**Chapter 1**

# 1. INTRODUCTION

## 1.1Background

Oil refining is one of the most complex chemical industries, which involves many different aspects and complicated processes with various possible connections. The objective in refinery operations is to generate as much profit as possible by converting crude oils into valuable products such as gasoline, jet fuel, diesel, and so on. (Zhang, 2000)

Khartoum refinery company was founded in 1997 and began operations in 2000 Six years later, on 2006 the Expansion Project was also put into operation. the output of the refinery jumped up to (90000 bbl/d) 5 million t/a. KRC built two separate production lines that enabled to refine the Nile blends (for old refinery) and Block 6 crudes (for new refinery) respectively. It runs major operational units and other related auxiliary facilities to produce dry gas, LPG, gasoline, diesel, jet fuel and petroleum coke (krcsd.com, 2020). The refinery is connected with flare gas system, everyday it burns 41950(nm3/h).

Gas flaring is a combustion device to burn associ`ated, unwanted or excess gases and liquids released during normal or unplanned over-pressuring operation in many refineries processes. Gas flaring is a significant source of greenhouse gases emissions. It also generates noise, heat and provided large areas uninhabitable. The World Bank reports that between 150 to 170 billion m3 of gases are flared or vented annually, an amount value about $ 30.6 billion, equivalent to one-quarter of the United States' gas consumption or 30 % of the European Union's gas consumption annually. (imam 2015)

Gas flaring is one of the most challenging energy and environmental problems facing the world today. In recent years environmental and economic considerations have led researches to study new technologies intended to recover the gases that are burned in the flare systems in refineries, oil and gas fields. Flare gas recovery system technology use to reclaim gases from vent header systems for other uses. With the help of technological advancement in this field, now we can dramatically reduce the volume of burned gases in refineries using a gas compression and recovery system. Flare gas recovery systems eliminate emissions by recovering flare gases (Mahdi Enayati 2015). In this project flare gas recovery system will be designed and simulated by using aspen Hysys for Khartoum Refinery Company.

## 1.2Problem statement

Increased demands for oil and gas production in the world resulted in associated gases flaring [M. Zolfaghari, 2017].Increased demands for oil and gas production in the world resulted in associated gases flaring. In addition, all facilities in refineries are equipped with flare network for safety purposes and pressure relief at abnormal conditions [M. Raimpour, 2012]. Flaring gas streams causes a great volume of carbon dioxide and other greenhouse gases (GHG) emission to atmosphere. As major consequences, global warming and environmental pollution are of great concern in the world. On the other hand, such streams also consist of valuable hydrocarbon components that burning them causes economical detriment(C. D. Elvidge, 2015).Flaring in refineries emit a number of substances that can affect human heath, livestock and environment and contribute to global warming. In Sudan the Khartoum Refinery Company (KRC) currently is using flaring gas system with a flow of 41950 nm3h. This research will study the effect of introducing flaring gas recovery system in KRC.

## 1.3Objectives

The primary goal of this research is to design flaring gas recovery system for Khartoum Refinery Company. The specific goals are to:

- To simulate gas flaring recovery system using aspen hysys v11program
- To do economic study for the process.

## 1.4 Scope of this study

The scope of this project is to give detailed study for design of flaring gas recovery unit. The project will cover the following:

1- ASPEN Hysys software.
2- Material balance.
3- Energy balance.

4- Process design.

5- Cost estimation.

**Chapter 2**

# 2. Literature review

## 2.1. Introduction

Petroleum refining plays an important role in our lives. Most transportation vehicles are powered by refined products such as gasoline, diesel, aviation turbine kerosene (ATK) and fuel oil. Petroleum refining is a manufacturing operation where crude petroleum, the raw material, is converted into usable finished products. In other words, it is the manufacturing phase of the oil industry. the main goal of refining is the conversion of as much of the barrel of crude oil into transportation fuels as is economically practical. (TA.AL-Sahhaf, 2010).

In the modern refinery, the refining processes are classified as either physical separation or chemical conversion ones.

Here in Sudan we have four refineries; Khartoum refinery, Obied refinery, Abu gabra refinery and Port Sudan refinery. (mop.gov.sd, 2020).

Khartoum refinery company (KRC) is the important refinery and the big one in Sudan consist of 6 refining units and 6 units related to other services the nominal capacity of the Khartoum refinery is 90000bbl/d (for the old refinery 50000 bbl/d and 40000bbl /d for the new one).

- Old refinery designed to process light crude (Nile blind crude oil) consist of Crude distillation unit, residue fluid catalytic cracking and diesel hydro treating.
- New refinery designed to process heavy oil (fula crude oil) consist of delayed coking unit, gasoline diesel hydro treating and continues catalytic reforming (see figure 1.1). (krcsd.com, 2020).

