually driven by either electric motors or gas engines, whereas centrifugal compressors use gas turbines or electric motors as drivers. While both gas engines and gas turbines can use pipeline gas as a fuel, an electric motor has to rely on the availability of electric power. However, fuel or energy cost is one of the key variables in natural gas compression process as it accounts for about 80% of the energy consumption of all the gas processing plant (Mourant, 1960).

2.3.1 Gas turbine compressor components

A gas turbine engine is a type of internal combustion engine. Essentially, the engine can be viewed as an energy conversion device that converts energy stored in the fuel to useful mechanical energy in the form of rotational power (Willson, 1995). The term ‘’gas” refers to the ambient air that is taken into the engine and used as the working medium in the energy conversion process. In a gas facility a gas turbine compressor is a mechanical device that increases the pressure of a gas by reducing its volume and is composed by three main components: the compressor, combustion system and turbine as described by the figure 5 where a part of processed natural gas considered as fuel gas is mixed with air to provide the driving force to run the compressor during natural gas transportation. This requires the combustion of a natural gas in a combustion chamber in order to get the energy to rotated the compressor's impellers while pushing the gas from low pressure to high pressure as demonstrated in the figure 5. Each component has a specific task in order for the unit to increase pressure gas from low pressure to high pressure (Rasmussen & Kurz, 2009).

- Intake: Natural gas enters the compressor through an inlet. The intake process usually involves filtration to remove any impurities or particles that could damage the compressor components.
- Turbine and Combustion system: air is first drawn into the engine where it is compressed, mixed with fuel and ignited. The resulting hot gas expands at a high velocity through a series of airfoil-shaped blades transferring energy created from combustion to turn an output compressor shaft, causing it to rotate and drive the compression process.
- Compression: The compressor uses a rotating impeller to compress the incoming gas. As the impeller spins, it accelerates the gas to high speeds, increasing its pressure and kinetic energy. This compression process is what allows the compressor to raise the pressure of the gas to the desired level for transportation or processing.
- Discharge: Once the gas has been compressed to the desired pressure, it is discharged from the compressor through an outlet. The compressed gas can then be transported through pipelines or further processed for various industrial applications.
- Exhaust: Directs the low emission spent gas out of the turbine section.

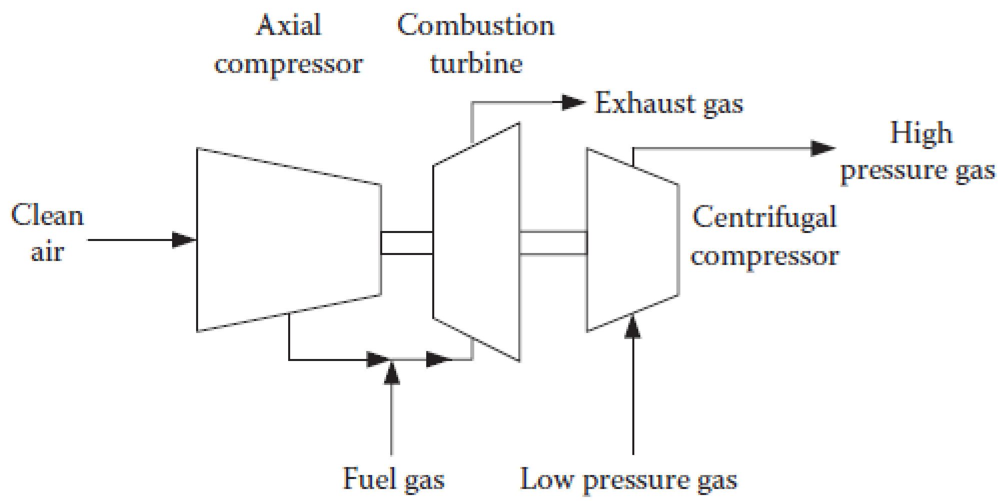

Figure 5: Schematic of a gas turbine-driven compressor (Kurz & Brun, 2012).

During gas compression process the consumption of natural gas by a compressor turbine involves the conversion chemical energy into mechanical energy enabling the compressor to work in order to efficiently transport the gas over long distances (Allison, Singh, & Thorp, 2018).

2.3.2 Combustion Process

In its simplest form, combustion is a process in which some material or fuel is burned. Whether it is striking a match or firing a jet engine, the principles involved are the same and the products of combustion are similar. Combustion of natural gas is a chemical reaction that occurs between carbon, or hydrogen, and oxygen. Heat is given off as the reaction takes place. The products of combustion are carbon dioxide and water. The reaction is as follows:

$$\mathbf{CH_4 + 2(O_2) \rightarrow CO_2 + 2H_2O + Heat} \tag{1}$$

(Methane + oxygen) (Carbon dioxide + Water + Heat)

Four parts of oxygen are required to burn one part of methane. The products of combustion are one part of carbon dioxide and two parts of water. One cubic foot of methane will produce one cubic foot of carbon dioxide gas. Oxygen used for combustion occurs in the atmosphere. The chemical composition of air is approximately 21% oxygen and 79% nitrogen, or one part of oxygen to four parts of nitrogen. In other words, for each cubic foot of oxygen contained in the air, there are about 4 ft3 of nitrogen. Oxygen and nitrogen molecules each contain two atoms of oxygen or nitrogen. Noting that one part, or molecule of methane requires four parts of oxygen for complete combustion, and since the oxygen molecule contains two atoms, or two parts, the volumetric ratio of methane and oxygen is as follows:

$$\mathbf{CH_4 + 2(O_2 + 4N_2) \rightarrow 2H_2O + CO_2 + 8N_2 + Heat} \tag{2}$$

(Methane + Air) (Water + Carbon dioxide + Nitrogen + Heat)

One cubic foot (0.03m^3) of methane requires 10 ft^3 (0.28 m^3) of air, 2 ft^3 (0.06 m^3) of oxygen, and 8 cubic feet (0.23 cubic meter) of nitrogen for combustion. The products are carbon dioxide, nitrogen, and water. The combustion product of 1 ft^3 of methane yields a total of 9 ft^3 of carbon dioxide gas. In addition, the gas burned contains some ethane, propane, and other hydrocarbons. The yield of inert combustion gas from burning a cubic foot of methane will be 9.33 ft^3 (0.26 m3). If the combustion process created only the reactions shown in the previous discussion, no provision would be necessary for control. Unfortunately, other reactions occur in which undesirable products are formed.

2.4 Natural gas as a source of energy

Natural gas is an energy source that can be used as a gaseous fuel (after processing) mainly as methane, however it can also be used as non-gaseous fuel after conversion: i) electricity after conversion in a turbine or engine, ii) heat, iii) liquid, as a result of the extraction on natural gas liquids or the conversion of natural gas into synthetic liquid fuels (gas-to-liquids) or hydrogen, through steam methane reforming (Munir et al., 2023).

2.4.1 Gaseous Form

- **Compressed natural gas**

Compressed Natural Gas (CNG) refers to natural gas that has been compressed to a high pressure of up to 200 bar or (2,900 psi). This fuel source is predominantly made up of methane (CH_4) and is maintained in a gaseous form for storage and distribution purposes. The process of compressing natural gas into CNG involves reducing its volume significantly, allowing for more efficient storage and transportation. By compressing the gas, it becomes easier to handle and can be stored in tanks at a much higher pressure than standard atmospheric conditions. This compression process is essential for making CNG a viable option for powering vehicles and other applications where natural gas is used as a fuel source (Bag, 2008).

The utilization of CNG as a fuel source has gained popularity due to its lower emissions compared to traditional fossil fuels like gasoline and diesel. In addition to being a cleaner alternative, CNG is also more cost-effective in many cases, making it an attractive option for both consumers and businesses looking to reduce their carbon footprint and operating costs. As advancements continue to be made in the development and distribution of CNG infrastructure, its role as a sustainable energy source is expected to grow in the coming years (Aktemur, 2017).

2.4.2 Non-Gaseous Form

- **Liquid fuel**

The production of liquid fuel from natural gas typically involves the utilization of Gas-to-Liquids (GTL) technology. This advanced technology enables the conversion of natural gas, which is primarily composed of methane (CH_4), into liquid fuels such as diesel, gasoline or jet fuel. The GTL process consists of two main stages that are crucial for the transformation of natural gas into a usable liquid fuel (Wood, Nwaoha, & Towler, 2012).

The first stage of the GTL process is known as Syngas Production. During this stage, natural gas undergoes a conversion process called steam reforming or partial oxidation. Through these processes, the natural gas is transformed into synthesis gas, also known as syngas. Syngas is a combination of hydrogen (H_2) and carbon monoxide (CO), which serves as the foundation for the subsequent stages of the GTL process (Powell, 2020).