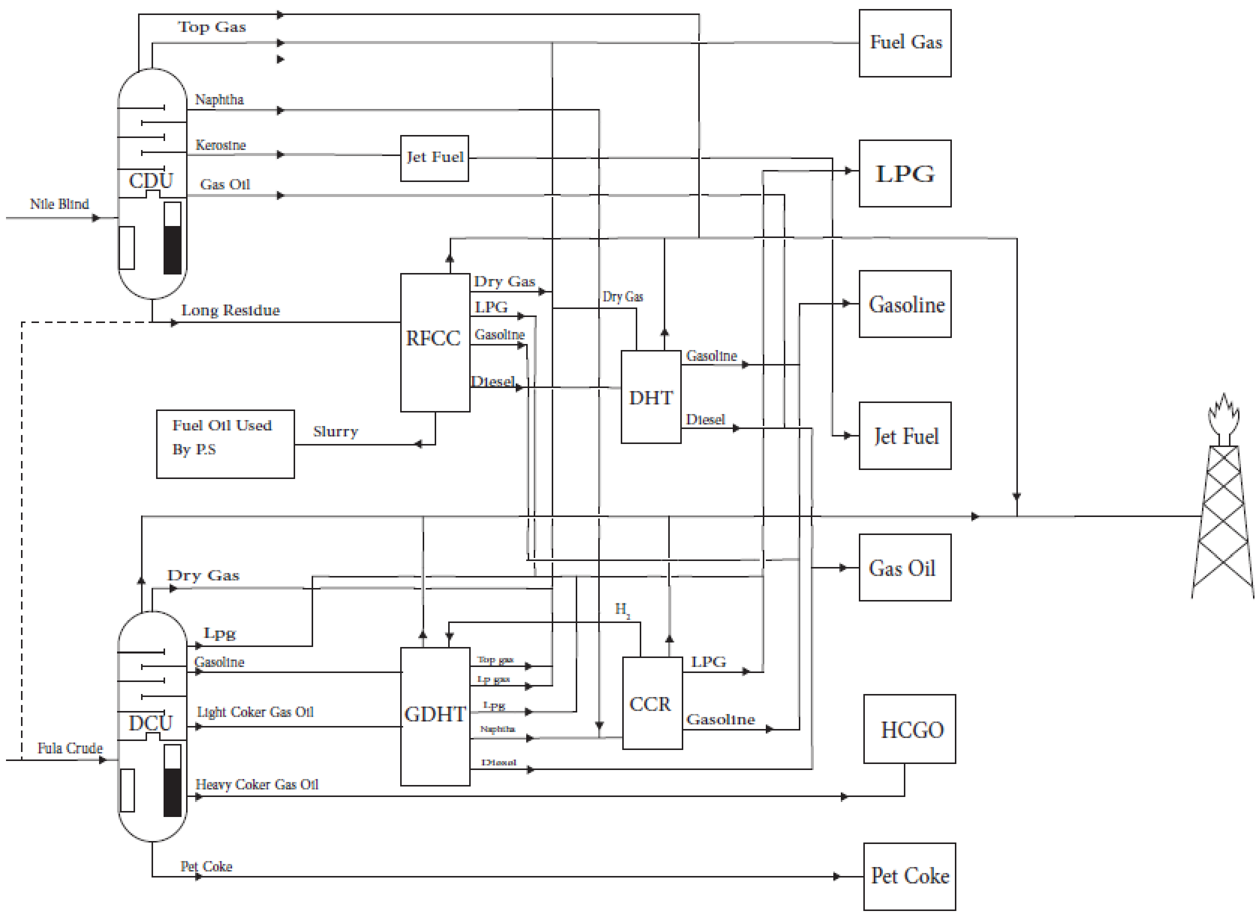



Figure 2.1 Khartoum Refinery Block Diagram

## 2.2. Crude distillation unit (CDU):

Atmospheric distilling unit of Sudan Khartoum Refinery Co., Ltd. is mainly used to process the mixed crude oil of Heglig, Unity, and Toma etc. of Sudan, with its crude oil processing capability of 2.5 million tons per year. It is fuel type unit, and its construction was undertaken by China Petroleum No.7 Construction Unit, started in August of 1999, finished in January of 2000, as well as succeeded together with its putting into production for one time in February of 2000.

The main products of the unit cover reformed feed, jet fuel components, No.10 diesel, and RFCC feed materials (>350℃ atmospheric column bottom distillates).

The unit produces raw products which have to be processed in downstream unit to produce products of certain specifications. (CDU Manual, 2010).

### 2.3. Residue Fluid Catalytic Cracking Unit (RFCC):

This unit has two stages complete catalyst regeneration technology to process annually 1.8 million tons (225 ton/hr) of atmospheric residue accounting for 65% to 68% of the total crude oil (Nile Blend) processed by the CDU while the main products of the unit are LPG, High octane gasoline, LCO, HCO along with the dry gas and slurry which are consumed as a fuel in the refinery and electricity as a by-product and mainly composed of the reaction-regeneration post, fractionation post, absorption-stabilization post, desulphurization post, heavy machines and waste-heat boiler section.(RFCC Manual,2010).

### 2.4. Diesel Hydro Treating Unit (DHT):

The unit consists of hydrogen recovery part (including hydrogen compressor and desorption gas compressor), hydro-treating part and utilities service part. Of which, the hydrogen recovery part consists of RFCC dry gas pretreatment part, variable pressure adsorption part, crude hydrogen DE oxidation part, hydrogen drying part and compression part; the hydro-treating part consists of reaction part (including make upside /circulating hydrogen compressor) and fractionation part.

The hydro-treating part of this unit uses the Sudan heavy oil catalytic cracking diesel oil as the feedstock and makes de sulfuration, DE nitrification and alkene saturation through catalytic hydro-treating reaction for refining catalytic diesel oil to improve the utilization performance of diesel oil product. The refined diesel oil can meet the specifications of diesel oil in the international standard (GB252-87) except cetane value and can be used as the blending component for diesel oil of the whole refinery. Additionally, the unit can produce a little quantity of gasoline, which can be used as the gasoline-blending component in the refinery or be delivered to the reforming catalyzing unit for retreatment. (DHT Manual, 2018).

### 2.5. Delayed Coking Unit (DCU):

Delayed coking is a thermal cracking process to upgrade and convert petroleum residuum and crude oil into liquid and gas product streams leaving behind a solid concentrated carbon material, petroleum coke. A fired heater with horizontal tubes is used in the process to reach thermal cracking temperatures of 485 to 505C. With short residence time in the furnace tubes, coking of the feed material is thereby “delayed” until it reaches large coking drums downstream of the heater.

The delayed Coker is the only main process in a modern petroleum refinery that is a batch-continuous process(semi batch).The flow through the tube furnace is continuous. The feed stream is switched between two drums. One drum is on-line filling with coke while the other drum is decoked and warmed up. The overhead vapors from the coke drums flow to a fractionator, usually called a combination tower. This fractionator tower has a reservoir in the bottom where the fresh feed is combined with condensed product vapors (recycle) to make up the feed to the Coker heater. (DCU Manual, 2010).

## 2.6. Gasoline Diesel Hydro Treating Unit(GDHT)

The objective of this section is elimination of poisonous or undesirable compounds (sulfur, nitrogen, metals, moisture content etc.) contained in the mixed feed stock which contaminate the downstream units’ catalyst and inhibit its selectivity and stability. Hydro treatment involving hydrodesulphurization and hydro denitrification reactions, which are carried out in a fixed catalytic bed axial reactor in presence of hydrogen. GDHT feed is a mixture of Coker naphtha (20%) and Coker diesel (80%). Recycled H2 is mixed with the feed prior to its entering the reactor. The major contaminants like S, N, and O are converted to H2S, NH3 or H2O respectively in the hydrotreater reactor. The liquid product from reactor is then stripped to remove H2S, water, NH3 and light hydrocarbons in a stripper column. The stripper bottom (Hydro- treated Naphtha) is then directly fed to the Reforming Section. Nominal capacity of the hydrotreater is 1200,000 metric tons per year based on a stream factor 8,000 h/year. (CCR Manual, 2006).

## 2.7. Continuous Catalytic Reforming (CCR):

Continuous Catalytic Reforming Unit (CCR) of Khartoum Refinery Company is built under the expansion project of the refinery, phase II. The unit is designed by Sinopec Engineering Incorporation. The process utilizes Axens's "State of the art" moving catalyst bed with continuous catalyst regeneration. The unit is designed to process 400,000 metrics tons per year and to operate at a severity of RON 98 with an on-stream factor of 8000 hours/year. (CCR Manual, 2006).

## 2.8. Flare Gas System

Flaring is defined as the controlled burning of off gases in the course of routine oil and gas or chemical manufacturing operations. This burning or combustion is accomplished at the end of a flare stack.(Nicholas, 2013).

Also we can define process of flaring as a combustion process used to dispose of natural gases (sweet gas, sour gas, acid gas or other hydrocarbon vapor) through a vertical stack. (Leslie B. Evans, 2000).

The primary function of the flare is to use combustion to convert flammable, toxic or corrosive vapor to less objectionable compounds. (API 521paragraph 6.4.1).

Flaring systems can be installed on many places such as onshore and offshore platforms production fields, on transport ships and in port facilities, at storage tank farms and along distribution pipelines.(Eman A. Emam, 2015).

Studies have reported that in 2016 more than 149 billion cubic meters of gas was burned in flares in the world. It represents a huge waste of energy and financial resources and an increase of about 2 billion cubic meters compared to 2015. (Ehsan Barekat-Rezaei, 2018)

### 2.8.1 Types of Flare

Flaring are generally categorized in two ways:

- By the height of the flare tip:

1. Ground
2. Elevated: Is the most commonly used type in refineries and chemical plants because it has many advantages than ground flare.

- By the method of enhancing mixing at the flare tip

3. Steam-assisted
4. Air-assisted
5. Pressure-assisted
6. Non-assisted flare (Leslie B. Evans, 2000)

### 2.8.2 Selection of flaring:

The selection of the types of flare is influenced by several factors such as:

1. availability of space
2. characteristics of the flare gas ( composition , quantity and pressure )
3. economics

4. investment and operating costs
5. public relations and protection
6. local and federal regulations (Nicholas,2013)

### 2.8.3 Flare components

#### 2.8.3.1 Gas Transport Piping

Process vent streams are sent from the facility release point to the flare location through the gas collection header. The piping (generally schedule 40 carbon steel) is designed to minimize pressure drop. Ducting is not used as it is more prone to air leaks. Valuing should be kept to an absolute minimum and should be "car-sealed" (sealed) open. Pipe layout is designed to avoid any potential dead legs and liquid traps. The piping is equipped for purging so that explosive mixtures do not occur in the flare system either on start-up or during operation (OMS manual, 2010).

#### 2.8.3.2 Knock-out Drum:

Liquids that may be in the vent stream gas or that may condense out in the collection header and transfer lines are removed by a knock-out drum. The knock-out or distrainment drum is typically either a horizontal or vertical vessel located at or close to the base of the flare, or a vertical vessel located inside the base of the flare stack. Liquid in the vent stream can extinguish the flame or cause irregular combustion and smoking. In addition, flaring liquids can generate a spray of burning chemicals that could reach ground level and create a safety hazard. For a flare system designed to handle emergency process upsets this drum must be sized for worst-case conditions (e.g., loss of cooling water or total unit de-pressuring) and is usually quite large. For a flare system devoted only to vent stream VOC control, the sizing of the drum is based primarily on vent gas flow rate with consideration given to liquid entrainment (OMS manual, 2010).

#### 2.8.3.3 Liquid Seal:

Process vent streams are usually passed through a liquid seal before going to the flare stack. The liquid seal can be downstream of the knockout drum or incorporated into the same vessel. This prevents possible flame flashbacks, caused when air is inadvertently introduced into the flare system and the flame front pulls down into the stack. The liquid seal also serves to maintain a positive pressure on the upstream system and acts as a mechanical damper on any explosive shock wave in the flare stack. (51 Other devices, such as flame arresters and check valves, May sometimes replace a liquid seal or be used in conjunction with it. Purge gas also helps to prevent flashback in the flare stack caused by low vent gas flow.

### 2.8.3.4 Flare Stack:

For safety reasons a stack is used to elevate the flare. The flare must he located so that it does not present a hazard to surrounding personnel and facilities. Elevated flares can be self-supported (freestanding), guyed, or structurally supported by a derrick.

Self-supporting flares are generally used for lower flare tower heights (30-100 feet) but can be designed for up to 250 feet. Guy towers are designed for over 300 feet, while derrick towers are designed for above 200 feet Free-standing flares provide ideal structural support. However, for very high units the costs increase rapidly. In addition, the foundation required and nature of the soil must be considered.

Derrick-supported flares can be built as high as required since the system load is spread over the derrick structure. This design provides for differential expansion between the stack, piping, and derrick. Derrick-supported flares are the most expensive design for a given flare height (OMS manual, 2010).

### 2.8.3.5 Burner Tip:

The burner tip, or flare tip, is designed to give environmentally acceptable combustion of the vent gas over the flare system’s capacity range. The burner tips are normally proprietary in design. Consideration is given to flame stability, ignition reliability, and noise suppression. The maximum and minimum capacity of a flare to burn a flared gas with a stable flame (not necessarily smokeless) is a function of tip design. Flame stability can be enhanced by flame holder retention devices incorporated in the flare tip inner circumference. Burner tips with modern flame holder designs can have a stable flame over a flare gas exit velocity range of 1 to 600 ft/sec. The actual maximum capacity of a flare tip is usually limited by the vent stream pressure available to overcome the system pressure drop. Elevated flares diameters are normally sized to provide vapor velocities at maximum throughput of about 50 percent of the sonic velocity of the gas subject to the constraints of CFR (OMS manual, 2010).

#### 2.8.3.6 Pilot Burners:

EPA regulations require the presence of a continuous flame. Reliable ignition is obtained by continuous pilot burners designed for stability and positioned around the outer perimeter of the flare tip. The pilot burners are ignited by an ignition source system, which can be designed for either manual or automatic actuation. Automatic systems are generally activated by a flame detection device using either a thermocouple, an infra-red sensor or, more rarely, (for ground flare applications) an ultra-violet sensor (OMS manual,2010).

## 2.9 Purpose of the Flare System

- A system of process safety Management (PSM) critical mechanical equipment that gathers and safely burns hydrocarbons from pressure relieving and vapor depressurizing system.
- Gases which are continuously produced as waste streams in the production process and which have to be disposed of.
- Gases which have occasionally (sometimes ) to be discharged from various pieces of equipment as result of repairs or maintenance being carried out or equipment pressure being released and of starting up and shutting down installations .
- Gases which are set operating plant emergency conditions, including a sit – wide general power failure.

## 2.10 Impact of Gas flaring (environmental issues, Health problems, and economical.)

### 2.10.1 Gas flaring composition

Generally the gas flaring will consist of a mixture of different gases. The composition will depend upon the source of the gas going to the flare system. Associated gases released during oil-gas production mainly contain natural gas. Natural gas is more than

90 % methane ($CH_4$) with ethane and a small amount of other hydrocarbons; inert gases such as $N_2$ and $CO_2$ may also be present. Gas flaring from refineries and other process operations will commonly contain a mixture of hydrocarbons and in some cases $H_2$. However, landfill gas, biogas or digester gas is a mixture of $CH_4$ and $CO_2$ along with small amounts of other inert gases. There is in fact no standard composition and it is therefore necessary to define some group of gas flaring according to the actual parameters of the gas. Changing gas composition will affect the heat transfer capabilities of the gas and affect the performance of the measurement by flow meter. An example of waste gas compositions at a typical plant is listed in Table