The second stage of the GTL process is the Fischer-Tropsch Synthesis. In this stage, the syngas produced in the previous stage is converted into liquid hydrocarbons using catalysts. The Fischer-Tropsch process involves a series of chemical reactions that facilitate the recombination of hydrogen and carbon monoxide molecules. These reactions result in the formation of longer-chain hydrocarbons, which are the essential components of liquid fuels. Through the combination of these two stages, natural gas can be effectively converted into a valuable and versatile liquid fuel source (Parkyns, Warburton, & Wilson, 1993).

- **Electricity**

The process of converting natural gas into electricity involves the utilization of either a gas turbine power plant or a combined cycle power plant. The initial step in this process is combustion, where natural gas is burned in a combustion chamber, reacting with oxygen to produce high-temperature, high-pressure gases. This combustion reaction is crucial as it serves as the foundation for the subsequent steps in the electricity generation process (Popli et al., 2012).

In a gas turbine power plant, the hot gases resulting from combustion expand through a turbine, causing it to spin. This spinning turbine is directly linked to a generator, which then converts the mechanical energy into electrical energy. This straightforward process efficiently converts the energy derived from burning natural gas into electricity, providing a reliable source of power for various applications (Atilgan & Azapagic, 2015).

On the other hand, a combined cycle power plant takes a more intricate approach by utilizing the hot gases produced from burning natural gas to generate steam in a heat recovery steam generator. The steam generated is then used to drive a steam turbine, which is also connected to a generator to produce additional electricity. This combined cycle configuration significantly enhances the overall efficiency of the power plant by effectively utilizing both gas and steam turbines in the electricity generation process. Subsequently, the electricity generated is connected to the electrical grid for distribution to consumers, ensuring a continuous and reliable power supply (Demirbas, 2006).

2.5 Benefit of efficient energy utilization

Adopting strategies to lower fuel consumption offers substantial advantages for natural gas processing plants, encompassing economic, environmental, and socio-economic gains. Investing in energy efficiency not only provides these primary benefits but also delivers additional advantages, including enhanced energy security and improved public health (refer to Fig. 6). In addition to these core benefits, Taylor (2007) highlights various other advantages of efficient energy use, such as job creation, poverty reduction, and better resource management, as illustrated in Figure 6.

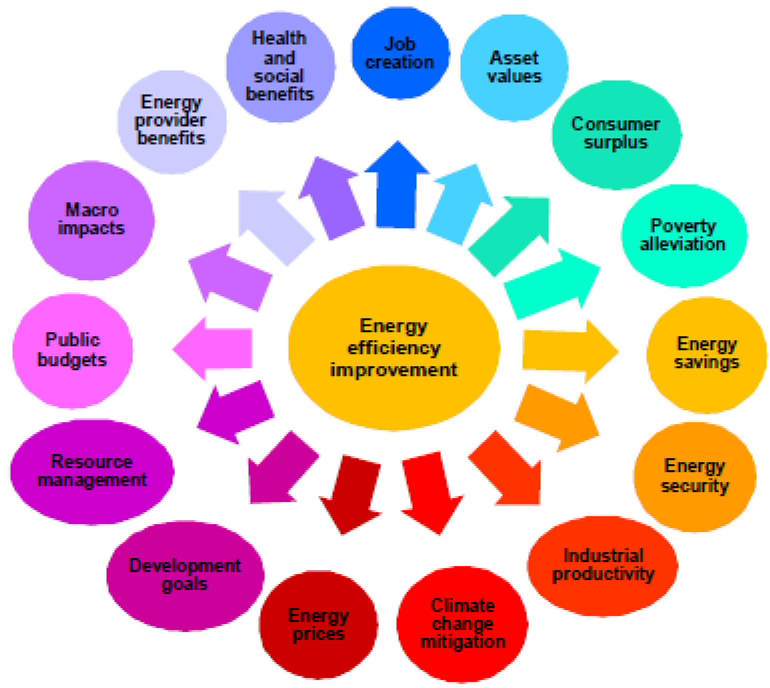

Figure 6: The multiple benefits of energy efficiency (Taylor, 2007)

2.5.1 Cost Savings

reducing fuel consumption results in significant cost savings. By improving fuel efficiency, gas processing facilities can reallocate the savings to other important areas such as expansion, employee benefits, or research and development. Over time, these cost reductions can greatly benefit the overall financial performance. For instance, the International Energy Agency (2012) estimates that adopting economically viable energy efficiency measures and addressing barriers to energy efficiency investments in natural gas processing facilities could prevent the consumption of fuel valued at up to USD 17.5 trillion. This would also avoid additional infrastructure costs amounting to USD 5.9 trillion by 2035.

2.5.2 Improved Environmental Sustainability

Reducing fuel consumption in industry basically contributes to environmental sustainability. By lowering greenhouse gas emissions and minimizing the carbon footprint associated with business operations, companies can demonstrate their commitment to environmental responsibility. This not only benefits the planet but also resonates with eco-conscious consumers who prefer environmentally friendly businesses (Lawrence et.al , 2018).

Energy efficiency is a special case in the energy sector as the multiple benefits associated with improving the amount of energy service available for a given energy input can help to meet a wide variety of public policy objectives. These include increased energy affordability, reduced environmental damage, improved health and well-being, enhanced energy security and resilience, improved national competitiveness and stronger trade balances. In addition, energy efficiency can support international public goods, such as climate change mitigation efforts, and generally reduce resource consumption (Ryan & Campbell ,2012).

2.5.3 Enhanced facility Reputation

Natural gas processing facility that prioritizes fuel efficiency and sustainability often enjoy an enhanced reputation in the market. Being recognized as an environmentally responsible company can attract environmentally conscious customers, increase brand loyalty, and differentiate a business from its competitors. A positive reputation as a fuel-efficient business can lead to increased customer trust and goodwill (Balat, 2005).

Energy professionals often measure the outcome of energy efficiency interventions in purely energy terms but, as with increases in energy supply to an economy, there are multiple benefits attributable to reduced energy demand through energy efficiency. These range from localized benefits, such as social development, to sectoral benefits, such as industrial productivity (International Energy Agency., 2013).

2.5.4 Natural resource management

Another familiar, but unmeasured, category of benefit from reduced energy demand is the alleviation of pressure on natural resources. Given that global production of conventional crude oil will be declining by 2035 (IEA, 2011c) and in light of other related supply constraints, energy efficiency will be increasingly important measure to relieve pressure on scarce resources. At the same time, oil demand is projected to increase along with economic growth, particularly as a result of needs in the transport sector. As options for fuel substitution are limited, energy efficiency will again provide an important response in this sector, reducing emissions of black carbon and other internationally monitored toxic gases, through measures such as fuel efficiency standards, eco-driving, public transport and logistics efficiency.

2.6 Impact of high consumption of energy

The utilization of fuel gas in a processing plant in an inefficient manner can result in various detrimental consequences, such as increased operational costs. When fuel gas is not used efficiently, it leads to wastage, requiring the plant to purchase more fuel to meet its energy needs. This not only increases expenses but also puts a strain on the plant's budget, potentially affecting its overall profitability (Filippini & Hunt, 2012).

The high consumption of fuel gas can also have negative environmental impacts. When fuel gas is not burned efficiently, typically results in higher emissions of pollutants such as carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxides (NO_x). These pollutants contribute to air pollution, which can have detrimental effects on both human health and the environment. Moreover inefficient fuel gas utilization can contribute to greenhouse gas emissions, exacerbating climate change and global warming (Lawrence et al., 2019).

2.7 Why Natural Gas

The widespread use of natural gas and the number of its applications demonstrate the importance of this fossil fuel, but do not answer the question "why shall we select natural gas for use rather than other sources of energy"? To answer that we should take into account a number of factors:

2.7.1 Economic factor

Natural gas is found in abundance in many regions of the world. Since the cost of producing energy from natural gas is less than or equal to the cost of other sources, it is obvious that its use will be a priority for the consumer. Thus, countries that are producers of it or servers or located near the producing countries or enjoy special preferential tariff, should have the use of natural gas as a key energy source as a part of their energy policy. The low cost of natural gas contributes to an extended range of economic growth from cheap domestic heating and industry development to job creation and saving payments in foreign currency. The implications of the use of natural gas in the economy of countries which do not have same stocks always depend on the relative savings compared of other sources, such as oil, renewable energy sources, nuclear power and coal (Mete, 2020).

An important financial factor is the development of technology which makes the use of natural gas more energy efficient (Gounaris, 2014). The energy efficiency of natural gas is designated as high and economic, compared with the corresponding of other sources. It should be clear that any comparison with the rest fossil fuels and energy sources is relative and depends significantly on the technology and methods of use of the fuel.

2.7.2 Environmental factor

Human activity and specific pollutants emitted into the atmosphere, mainly CO_2, burden the natural evolution of the phenomenon and lead to increased climatic and environmental impacts. Besides its abundant reserves and good heating value , natural gas is by far cleaner than all the other fossil fuels (oil, coal) with significantly lower emissions of CO_2 and other pollutants (Table 2) (Jain et al., 2022). However, natural gas does not cease to participate in the emission of gases that contribute to the greenhouse effect since the level of carbon dioxide emissions resulting from the combustion of natural gas also plays a significant role in its significance in mitigating global warming and its effects (Siemek & Nagy, 2012).