Table 2.1 Waste gas compositions at a typical plant

| Gas flaring constituent | Gas composition, % | Gas flaring, % | | |
|---|---|---|---|---|
| | | Min. | Max | Average |
| Methane | $CH_4$ | 7.17 | 82.0 | 43.6 |
| Ethane | $C_2H_6$ | 0.55 | 13.1 | 3.66 |
| Propane | $C_3H_8$ | 2.04 | 64.2 | 20.3 |
| n-Butane | $C_4H_{10}$ | 0.199 | 28.3 | 2.78 |
| Iso-butane | $C_4H_{10}$ | 1.33 | 57.6 | 14.3 |
| n-Pentane | $C_5H_{12}$ | 0.008 | 3.39 | 0.266 |
| Iso-pentane | $C_5H_{12}$ | 0.096 | 4.71 | 0.530 |
| neo-Pentane | $C_5H_{12}$ | 0.000 | 0.342 | 0.017 |
| n-Hexane | $C_6H_{14}$ | 0.026 | 3.53 | 0.635 |
| Ethylene | $C_2H_4$ | 0.081 | 3.20 | 1.05 |
| Propylene | $C_3H_6$ | 0.000 | 42.5 | 2.73 |

| | | | | |
|---|---|---|---|---|
| 1-Butene | $C_4H_8$ | 0.000 | 14.7 | 0.696 |
| Carbon monoxide | CO | 0.000 | 0.932 | 0.186 |
| Carbon dioxide | $CO_2$ | 0.023 | 2.85 | 0.713 |
| Hydrogen sulfide | $H_2S$ | 0.000 | 3.80 | 0.256 |
| Hydrogen | $H_2$ | 0.000 | 37.6 | 5.54 |
| Oxygen | $O_2$ | 0.019 | 5.43 | 0.357 |
| Nitrogen | $N_2$ | 0.073 | 32.2 | 1.30 |
| Water | $H_2O$ | 0.000 | 14.7 | 1.14 |

The value of the gas is based primarily on its heating value. Composition of flared gas is important for assessing its economic value and for matching it with suitable process or disposal. For example, for transport in the upstream pipeline network, the key consideration is the $H_2S$ content of the gas. Gas is considered sour if it contains 10 mol/kmol $H_2S$ or more. (Eman A. Emam, 2015).

### 2.10.2 Environmental impacts:

Gas flaring is one of the most challenging energy and environmental problems facing the world today. Environmental consequences associated with gas flaring have a considerable impact on local populations, often resulting in severe health issues. Generally, gas flaring is

Normally visible and emitted both noise and heat. Ghadyanlou and Vatani calculated the thermal radiation and noise level as a function of distance from the flare using commercial software for flare systems [EPE]. (Eman A. Emam, 2015).

Table 2.2 Thermal and noise emissions from flaring

| Distance, m | Thermal radiation, kW/m2 | Noise level, dB |
|---|---|---|
| 10 | 5.66 | 86.3 |
| 20 | 5.87 | 86.19 |
| 30 | 6.04 | 86.02 |

| | | |
|---|---|---|
| 40 | 6.14 | 85.78 |
| 50 | 6.17 | 85.50 |
| 60 | 6.14 | 85.18 |
| 70 | 6.04 | 84.83 |
| 80 | 5.88 | 84.46 |
| 90 | 5.67 | 84.08 |
| 100 | 5.42 | 83.68 |

**2.10.3 Health problems:**

The technology to address the problem of gas flaring exists today and the policy regulations required are largely understood. Global emissions from gas flaring stand for more than 50 % of the annual Certified Emissions Reductions (624 Mt CO2) currently issued under the Kyoto Clean Development Mechanisms. However, flaring is considered as much safer than just venting gases to the atmosphere [EPE]. Pollutants of flare and their health effect are summarized in Table 2.3

Table 2.3 Pollutants of flare and their health effect

| Chemical name | Health effect |
|---|---|
| Ozone in land | In low densities eye will stimulate and in high densities especially children and adults it will cause respiratory problems. |
| Sulphide hydrogen | In low densities it will effect on eye and nose which result in insomnia<br>and headache. |
| Dioxide nitrogen | It will effect on depth of lung and respiratory pipes and aggravates symptoms of asthma. In high densities it will result in meta-haemo globin's which prevents from absorption of oxygen by blood. |
| Particles matter | There is this believe that it will result in cancer and heart attack. |
| Dioxide of Sulphur | It will stimulate respiratory system and as a result aggravating asthma and bronchitis. |
| Alkanes: Methane, Ethane, Propane | In low densities it will result in swelling, itching and inflammation and in high densities it will result in eczema and acute lung swelling. |
| Alkenes: Ethylene, | It will result in weakness, nausea and vomit. |

| | |
|---|---|
| Propylene | |
| Aromatics: Benzene, Toluene, Xylene | It is poisonous and carcinogenic. It influences on nerve system and in low densities it will result in blood abnormalities and also it will stimulate skin and result in depression. |

$CO_2$ and $CH_4$ are GHG that, when released directly into the air, traps heat in the atmosphere. The climate impact is obvious, suggesting a great contribution to global GHG emissions. For example, about 45.8 billion kW of heat into atmosphere of Niger Delta from flared gas daily released. As a result of the environment, gas flaring has raised temperatures and rendered large areas uninhabitable. $CO_2$ emissions from flaring have high global warming potential

And contribute to climate change. $CO_2$ emissions come from only the combustion of fossil fuels for about 75 %. $CH_4$ is actually more harmful than $CO_2$. It has about 25 times greater global warming potential than $CO_2$ on a mass basis. It is also more prevalent in flares that burn at lower efficiency. Therefore, there are concerns about $CH_4$ and other volatile organic compounds from different operations.

Other pollutants such as sulfur oxides ($SO_x$), nitrogen oxides ($NO_x$) and volatile organic components (VOC) also released from flaring. Ezersky and Lips studied an emissions in US from a number of oil refinery flare systems in the Bay Area Management District (California). They concluded that, the emissions ranged from 2.5 to 55 tons/day of total organic

Compounds, and from 6 to 55 tons/day $SO_x$. Therefore, flare emissions may be a significant percentage of overall $SO_2$ and VOC emissions. In addition, gaseous pollutants like $SO_2$ that are once emitted into the atmosphere have no boundaries and become uncontrollable and cause acid deposition. Several toxicological/epidemiological investigations during the last few decades have shown that the effect of this gas is severe. $SO_x$ and $NO_x$ are the major causes of acid rain and fog which harm the natural environment and human life. Also ozone has been revealed to cause damage. Ozone is also produced by the photochemical reaction of VOC and $NO_x$ as the main components of the oxidant. The oxidant accelerates the oxidation of $SO_2$ and $NO_x$ into toxic sulfuric and nitric acids, respectively. The removal of VOC and NO is very important to reduce the concentration of ozone. On the other hand, a smoking flare may be a significant contributor to overall particulate emissions. Because the most flared gas normally has not been treated or cleaned, pose

Demanding service applications where there is a potential for condensation, fouling (e.g., due to the build-up of paraffin wax and asphaltine deposits), corrosion (e.g., due to the presence of H2S, moisture, or some air) and possibly abrasion (e.g., due to the presence of debris, dust and corrosion products in the piping and high flow velocities). The quantity of the generated emissions from flaring is dependent on the combustion efficiency. The combustion efficiency generally expressed as a percentage is essentially the amount of hydrocarbon converted to CO2. In other words, the combustion efficiency of a flare is a measure of how effective that flare is in converting all of the carbon in the fuel to CO2. There are some factors effects in the efficiency of combustion process in flares such as heating value, velocity of gases entering to flare, meteorological conditions and its effects on the flame size.