Table 2: Emissions from burning in lbs per billion BTU (Gounaris, 2014).

Pollutants	Natural gas	Oil	Carbon
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxides	40	33	208
Nitrogen Oxides	92	448	457
Sulfur dioxide	1	1,122	2,591
Particles	7	84	2,744
Mercury	0	0.007	0.016

2.8 Energy management in natural gas processing facility

The industry's significant energy consumption and immense capacity for energy conservation make it an appealing focus for enhancing energy security and addressing climate change through enhanced energy efficiency. Nevertheless, the allure is diminished by the policy obstacles that arise due to the industry's extensive diversity. The energy usage within this sector is influenced by a multitude of factors, including various technologies, processes, and products, as well as energy sources, pricing, political and economic circumstances, and managerial priorities and decision-making frameworks (Tanaka, 2011). Further, its energy efficiency can be improved by a wide variety of technical actions (Figure 7), including:

- maintaining, refurbishing and retuning equipment to counter natural efficiency degradation and to reflect shifts in process parameters.
- retrofitting, replacing and retiring obsolete equipment, process lines and facilities to new and state of art technologies.
- using heat management to decrease heat loss and waste energy by, for example: proper use of insulation and utilization of exhausted heat and materials from one to other processes.
- Improving process control, for better energy and materials efficiency and general process productivity.
- streamlining processes, eliminating processing steps and using new production concepts.
- Regular monitoring and auditing of fuel gas usage and emissions to improve and ensure compliance with environmental regulations.
- Implementing process optimization strategies, and adopting cleaner fuel sources or alternative energy sources where feasible.

As mentioned in the figure 7 industrial plant with energy loss, no reuse of feedstock or wastes and old production process should be stopped or avoided for efficiently use of energy.

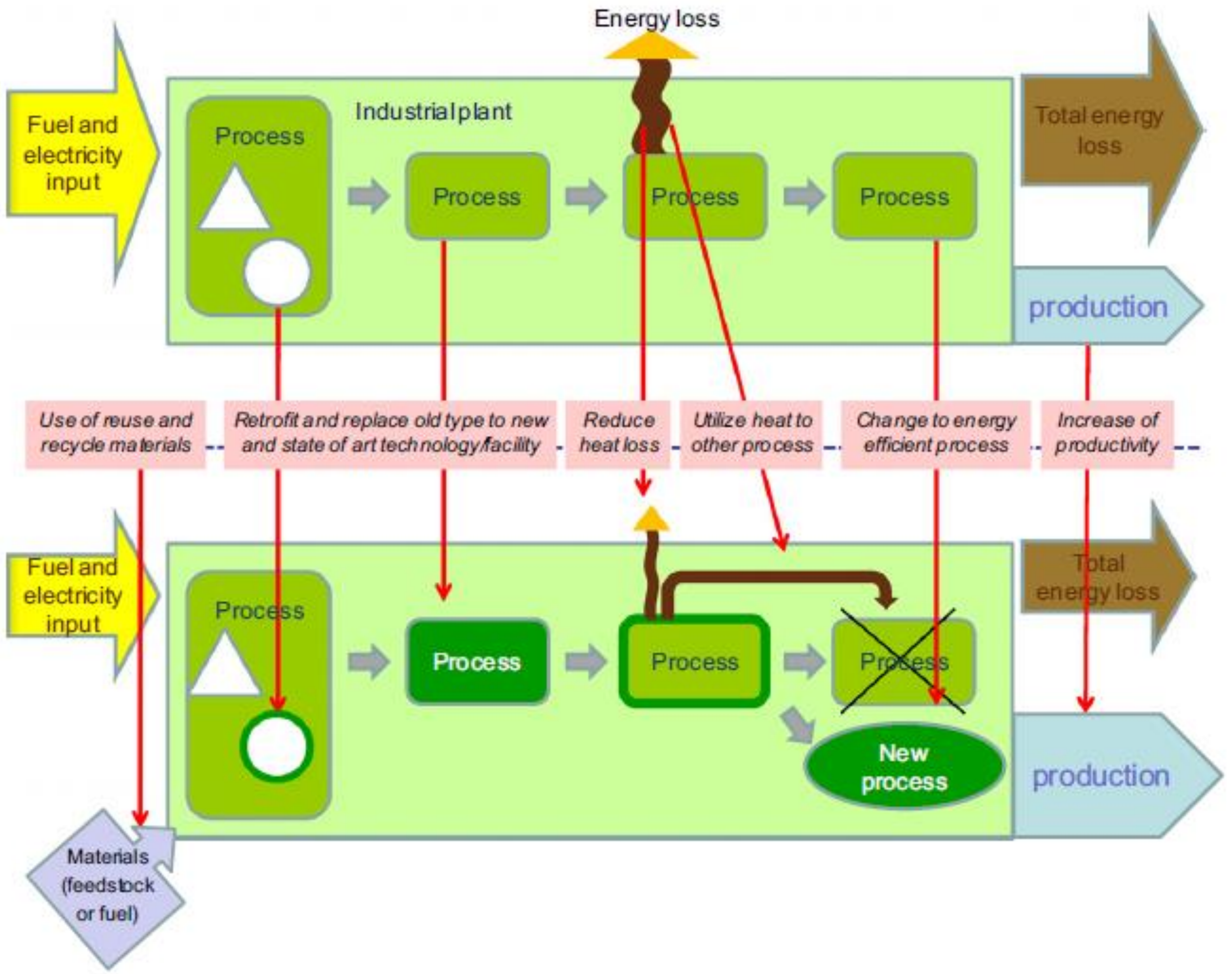

Figure 7: Sample of technical means of energy efficiency improvement (Tanaka, 2011)

To mitigate inefficient use of energy, the gas plants can also implement measures such as improving combustion efficiency through better equipment maintenance and tuning, investing in energy-efficient technologies.

2.9 State of art of energy efficiency for offshore gas platform

The energy use and emissions associated with gas production differ from one field to another, depending on the field conditions (e.g. crude oil temperature), export specifications (e.g. purity requirements and pressure), and field lifetime (e.g. 'plateau' or 'end-life' production) (Bothamley, 2007). Different strategies can be applied to improve the energy performance of oil and gas facilities, which can be classified into two categories.

The first possibility is to reduce the energy requirements of the processing plant, by increasing the efficiency of the most energy-intensive processes, promoting system integration or recovering energy from the feed (after the production manifolds) or product (in the gas treatment section) flows. Several measures for promoting energy savings were proposed in the works of (Nguyen el al., (2016), such as flaring reduction, energy and process integration, as well as re-wheeling of turbomachinery components. De Oliveira & Van Hombeeck,(1997) proposed to focus on the plant energy integration, focusing on the separation sub-system. Nguyen el al., (2014) suggested to analyze the possibility of reducing anti-surge recirculation, reducing losses in the manifolds and increasing the compressors efficiency, as significant power savings could be achieved. Subsequent work (Voldsund et al., 2014) pinpointed the same findings for two other platforms, although the system configurations were highly different. Nguyen el al., (2014) extended their studies to include the utility plants, showing that about 55 to 60% of the performance losses take place in the gas turbines, but that they are unavoidable. On the contrary, those taking place in the oil separation and gas compression operations could be reduced by exploiting high-energy streams, but they require changes in the system set-up, replacement of existing components or addition of other processes.

The second possibility is to improve the energy conversion processes, by converting the existing gas turbines and furnaces into cogeneration plants, importing electricity from the shore, or replacing the existing gas turbines by smaller and more efficient ones, if possible.

The present work aims to enhance the efficient fuel gas consumption through installation of a small compressor to boost the suction pressure of low-pressure compressor to regulate the discharge pressure of the gas taken to this unit so that it can consumes fuel gas below or around the baseline.

Chapter 3

RESEARCH METHODS AND STRATEGIES

This section provides a comprehensive overview of the methodology employed in conducting this dissertation, which was divided into two distinct parts. The initial part focuses on the collection and processing of fuel gas consumption data, while the subsequent part delves into the design and simulation of the natural gas compression process.

3.1 Data collection and processing

For the purpose of this study fuel gas consumption data from a natural gas processing facility has been gathered and analyzed to identify operation unit or equipment's fuel gas consumption behavior. In addition, lower pressure and high-pressure compressor's discharge and suction pressure were collected to analyze their effect on compressor fuel gas consumption. The collected data is within a period of three months.

The collected data was processed and analyzed using Microsoft Excel software. This processing involved generating graphs and pattern trends, which provided valuable insights into the data. By utilizing the capabilities of Excel, a more comprehensive understanding of the data was achieved, enabling the identification of the unity that exhibited significant fuel gas consumption.

In the analysis of pressure's data, compression ratio which is the ratio of the discharge pressure to suction pressure in equation 3 has been calculated for both LPC and HPC and utilized in the analysis of the data in order to identify equipment with high fuel gas consumption.

$$CR=\frac{\text{Discharge pressure}}{\text{Suction Pressure}} \tag{3}$$

3.2 Flowsheet design and simulation: Natural gas compression process

As aforementioned in section 2.9, 60% of the natural gas consumption by the gas processing plant is utilized during the compression of the natural gas. Therefore, two stages natural gas compression process as shown by the figure 8 was modelled where the first stage is the natural gas compression to boost the suction pressure of the existing LPC in gas processing plant as the gas is received to the latter unit at different pressures (14-22bar) which affect the operation of the

LPC. The second stage is the natural gas compression to meet the required suction pressure (~60bar) of the HPC in order to transport the processed gas from the plant facility to the customer. The third stage is the compression to push the natural gas to the customer with no pressure loss that is, a high pressure which is around 125bar. In addition, both LPC and HPC are existing in the gas processing facility. The flowsheet has been designed and simulated in ASPEN HYSYS Software V 11 and to perform case studies optimization where the latter software was used.

For process simulation some choices and assumptions were made and the descriptions are given below:

- Natural gas, water, air, and carbon dioxide were considered as process feed.
- The full compressor was separately modelled in three parts. A compressor to compress the gas, a turbine to generate the power to the compressor and a conversion reactor as the turbine fuel combustor. After designing all the mentioned equipment it has been joined together in order to operate as a single unit (compressor) and all operation conditions were specified.
- Conversion reaction was chosen as combustion technology to combust natural in turbine. The combustor was modelled as a conversion reactor which performs the conversion of natural gas into carbon dioxide and water as well as energy release. Operational conditions and reactive compounds were specified.
- The model set in the property package definition is Peng Robinson equation of state.

The natural gas compression flowsheet includes units below:

- Natural gas combustion reactor.
- Natural gas compressor.
- Expender or turbine to generator the power.

3.2.1 Fuel gas conversion reactor or combustor

The conversion reactors receive two different streams of natural gas as fuel from fuel gas system (HP fuel gas by assumption) for the first stage or LP compressor and second stage or HP compressor mixed with another two different streams of air (a mixture of nitrogen and oxygen) to burn the fuel. Before entering the reactor air that is taken from atmosphere has been assumed compressed to increase its pressure. The feed enters the reactor at 30℃ and 15bar. In conversion reactor reaction take place with no kinetics. The main specifications about the reactor are shown in the table 3 (LP turbine combustor) and table 4 (HP turbine combustor), further details can be found in appendix 1.

Table 3: LP turbine combustor specification

Parameter	**Value**	
	Fuel gas	**Air**
Phase	Vapor	Vapor
Temperature (℃)	30	30
Pressure (bar)	20	30
Molar flowrate (Kgmol/h)	430.7	4737.7

Table 4: HP turbine combustor specification

Parameter	**Value**	
	Fuel gas	**Air**
Phase	Vapor	Vapor
Temperature (℃)	30	30
Pressure (bar)	20	30
Molar flowrate (Kgmol/h)	120	1320

3.2.2 Gas turbine

A mixture of hot gases from combustion chamber is expanded in both LP and HP turbines. The feed enters the turbine at 2000℃ and 15bar. The turbine efficiency was set at 75%. The main specifications about both turbine is shown in the table 5.

Table 5: Turbines specification

Parameter	Value
Phase	vapor
Temperature (℃)	2000
Pressure (bar)	20-15
Efficiency (%)	75

3.2.3 Compressor

The processed natural gas has been compressed using LP compressor in the first stage. This increases the compressed gas temperature up to 225℃ since as the ideal gas law said the increase in pressure increases the temperature, however the gas has been cooler to 55℃ before entering in second stage where it was compressed using a HP compressor to meet the desired pressure for gas transportation to the customer. the specification of the compressors is shown in table 6 (LP Compressor) and table 7 (HP Compressor).

Table 6: Stage one compressor specification

Parameter	Value
Phase	vapor
Suction temperature (℃)	32
Discharge temperature (℃)	55
Suction pressure (bar)	22
Discharge pressure (bar)	61
Efficiency (%)	75

Table 7: Stage two compressor specification

Parameter	Value
Phase	vapor
Suction temperature (℃)	55
Discharge temperature (℃)	68
Suction pressure (bar)	61
Discharge pressure (bar)	125
Efficiency (%)	75

3.3 Study limitation

Natural gas is processed through different unit operation and consumed as a source of energy for various purpose such blanketing, power generation, sweeping and drive compressor in a gas processing facility. However, the design and simulation done in this thesis is limited to natural gas compression unit for its transportation to the customer only and the analysis for fuel gas consumption made is about fuel gas compression process. The complete flowsheet of natural gas compression via two stages is shown in the figure 8.

3.4 Natural gas compression simulation flowsheet description

The simulation of natural gas compression studies has been made within two stages as shown by the figure 8. Each and every stage comprised three equipment's namely compressor, combustion chamber and gas turbine. The first stage of compression was simulated using a low-pressure compressor (LPC) where a raw natural gas with ~ 22bar has been fed and compressed from inlet gas pressure up ~ 55 bar which is the suction pressure of high-pressure compressor (HPC). The driving force for the latter compressor has been provided by mixing air (Air LP stream) and fuel (LP fuel stream) combusted in a combustion chamber (CRV-100) the hot gas generated has been expanded via gas turbine (LPT) generating power to run the low-pressure compressor (see figure 8).

The second stage of gas compression was simulated using a high-pressure compressor (HPC) where compressed natural leaving the low-pressure compressor has been fed and compressed up ~125 bar which is export natural gas pressure using a high-pressure compressor (HPC). The driving force for high pressure compressor has been provided by mixing air (Air HP stream) and fuel (HP fuel stream) combusted in a combustion chamber (CRV-101) the hot gas generated has been expanded via gas turbine (HPT) generating the power to run the high-pressure compressor (see figure 8).

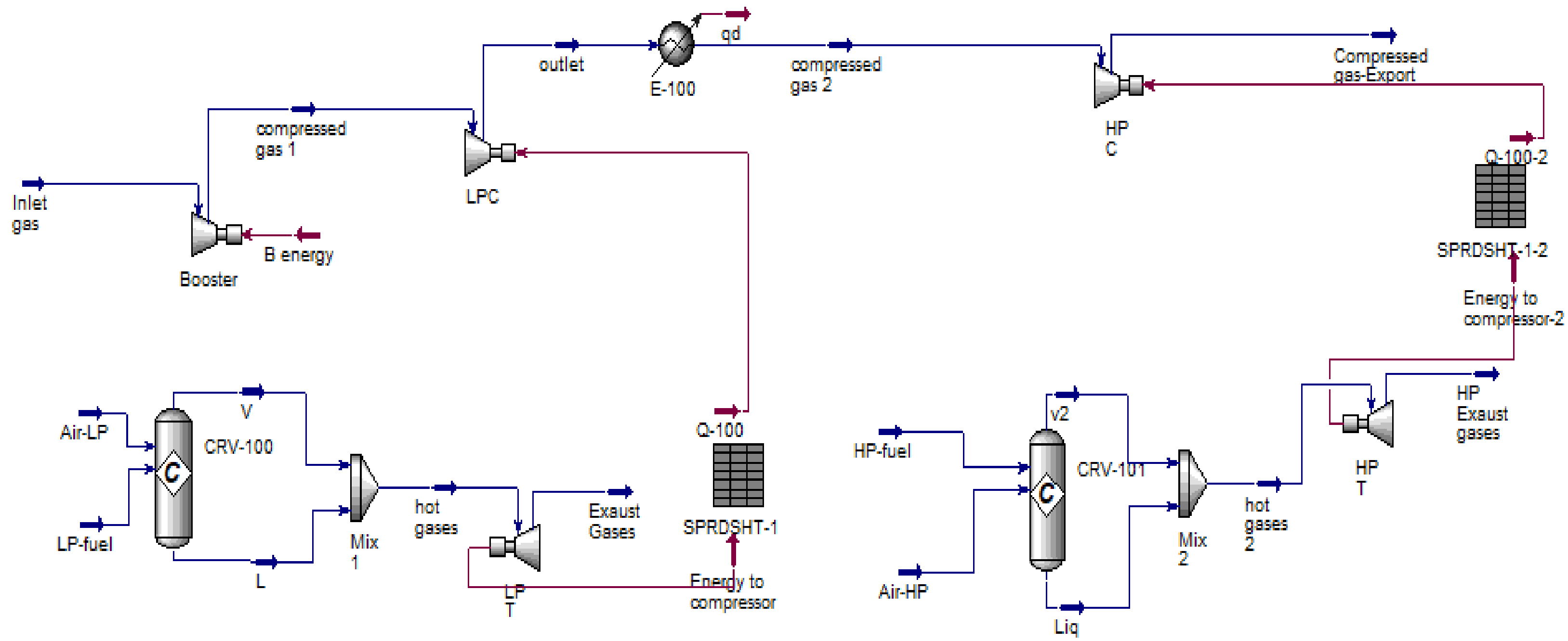

Figure 8: flowsheet of natural gas compression via two stages

Chapter 4

RESULTS AND DISCUSSION

This Dissertation has been done based on a case study on fuel gas consumption at a gas processing facility. The main target was to evaluate and analyze the data for fuel gas consumption at gas processing facility in order to identify the unit with high fuel gas consumption and figure out the main route cause of high fuel gas consumption observed. In addition, a natural gas compression process has been designed, simulated and analyzed to study the main root cause of high fuel gas consumption in gas processing plant. a parametric study on compressor inlet pressure or suction pressure and compression ratio as well as compressor efficient and work effect on fuel gas consumption have been made. The results are presented in section 4.1 and 4.2.