Properly operated flares achieve at least 98 % combustion efficiency in the flare plume, meaning that hydrocarbon and CO emissions amount to less than 2 % of species in the gas

Stream demonstrated that properly designed and operated industrial flares are highly efficient. Many studies concluded that flares have highly variable efficiencies between (62

99) % In order to increase the combustion efficiency, the steam or air is used as assistant in flares, which create a turbulent mixing, and better contact between carbon and oxygen Excess air has implications on emissions, specifically related to the creation of NOx. The availability of extra nitrogen found in the air and additional heat required to maintain combustion temperatures are favorable conditions for the formation of thermal NO. More-over,

Greater amounts of excess air create lower amounts of CO but also cause more heat loss. As a results from the above, gas flaring has a significant impact on environment due to possible presence of many harmful compounds. The scale of impact depends on the flared gas composition. The impacts of flare emissions can be concluded as the following:

•The low quality gas that is flared releases many impurities and toxic particles into the atmosphere,

•Harmful effects on human health associated with exposure to these pollutants and the ecosystems.

•Products of combustion can be hazardous when present in high amounts,

•The waste gas contains $CO_2$ and $H_2S$, which are both weakly acidic gases and become corrosive

In the presence of water.

•Acidic rain, caused by SOx in the atmosphere, is one of the main environmental hazards.

•Acid rains wreak havoc on the environment destroying crops roofs and impacting human Health.

•CO causes reduction in oxygen-carrying capacity of the blood, which may lead to death,

•Uncontrolled NOx emission could be injurious to health,

•when NOx reacts with $O_2$ in the air, the result is ground-level ozone which has very negative effects on the respiratory system and can cause inflammation of the airways, lung cancer etc. [EPE]. (Eman A. Emam, 2015).

### 2.10.4 Economic Effects:

Aside from effects on the environment/host communities, animals, plant life, and human health, gas flaring also impact grossly on the economics of a nation, in terms of the loss of funds and revenue which it could have realized if it had conserved gas instead of flaring same. Nigeria provides an appalling example of such a loss. Oil companies in Nigeria flare an estimate 2.5 billion cubic feet of gas every day and this action, amounts to the loss of revenue, estimated at 2.5 billion US dollars yearly (O. Saheed Ismail, 2012). It is considerable to know that in 2012, more than 143 billion cubic meters of natural gas was flared which accounts for around 3.5% of the world's natural gas consumption. Reports showing emission of 400 million tons of $CO_2$ due to natural gas flaring. Iran as the world's second natural gas reserve holder produces about 200 billion cubic meters per year and burns about 10.4 billion cubic meters of produced gas as flare. This amount is about 5.2% of produced gas, which is significantly higher than world average flaring (Abdollah Hajizadeh, 2017) From an economic perspective, the flaring of this associated gas is a colossal waste to the communities [EPE].

The economic cost of total gas flared is quite staggering which implies great investment opportunities for the private sector. Hence, more gas intensive modes of production, greater private sector investment are encouraged in the sector and governments should recycle and seek for more trading opportunities for the gas sector. Apart from the release of greenhouse gases into the atmosphere, gas flares are said to release some 45.8 billion kilowatts of heat into the atmosphere of the Niger Delta from gas flared daily. As a result of this incineration of the environment, gas flaring has raised temperatures and rendered large areas uninhabitable [EPE] (O. Saheed Ismail, 2012).

**2.11 Advantages of using flare system**:

- can be an economical way to dispose of sudden of gas
- in many cases do not require auxiliary fuel to support combustion
- can be used to control intermittent or fluctuating waste stream. (epa.gov, 2020).

**2.12 Disadvantages of flare system**:

- Can produce undesirable noise, smoke heat radiation and light
- Can be a source of sox nox and co
- Cannot be used treat waste streams with halogenated compounds (epa.gov, 2020)
- Released heat form combustion is lost
- Limited ability to perform maintenance while in service
- Thermal radiation
- Blockage by:
- Soot
- Freezing condensate in cold climates
- Mechanical failure
- Loss of flame/pilot
- Liquid carry-over

- Flashback air intrusion
- Loss or insufficient purge
- Steam control under/over
- Freezing condensate in cold climates
- Inconsistent composition, pressure, and temperature
- Brittle fracture of material for cold relief (emis.vito.be 2020)

Due to many defects associated with flare system which mentioned and explained previously (environmental impact, health issues and economic loss), it was necessary to find a solution to reduce the environmental and health impact and to limit the economic loss. The proposed solution is Flare Gas Recover System (FGRS)

## 2.13 Flare Gas Recovery System

### 2.13.1 Definition

FGRS is a technology used to recover the gases that are burned in the flare system in order to benefit from it as a fuel inside the plant instead of burning it (in oil field to improve the production (gas injection) or in refinery as a fuel for turbine to generate electricity) or it is compressed, shipped and sold if its quantity is large, also to reduce the harmful emissions such as C1, $CO_2$ and $H_2S$.

The implementation of no-flare design will have a great impact in reducing the emissions from production. With increasing awareness of the environmental impact and the ratification of the Kyoto protocol by most of the member countries, it is expected that gas flaring will not be allowed in the near future. This will require significant changes in the current practices of oil and gas production and processing. (M. Enayati Sangsaraki, 2017).

Environmental and economic considerations have increased the use of gas recovery systems to reclaim gases from vent header systems for other uses. With the help of technological advancement in this field, now we can dramatically reduce the volume of burned gases in refineries using a gas compression and recovery system. Flare gas recovery systems eliminate emissions by recovering flare gases. Vent gas recovery systems are commonly used in refineries to recover flammable gas for reuse as fuel for furnace (C1, C2). Even in most advanced countries just few years has passed from flare gas recovery technology, thus the method is a new methods for application in refineries wastes. Of such countries active in flare gas recovery are USA, Italy, the Netherlands, and Switzerland. Most FGR system has been installed based primarily on economics, where the payback on the equipment was short enough to justify the capital cost. However, there is increasing interest in reducing flaring not based on economics, but on environmental stewardship (M. Enayati Sangsaraki, 2017).

The FGR system is designed to capture waste gases that would normally go to the flare system. The FGR system is locatedupstream of the flare to capture some or all of the waste gases before they are flared. There are many potential benefits of an FGR system. The flare gas may have a substantial heating value and could be used as a fuel within the plant to reduce the amount of purchased fuel. In certain applications, it may be possible to use the recovered flare gas as feedstock or product instead of purchased fuel. The FGR system reduces the continuous flare operation, which subsequently reduces the associated smoke, thermal radiation, noise and pollutant emissions associated with flaring. (M. Enayati Sangsaraki, 2017)

## 2.13.2Examples for Flare Gas Recovery System:

Flare Gas Recovery System for the Tabriz Petroleum Refinery and Shahid Hashemi-Nejad both in Iran:

The Tabriz petroleum refinery and Shahid Hashemi-Nejad (Khangiran) gas refinery are the important examples to take the idea of great benefit of FGRS. The results of these case studies are discussed.