4.1 Data Analysis Results

4.1.1 Compressors pressure ratio

Pressure plays a major role in gas processing, as it moves the gas from the field through the gas plant and into the sales or export gas line. Gas gathering and field operations dictate upstream gas compression requirements. A small change between suction and discharge gas pressure affects the efficiency of the compressor since a decrease in the gas suction pressure increases the compression ratio, thus high fuel gas consumption by the equipment (Chala, Aziz, & Hagos, 2018).

4.1.1.1 L P compressor pressure ratio

The LP compressor serves as the equipment installed in a gas processing facility to elevate the pressure of natural gas to the necessary suction pressure of the HP compressor for exporting natural gas, following the identification of a pressure decrease at the gas reservoir. The initial pressure from the wells corresponds to the suction pressure of the HP compressor. Consequently, the pressure ratio for the LP compressor is determined by the ratio between the discharge pressure of the gas from the LP compressor and its suction pressure prior to entering the subsequent unit. The pressure ratio characteristics for the lower pressure compressor are detailed in figure 9.

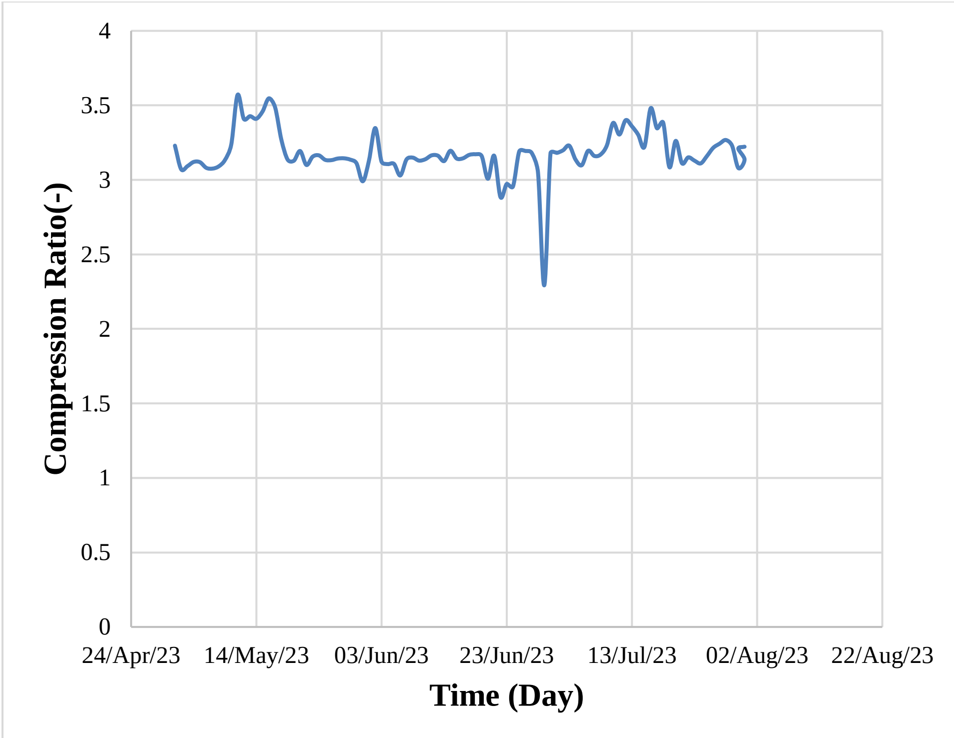

Figure 9: LP compressor pressure ratio

Figure 9 displays a graph depicting the daily compression ratio of the LP compressor in the gas plant. The data suggests that the unit operates at different compression ratios. Examination of the graph shows that the compression ratio fluctuates over a three-month period, exceeding the expected pressure ratio of around 3. This variability in compression ratio reduces the efficiency of the unit. Thus, suggests that a significant amount of excess fuel gas is wasted due to displacement of natural gas and fluctuations in gas pressure entering the low-pressure compressor.

4.1.1.2 H P compressor Pressure ratio

The HP compressor serves as the primary compressor utilized by the gas processing plant to transport the dry gas to the customer at a high pressure, considering the long distance it needs to travel. The pressure ratio for the HP compressor is determined by the ratio between the discharge pressure of the dry gas intended for export and the suction pressure of the dry gas supplied to the HP compressor. The graphical representation of the pressure ratio trend for the high-pressure compressor can be observed in Figure 10.

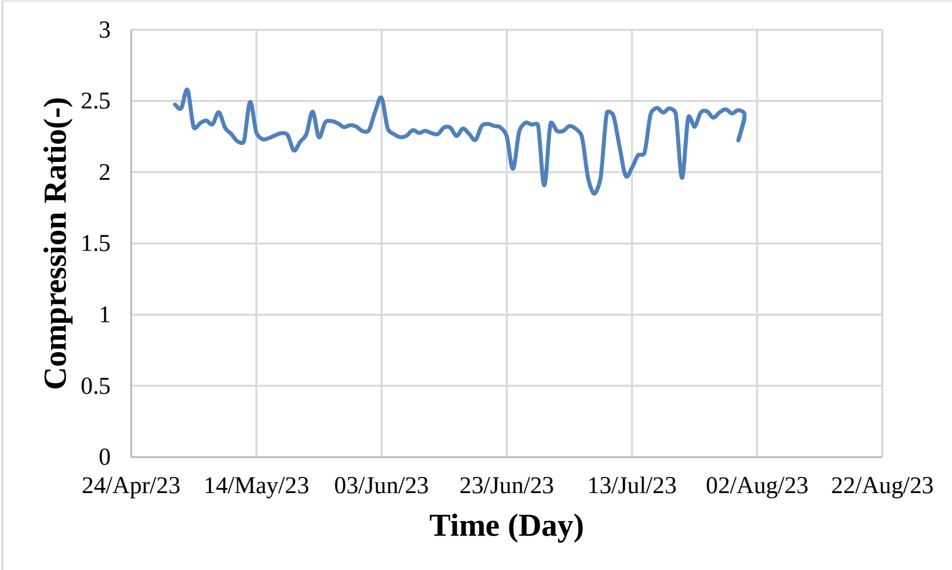

Figure 10: HP compressor compression ratio

The figure 10 shows the daily compression ratio for high pressure compressor in gas processing facility. The results show that the optimum compression ratio for HPC is ~ 2.5 since the operating suction pressure and discharge pressure for high pressure compressor is 50 and 125bar respectively. It was noted that from 05-May-2023 until 22-June-2023 the compression ratio for high pressure compressor has not been goes above the optimum expect that it was oscillating between 24-June-2023 and 21-July-2023. The consistence compression ratio for high compression ratio was due to that its suction pressure do not change too much as it is boosted by LP compressor.

4.1.2 Units' operation fuel gas consumption

The LP and HP compressors are a fuel gas turbine compressor. However, this equipment use fuel gas as a source of energy to run the compressor. Gas turbine generator also consumes fuel gas a feedstock to generate electricity at gas processing plant. For the purpose of this study this section shows the result got about the fuel gas consumption by the main fuel gas users at gas plant facility.

4.1.2.1 Lower pressure compressor

The data for fuel gas consumption at lower pressure compressor unit has been collected and processed and the daily fuel gas consumption by LPC is reported in the figure 11.

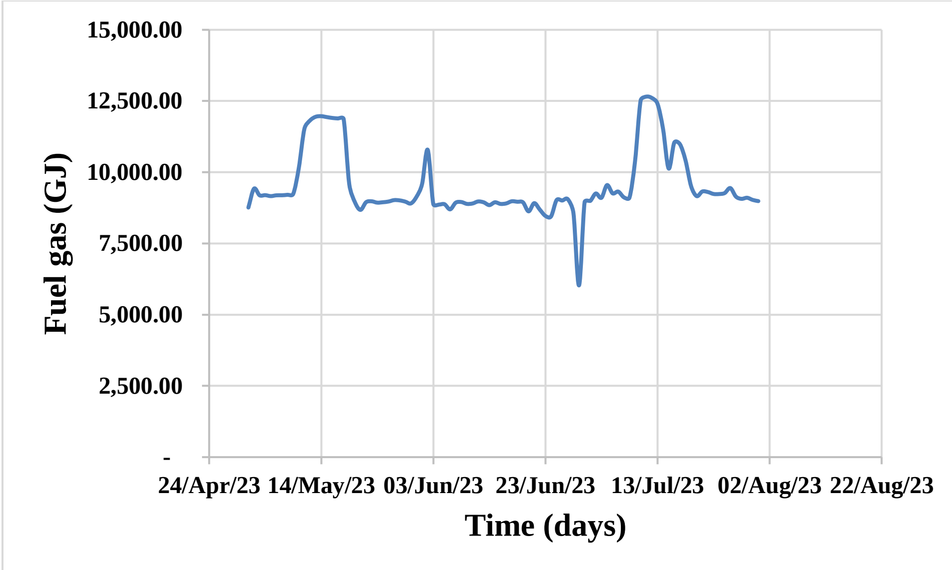

Figure 11: LPC fuel gas consumption

The data presented in Figure 11 provides a visual representation of the quantity of fuel gas utilized by the low-pressure compressor over a span of three months. The graph clearly illustrates a significant surge in fuel gas consumption during the months of May, June, and July. Upon conducting a more detailed analysis, it was observed that this spike in fuel gas usage corresponded with a simultaneous increase in compression ratio. However, it is worth noting that there were instances where the fuel consumption remained constant in a similar proportion despite the rise in compression ratio.

The examination of the data reveals that the low-pressure compressor utilizes an average quantity of fuel gas, approximately 9500Gj/day, under normal circumstances. However, there are instances when excess fuel gas is consumed, amounting to around 3500Gj/day. The fluctuations in fuel gas consumption primarily stem from variations in the efficiency or performance of the compressor.

4.1.2.2 High pressure compressor

The data pertaining to the consumption of fuel gas at the high-pressure compressor unit has been gathered and analyzed. An optimal fuel gas consumption rate of 8000GJ per day has been identified for the high-pressure compressor unit. The daily trends in fuel gas consumption by the high-pressure compressor are illustrated in Figure 12.

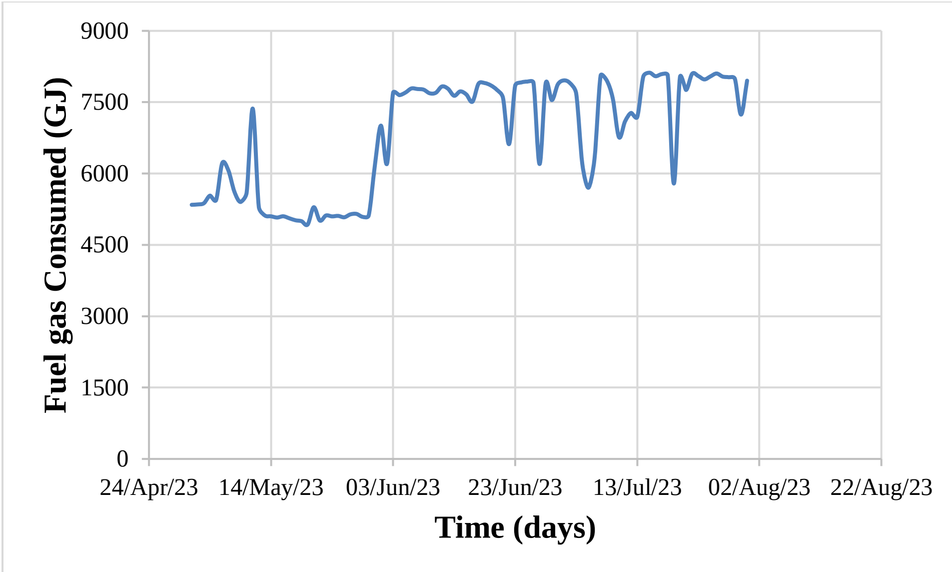

Figure 12: HPC fuel gas consumption

The data from Figure 12 clearly shows that the fuel gas consumption of the high-pressure compressor remains consistent with the baseline even after three months. The analysis reveals no notable spikes in fuel gas consumption, indicating that the unit operates efficiently. As a result, this efficient operation does not contribute to the high fuel gas consumption observed in the natural gas processing facility.

4.1.2.3 Gas turbine generator

The data for fuel gas consumption at gas turbine generator unit has been collected and processed. The baseline amounts of fuel gas consumption of 3500GJ/day for gas turbine generator unit have been found. The trend of the daily fuel gas consumption by gas turbine generator (Ggt) at gas processing facility is reported in the figure 13.

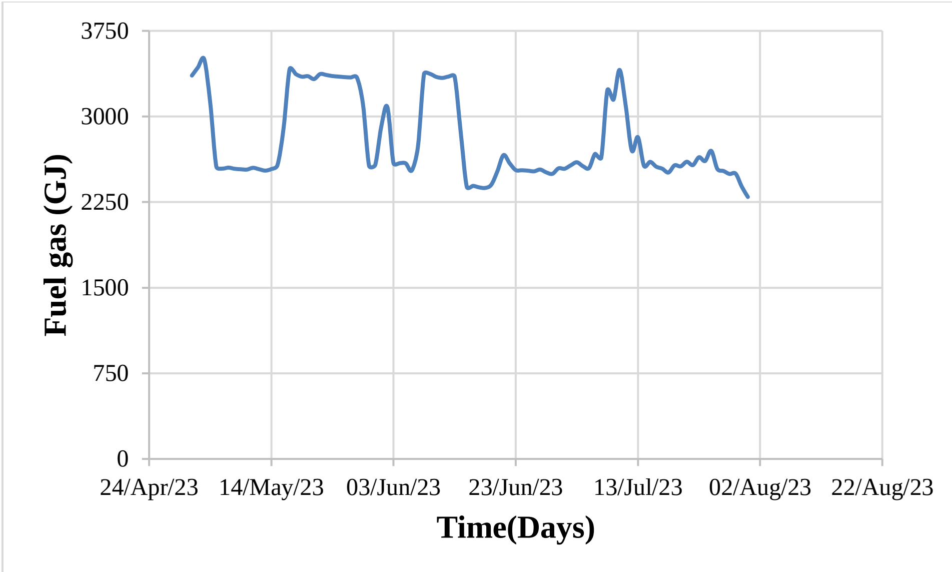

Figure 13: GTG fuel gas consumption Trend

The findings indicate that there is a peak in fuel gas consumption during the months of May and July, yet the quantity of fuel gas utilized by the gas turbine generator remains below the baseline level. This discrepancy can be primarily attributed to breakdowns and maintenance activities within the plant. Interestingly, the gas turbine generator does not significantly contribute to the high fuel gas consumption observed in the natural gas processing facility, as illustrated in figure 13.

4.1.3 Total fuel gas consumption

The objective of this study was to assess and identify the specific units responsible for the excessive consumption of fuel gas at the gas plant. To achieve this, data on fuel gas consumption was gathered for the three primary fuel user units at the plant. This data was then processed and analyzed to determine the total fuel gas consumption per day by all the fuel users. The findings were presented in figure 14, which illustrates the contribution trends of the fuel gas consumption from the LPC, HPC, and Gtg units to the overall fuel gas consumption at the gas plant.

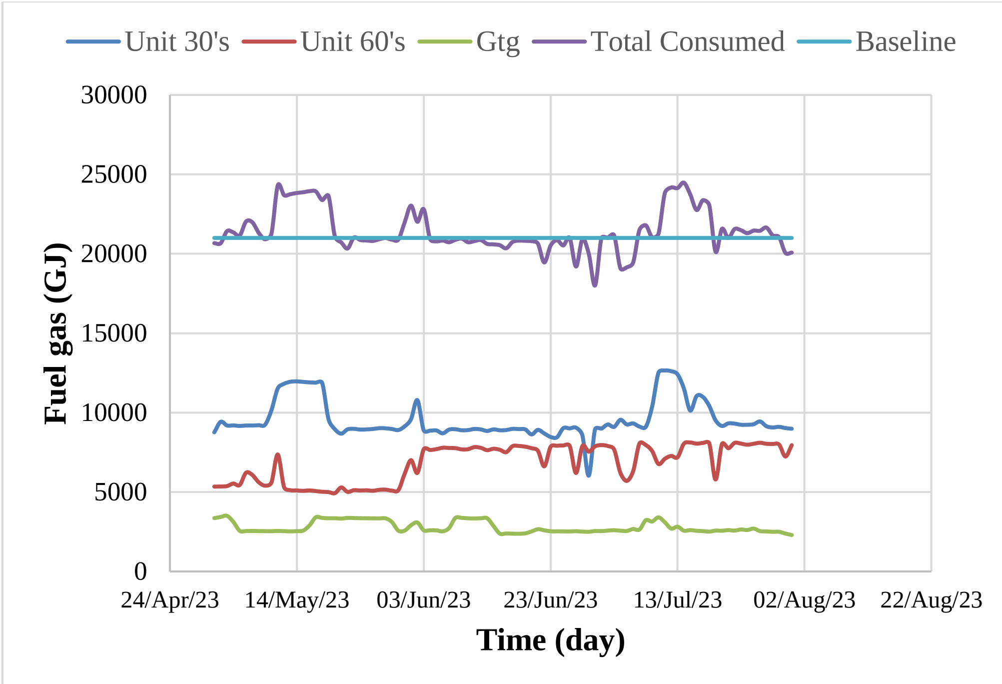

Figure 14: Total fuel gas consumption Trend

The fluctuations in total fuel gas consumption were observed to be non-constant, with peaks occurring in May, June, and July of 2023. These peaks indicated that the plant facility utilized approximately 24000GJ/day of fuel gas, exceeding the baseline amount expected to be consumed by the facility as shown in figure 14. The high fuel gas consumption can be primarily attributed to the LP compressor unit, which is operating at a high compression ratio and therefore performing a significant amount of work during natural gas compression.