### 2.13.2.1 Flare Gas Recovery for the Tabriz Petroleum Refinery

The Tabriz petroleum refinery consists of 14 refining units and 10 units related to other services. The nominal capacity of the Tabriz refinery is 80000 barrels per day, but by executing the authorities' augmenting schemes, nominal capacity has been increased to 115000 barrels per day. The crude oil, up to 115000 barrels in a day, is brought from crude oil preserving tanks to a distillation unit in order to be separated into oil cuts. The necessary crude oil is supplied from the Ahwaz oil fields via a 16-inch pipeline. The Tabriz petroleum refinery normally burns off 630 kg/h gas in flare stacks the average quantity and quality of flare gas are shown in Table below (O. Zadakbar, 2015).

Table 2.4 the average quantity and quality of Tabriz flare

| Component | $H_2$ | $C_1$ | $C_2$ | $C_3$ | $C_4^+$ | $H_2S$ |
|---|---|---|---|---|---|---|
| Mol% | 43 | 10 | 30 | 2 | 10 | 5 |

| Temperature | 80°C |
|---|---|
| Pressure | 1 bar |
| Flow | 630 kg/h |
| MW | 19.9 |

Having investigated the operational conditions of the Tabriz petroleum refinery, especially the units which produced flare gases, we proposed practical methods to reduce, recover and reuse flare gases for the Tabriz petroleum refinery. There are some alternative choices for using recovered gases. The most important choices are: using flare gases as fuel gas, for electricity generation and as feed gas. In the next step, we tried to find the best choice for using recovered flare gases. Regarding the operational and economic evaluation, recovery of hydrocarbon gases discharged to the flare relief system is probably the most cost-beneficial plant retrofit available to the refinery. Use of flare gases to provide fuel for process heaters and steam generation leaves more in fuel processing, thus increasing yields. Regarding the results of data analyses, the mean value of molecular weight of the gas is 19.9, and the flow discharge rate is modulated between 0 and a maximum of 800 kg/h. The average temperature is 80◦C and the average pressure is 1 bar (O. Zadakbar,2015).

### 2.13.2.2 Flare Gas Recovery for the Shahid Hashemi-Nejad

The Shahid Hashemi-Nejad (Khangiran) is one of the most important gas refineries in Iran. The necessary natural gas is supplied from the Mozdouran gas fields. The Shahid Hashemi-Nejad (Khangiran) Gas Company consists of 5 sour gas refineries, 3 dehydration units, 3 sulfur recovery units, 2 distillation units, 2 stabilizer units and 14 additional units related to other services. The Shahid Hashemi-Nejad (Khangiran) gas refinery normally burns off 25000 m3/h gas in flare stacks. The analysis of operational conditions shows that some units normally produce flare gases more than other units. The compositions of flare gases produced by these units are shown in Table 3. These streams make the main flare stream. In addition, the process specifications of flare gases in the Shahid Hashemi-Nejad (Khangiran) gas refinery are shown in Table 2.5 below (**O**. Zadakbar, 2015)

Table 2.5 The composition of flare gases produced by important nods (**O**. Zadakbar, 2015)

| Component | MDEA flash drum | MDEA regenerator/reflux drum | Residue gas filter | inlet gas separator |
|---|---|---|---|---|
| Methane | 47.07 | 0.6 | 98.5 | 88.38 |
| Ethane | 0.16 | - | - | 0.56 |
| Propane | 0.0058 | - | - | 0.09 |
| i-Butane | 0.0019 | - | - | 0.02 |
| n-Butane | - | - | - | 0.03 |
| i-Pentane | - | - | - | 0.02 |
| n-Pentane | - | - | - | 0.02 |
| n-Hexane | - | - | - | 0.1 |
| $CO_2$ | 40.85 | 56.39 | 0.01 | 6.41 |
| $H_2S$ | 8.06 | 33.96 | 4 ppm | 3.85 |
| $N_2$ | 0.94 | - | 0.57 | 0.52 |
| $H_2O$ | 2.91 | 9.05 | 0.01 | 0.03 |
| COS | - | 91 ppm | 8 ppm | 17 ppm |

Table 2.6 Process specification of flare gases in the shahid Hashemi-Nejad (**O**. Zadakbar,2015)

| | Min. | Nor. | Max. |
|---|---|---|---|
| *P* (psig) | 2 | 6 | 10 |
| *T* (°C) | −29 | 30 | 75 |
| Flow ($m^3$/h) | 2500 | 25000 | 100000 |
| Sp. Gr. | 0.56 | 0.66 | 1.314 |

After a comprehensive process evaluation, we devised practical methods to reduce, recover and reuse flare gases for the Shahid Hashemi-Nejad (Khangiran) gas refinery. In addition, the flame igniter system, the flame safeguards and the existing flare tip have to be replaced. The fuel gas of the Shahid Hashemi-Nejad (Khangiran) gas refinery is supplied by sweet gas treated in the gas treating unit (GTU). Due to a pressure drop in the gas distribution network in Mashhad city in the northeast of Iran, during cold seasons, they encourage using flare gases as an alternative fuel gas resource and eliminating the use of sweet gas produced in a GTU. Regarding the Shahid Hashemi-Nejad (Khangiran) gas refinery recommendations and the operational evaluations, recovery of hydrocarbon gases discharged to the flare relief system is probably the most cost-beneficial plant retrofit available to the refinery.(O.Zadakbar,2015).

## 2.13.3 FGRS Design

### 2.13.3.1 Flare Gas Design for the Tabriz Petroleum Refinery:

The design considerations include: the flare relief operation and liquid seal drum, the flow and composition of flare gases and the refinery fuel system. The considerations led to a unit design for normal capacity up to 630 kg/h. Our proposed flare gas recovery system is a skid-mounted package which is located downstream of the knockout drum, as all flare gases from various units in the refinery are available at this single point. It is located upstream of the liquid seal drum as pressure control at the suction to the compressor will be maintained precisely, by keeping the height of the water column in the drum. The compressor selection and design depends on the system capacity and turndown capability. The most appropriate type and number of compressors for the application are selected during the design phase of the project. Liquid ring compressor technology is commonly used because of its rugged construction and resistance to liquid slugs and dirty gas fouling. A number of characteristics which must be taken into account when compressing flare gas are as follows: The amount of gas is not constant, the composition of the gas varies over a wide range, the gas contains components which condense during compression, and the gas contains corrosive components. A modular design which includes two separate and parallel trains capable of handling various gas loads and compositions is recommended for the Tabriz petroleum refinery. The recommended system consists of compressors which take suction from the flare gas header upstream of the liquid seal drum, compress the gas and cool it for reuse in the refinery fuel gas system. It includes two LR compressors, two horizontal 3-phase separators, two water coolers, piping and instruments. The compressed gas is routed to the amine treatment system for $H_2S$ removal. The effect of the devised FGRS on flaring in Tabriz petroleum refinery and The FGR system with LR compressor for the Tabriz petroleum refinery is shown in Figure 2.2 below (O.Zadakbar,2015)