4.2 Simulation of natural gas compression via two stages

In section 4.1, the findings regarding fuel gas consumption, as well as the data on compressor suction and discharge pressures, were thoroughly examined and deliberated upon. This particular section serves as a comprehensive report on the simulation conducted for the compression of natural gas.

4.2.1 Effect of suction pressure on compressor pressure ratio

The downstream pressure operation following the field operation plays a crucial role in facilitating the recovery of liquids from hydrocarbon-rich gas, and its significance varies depending on the local markets and logistical factors. In certain cases, transportation pipelines necessitate higher pressure levels to maintain smaller pipe diameters and ensure that the gas remains in a dense phase, thereby preventing condensation and the occurrence of two-phase flow within the pipeline. When the pressure at the field operation is relatively low, it may be necessary to employ upstream compression to compress the gas to medium to high pressure (ranging from 20 to 60 bar) in order to meet the required specifications for pipeline or plant processing. In the simulation, the inlet or suction pressure has been assumed to be approximately 22 bar, which aligns with the operating pressure of the gas processing facility or the natural gas pressure obtained from wells. The compressor compression ratio profile is depicted in Figure 15.

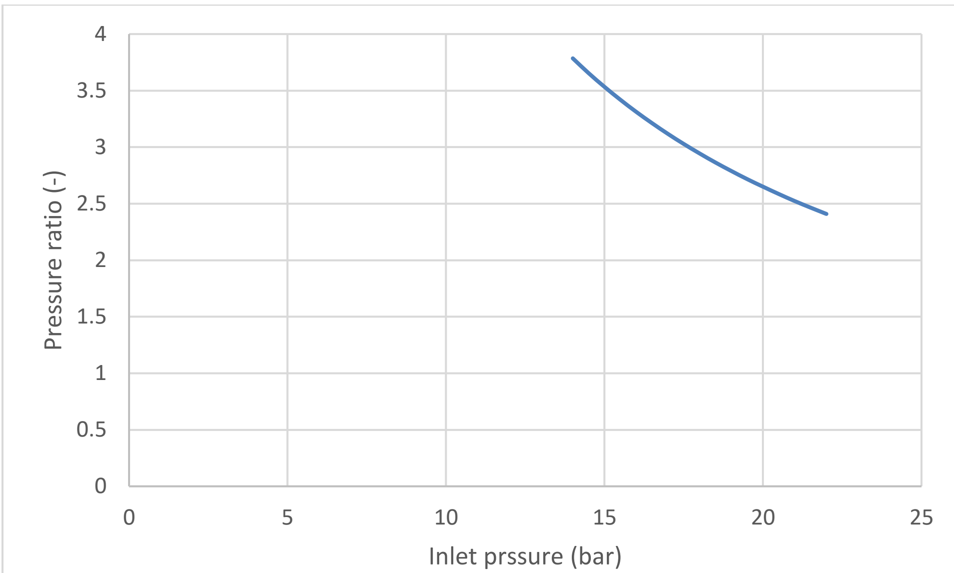

Figure 15: suction pressure vs compressor pressure ratio

Upon examining the plot depicted in figure 15, it becomes apparent that the compression ratio diminishes as the compressor suction pressure rises, conversely, it escalates as the compressor suction pressure declines. This phenomenon is primarily attributed to fluctuations in the suction pressure supplied to the equipment, resulting in a reduction in compressor efficiency based on the pressure at which gas is intended to be discharged. Consequently, a consistent compression ratio signifies the effective operation of the compressor, as it compresses the gas at a uniform suction pressure, thereby obviating the necessity for additional fuel gas.

4.2.2 Effect of compressor work on fuel gas consumption

The first law of thermodynamics states that in order to move a natural gas from a low pressure to a high pressure using a compressor, mechanical work is necessary. Consequently, this has an impact on the amount of fuel gas consumed during the operation of the compressor. The relationship between the work done by the compressor and the fuel gas consumption is illustrated in figure 16.

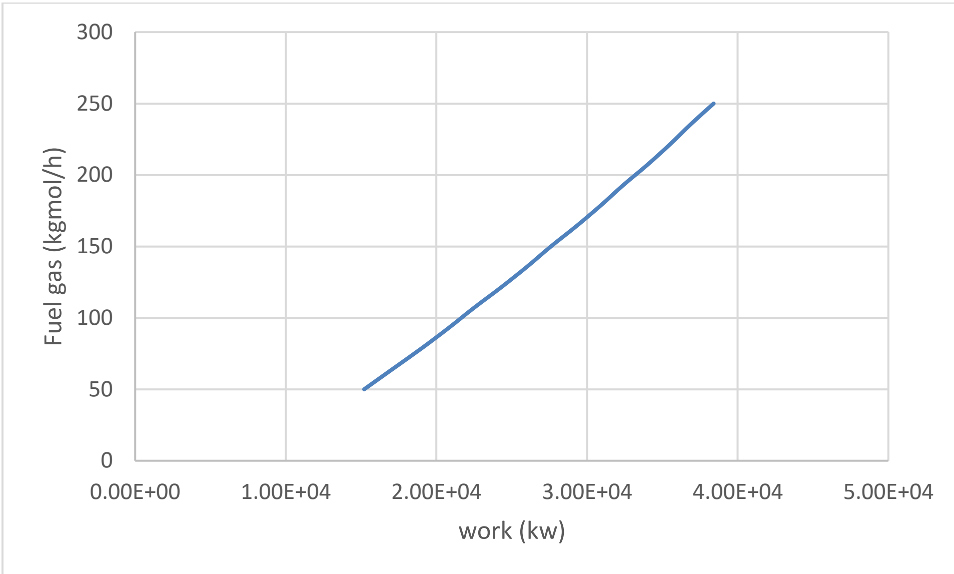

Figure 16: compressor work vs fuel gas consumption

This relationship showed that the increase in level of work performed by the compressor increases the consumption of fuel gas. This can be further explained by examining the factors that contribute to this phenomenon. Firstly, the reduced suction pressure on the compressor plays a significant role in increasing the compression ratio. The compression ratio is the ratio of the discharge pressure to the suction pressure, and it determines the amount of work required to compress the gas. When the suction pressure is lower, the compression ratio increases, meaning that the compressor needs to work harder to achieve the desired discharge pressure.

As the compression ratio increases, the compressor has to exert more effort to compress the gas effectively. This increased effort translates into a higher consumption of fuel gas. The compressor needs to draw in more gas and compress it to the desired pressure, which requires more energy and fuel. Additionally, the increased compression ratio can also lead to a decrease in the efficiency of the compressor. Higher compression ratios often result in higher discharge temperatures, which can negatively impact the efficiency of the compressor. In order to maintain the desired discharge temperature, additional cooling mechanisms may be required, further increasing the energy consumption and fuel gas consumption.

4.2.3 Effect of pressure ratio on fuel gas consumption

To analyze the impact of the pressure ratio on fuel gas consumption, a simulation was conducted. The results of this simulation, depicted in Figure 17, showed a clear relationship between the pressure ratio and the flowrate of fuel gas. As the pressure ratio increased, the flowrate of fuel gas also increased.