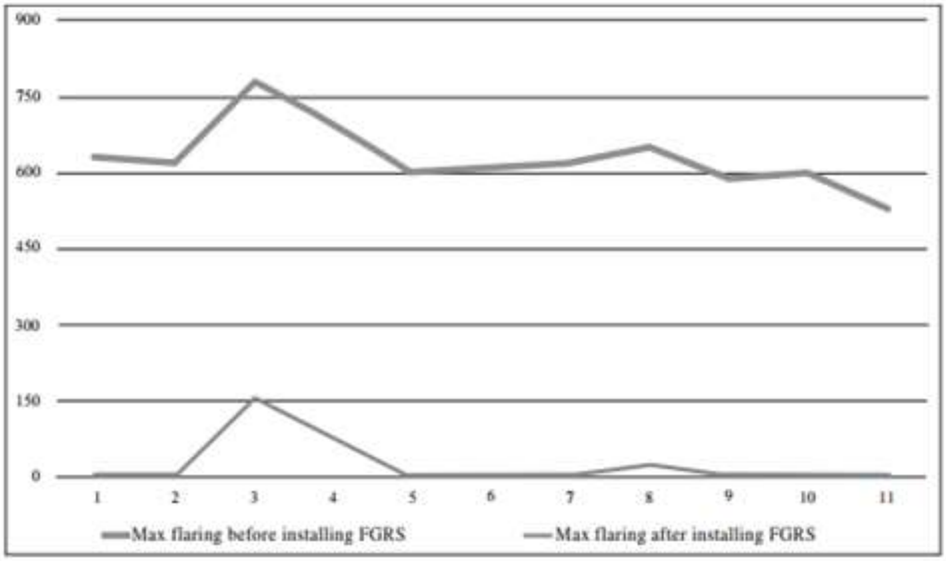



Figure 2.2 max flaring before and after FGRS

### 2.13.3.2 Flare Gas Design for the Shahid Hashemi-Nejad (Khangiran) Gas Refinery

In this case, the considerations led to a unit design for normal capacity up to 25000 m3/h. The process specifications of the outlet must be similar to refinery fuel gas. The proposed flare gas recovery system is like the proposed system for the Tabriz petroleum refinery. It has a modular design and comprises three separate and parallel trains capable of handling various gas loads and compositions (O. Zadakbar,2015).

**Chapter 3**

# 3. METHODOLOGY

## 3.1 Introduction:

Generally in the field of scientific research it is important to describe in detail the methods which are followed up and used. In this work and in order to achieve the objectives of this study, the methods can be divided into four main categories as follows;

- Data collection
- Simulation program
- Flare gas recovery system
- Process description

### 3.2 Data Collection:

Data of flare gases from Khartoum Refinery Company (KRC). The data is production data and design data

### 3.2.1 Production data:

The production data is the amount of flare gases (molar flow rate) from:

RFCC: 1115 kg mole/hr.

DCU: 713.8 kg mole/hr.

CCR-D1: 26.77 kg mole/hr.

CCR-D2: 26.77 kg mole/hr.

DHT: 11.15 kg mole/hr.

Table, 3.1 Composition and condition of each unit flare line

| Component | RFCC | DCU | CCR-D1 | CCR-D2 | DHT-1 |
|---|---|---|---|---|---|
| Methane | 0.2269 | 0.5202 | 0.0480 | 0.0344 | 0.2176 |
| Ethane | 0.1147 | 0.2049 | 0.0376 | 0.1992 | 0.2036 |
| Ethylene | 0.0908 | 0.0399 | 0.0000 | 0.0000 | 0.0000 |
| Propane | 0.0079 | 0.0295 | 0.0365 | 0.3099 | 0.1115 |
| Propene | 0.0435 | 0.0210 | 0.0000 | 0.0000 | 0.0000 |
| i-Butane | 0.0000 | 0.0035 | 0.0125 | 0.2286 | 0.0328 |
| n-Butane | 0.0269 | 0.0127 | 0.0353 | 0.0626 | 0.0776 |
| i-Pentane | 0.0000 | 0.0001 | 0.0238 | 0.0023 | 0.0155 |
| n-Pentane | 0.0008 | 0.0001 | 0.0195 | 0.0001 | 0.0219 |
| n-Hexane | 0.0001 | 0.0002 | 0.0000 | 0.0000 | 0.0037 |
| Hydrogen | 0.2371 | 0.1127 | 0.7868 | 0.1629 | 0.3158 |
| Nitrogen | 0.2267 | 0.0186 | 0.0000 | 0.0000 | 0.0000 |
| Oxygen | 0.0051 | 0.0036 | 0.0000 | 0.0000 | 0.0000 |
| CO | 0.0096 | 0.0191 | 0.0000 | 0.0000 | 0.0000 |
| CO2 | 0.0098 | 0.0139 | 0.0000 | 0.0000 | 0.0000 |
| H2S | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Temperature ( C ) | 35 | 37.5 | 40 | 40 | 34 |
| Pressure ( Kpa ) | 101.3 | 101.3 | 101.3 | 101.3 | 101.3 |
| Flow rate ( Kgmole/h ) | 1115 | 713.8 | 26.77 | 26.77 | 11.15 |

### 3.2.2 Design Data:

The FGRU consist of mixer, tee, two centrifugal compressors, two coolers and two two-phase separators. The flow from each unit collects by mixer which consist of five inlet streams and one out let stream and outlet pressure set to lowest inlet pressure. Then the flow split to two steam by tee which consist of one inlet stream and two outlet streams with flow ratio 90% to FGRU an 10% to flare system.

#### 3.2.2.1 Compressor 1:

Compressor 1 is center fugal compressor, consist of inlet stream, outlet stream and energy stream, adiabatic efficiency is 75%, suction pressure is 101.3 kpa and discharge pressure is set to be 1000 kpa.

#### 3.2.2.2 Cooler 1:

Cooler 1 consist of inlet stream, outlet stream and energy stream. Refrigerant -Freon 12 use as refrigerant fluid, outlet temperature and pressure are set to be -20 C and 2000 kpa respectively.

#### 3.2.2.3 Separator 1:

Separator 1 is vertical, flat cylinder two phase separator which consist of inlet stream and two outlet streams (bottom stream is liquid stream and top stream is gas stream),liquid percent level 50%, liquid volume percent 50%.

#### 3.2.2.4 Compressor 2:

Compressor 2 is center fugal, consist of inlet stream, outlet stream and energy stream, adiabatic efficiency is 75%, suction pressure is 2000 kpa and discharge pressure is set to be 3000 kpa.

#### 3.2.2.5 Cooler 2:

Cooler 2 consist of inlet stream, outlet stream and energy stream. Refrigerant -Freon 12 use as refrigerant fluid, outlet temperature and pressure is -18 C and 3000 kpa respectively.