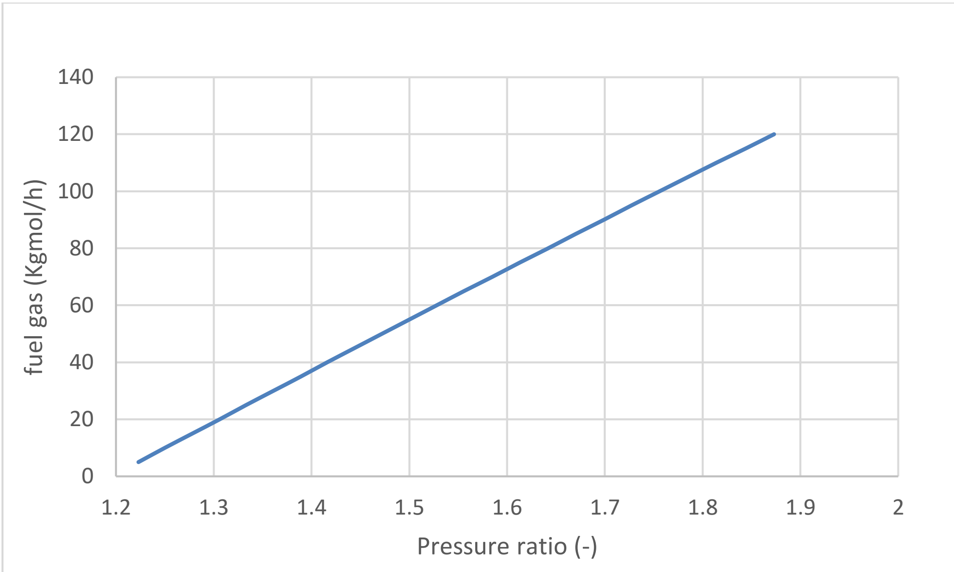

Figure 17: Pressure ratio vs fuel gas consumption

The pressure ratio is a key factor in compressor design as it determines the efficiency and performance of the equipment. A higher-pressure ratio indicates a greater difference between the discharge and suction pressures, resulting in a more fuel gas consumption. This is because a larger pressure difference allows for a greater compression of the gas, leading to higher discharge pressures. The pressure ratio also has a direct impact on the amount of fuel gas required to operate the compressor. As the pressure ratio increases, the compressor suction pressure decreases. This decrease in suction pressure leads to an increase in the flowrate of fuel gas needed to maintain the desired discharge pressure. Therefore, it is crucial to consider the pressure ratio when designing compressors to ensure that the fuel gas requirements are met for efficient operation.

4.2.4 Effect pressure ratio on the gas main inlet flowrate

The measurement of flowrate plays a critical role in quantifying the volume of natural gas moving from a well to a gas processing facility within a specific timeframe. This measurement is influenced by the pressure, as per the principles of the ideal gas law, which ultimately impacts the operation of the compressor in the facility, as evidenced by simulation studies.

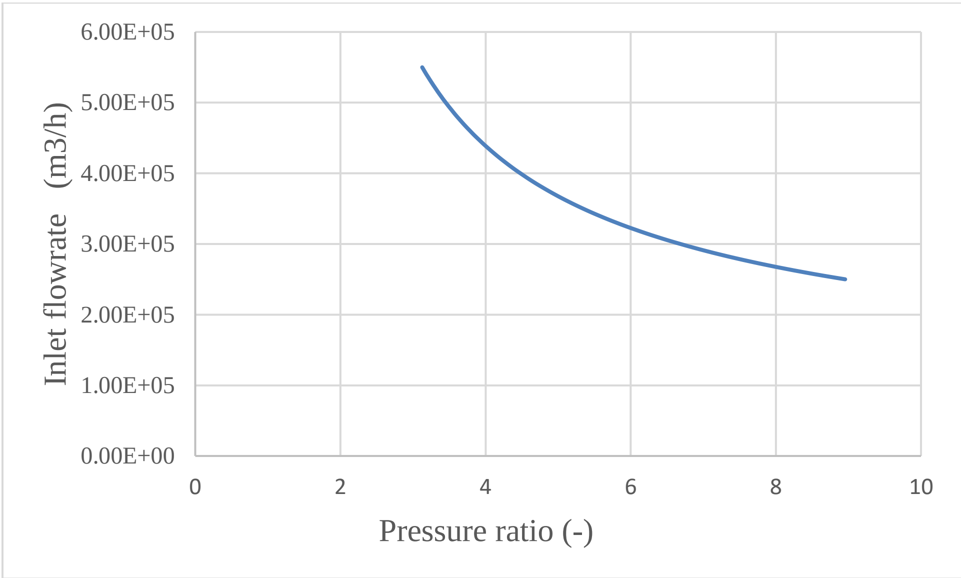

Figure 18: Gas volumetric flowrate vs compression ratio

In the context of compressor pressure ratio, the data presented in figure 18 offers valuable insights into how pressure relates to the volumetric flowrate of natural gas. Analysis of this information indicates that as the pressure ratio rises, the amount of natural gas entering the compressor for compression per hour decreases. This decline is linked to the drop in compressor suction pressure.

It is crucial to recognize that this decrease in flowrate can have negative consequences on the compressor's efficiency, potentially resulting in increased fuel gas consumption. Furthermore, the relationship between flowrate and pressure in natural gas systems is not linear. Thus, as pressure increases, the flowrate initially increases, but eventually reaches a point where it plateaus and no longer increases with further pressure increases.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objective of the present research was to enhance efficiency fuel gas consumption at gas processing plant through installing a booster compressor to regulate the suction pressure of the lower pressure compressor to around 22bar. To do so, fuel gas consumption and pressure's data, design and simulation of compression process were made. Data and simulated flowsheet were analyzed and compared. The overall conclusions of this study are summarized below:

It has been found that the LP compressor unit consumes high quantity fuel gas compared to the remaining fuel gas user at gas plant. In normal situation it consumes ~ 9500GJ/day and ~ 3000GJ/day of gas as excess when it is operating at a high compression ratio which above ~3 since the suction pressure of this unit always changes. However, the use of a small compressor as booster showed a significant impact of fixing the pressure thus reducing the amount of fuel gas consumption as it reduces the compression ratio at which the unit is operating with.

Installation of compressor booster reduced fuel gas flowrate from 430.7 Kgmol/h up to 400.5kgmol/h.

5.2 Recommendations

- The simulation has shown that the gas volumetric flow rate decreases with suction pressure decreasing however a study on gas pipeline dimension from wells to the inlet of gas plant should also be conducted as the pipeline size could increase the pressure or pressure of the gas.
- To develop a fuel gas consumption optimization model for the gas facility.

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CURRICULUM VITAE

I. IDENTIFICATION

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II. EDUCATIONAL BACKGROUND

Academic year	**School/Institute/University**	**Awards**
2010-2013	UR/College of science and Technology formerly Kigali institute of science and technology (KIST), Kigali/Rwanda	Bachelor degree in Applied chemistry/Environmental chemistry option
2005-2008	Collège de GISENYI-Inyemeramihigo, Rubavu/Rwanda	Advanced general certificate of secondary education (A_2) **Option**: Biochimie
2002-2005	Ecole des Lettres de Gatovu, Nyabihu/Rwanda	O-level
1996- 2002	Kanyove Primary School, Nyabihu/Rwanda	

III. EXPERIENCES

July-October/2023: Professional training at Sasol Petroleum Temane (SPT). The training was all about natural gas production process, transportation and data collection and interpretation plus SHE training towards environmental awareness and Hazard Identification, management and Assessment.

July/2016-June/2021: Assistant Lab and HSE Team member at SULFO RWANDA INDUSTRIES LTD.

Duties and Responsibilities:

-supervising and coordinating all activities meant for the factory good housekeeping.

-Quality control of both incoming raw materials and finished products using different analytical techniques.

-daily products analysis, results interpretation and recording in both plant's database and log book.

-Packed product control of finished product

-finished products and raw material's sample collection and storage

-plant's wastewater sample collection and analysis

-chemical solution preparation and standardization to use in raw material and product's quality control.

August/2012: I was conducted a research project related to the preparation of sisal fibers for an absorbent material (sanitary pads).

December/2012: I have done an internship at IRST (Institute of Research Science and Technology). the training was about Essential oil extraction from different plant's leaves and the production of briquettes from organic wastes.

SPOKEN LANGUAGES

LANGUAGE	WRITING	SPEAKING	LISENING
English	Professional working	Professional working	Professional working
French	Professional Working	Limited working	Professional working
Kinyarwanda	Native	Native	Native
Portuguese	Limited working	Limited working	Limited working

IV. CAPABILITIES

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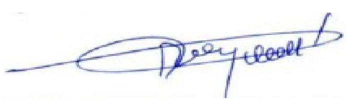
VI. DECLARATION

I, the undersigned, certify that to the best of my knowledge, these data describe me and my qualifications.



ITANGISHAKA ELISEE

Appendix A: Natural gas composition feed at gas processing plant

Component names	mole %	
	Reservoir A	Reservoir B
Methane	0,9179	0,9405
Ethane	0,0295	0,0169
Propane	0,0131	0,0058
i-Butane	0,0021	0,002
n-Butane	0,007	0,0018
i-Pentane	0,0013	0,001
n-Pentane	0,0019	0,0007
n-Hexane	0,0029	0,0011
n-Heptane	0.0013	0,0003
n-Octane	0,0015	0,0006
n-Nonane	0,0005	0,0002
n- Decane	0,0005	0,0002
n- C11	0,0001	0,0001
n-C12	0	0
Methyl cyclopentane	0	0,0002
Cyclohexane	0,0001	0,0004
Methyl cyclohexane	0,0007	0,0003
Carbon Monoxide	0	0,0029
Nitrogen	0,0147	0,0001
Water	0,012	0,0248
Toluene	0,0001	0,0001