#### 3.2.2.6 Separator 2:

Separator 2 is vertical, flat cylinder two phase separator which consist of inlet stream and two outlet streams (bottom stream is liquid stream and top stream is gas stream), liquid percent level 50%, liquid volume percent 50%. See figure 3.1

### 3.3 Simulation program:

The Aspen Hysys (V11)simulation program was used for the simulation studies and the investigation of the effect of various operating parameters, use it offers a high degree of flexibility to accomplish a specific task.

HYSYS has strong thermodynamic foundation. The inherent flexibility contributed through its design, combined with the unparalleled accuracy and robustness provided by its property package calculations lead to the representation of a more realistic model. The equation of State models was chosen as a fluid property package, because it has proven to be very reliable in predicting the properties of most hydrocarbon based fluids over a wide range of operating conditions. For oil, gas and petrochemical applications, the Peng-Robinson Equation of State was used among the equation of states models because it has a high accuracy for a variety of systems over a wide range of conditions.

### 3.4 Flare Gas Recovery System:

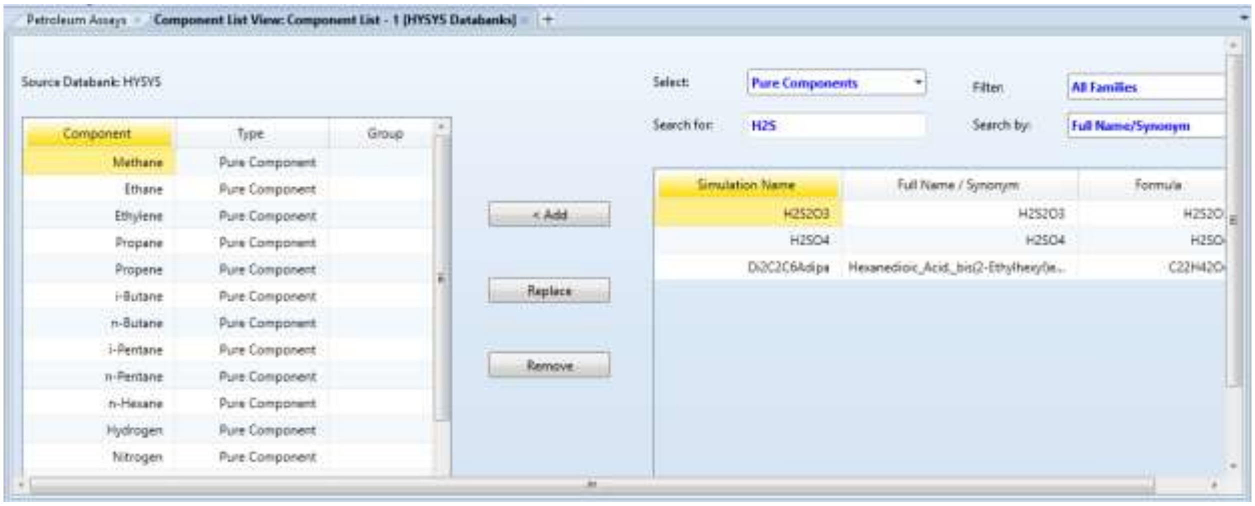
Because of there is no previous attempts to recover the gases that is burned in the flare system in the Khartoum refinery in the past. A proposed design for system to recover the flare gases based on the data that has been got from the Khartoum Refinery.

The design based on the proposed design method to flare gas recovery in giant gas refinery in Iran (Abdollah Hajizadeh, 2017). The method studied option is using three-stage compression unit to compress the flare gases.

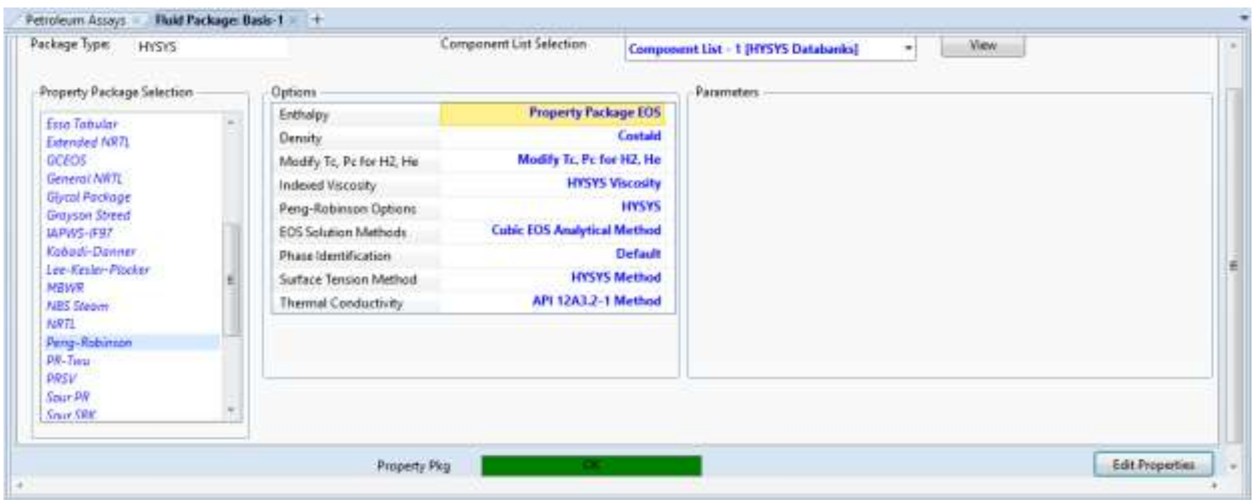
The FGRU consist of two centrifugal compressors, two coolers and two two-phase separators. The flare gases from production units (RFCC, DCU, CCR-D1, CCR-D2 and DHT-1) represent as streams which have conditions (temperature, pressure and flow rate) and compositions (mole %) of each one.

### 3.5 Process Description:

Design is simulated by Aspen Hysys start by add the component list and then add the fluid package (Peng-Robinson), see Fig, 3.1 and Fig, 3.2.




Fig, 3.1 adding component list




Fig, 3.2 adding fluid package

All streams are mixed into a pipeline known as a header that contains all the flare gases. After that, the flow is divided into two streams. One part is routed to the flare system and the second part is sent to the FGRS unit.

In the first compressor, which is a centrifugal compressor, the gas is compressed up to 2000 kpa, and then the product is introduced to the cooler1, in order to cooled down to -20 ° C, the mixture produced from the cooler1 is introduced into a two-phase separator in which LPG is obtained in the liquid stream at the bottom of separator . The rest of the gases leave from the gas stream at the top of separator1, which are mainly composed of methane, ethane and hydrogen.

The gas stream coming from the first separator is compressed in the second compressor up to 3000 kpa and then it is fed into the second cooler in order to cool it down to -18 ° C. The resulting mixture is entered into a two-phase separator and additional quantities of LPG are obtained in the outlet liquid stream at the bottom of separator. From the top stream of the separator2 the gas stream consist of dry gas and hydrogen.

The performed simulation using Aspen HYSYS is valid and successful and the results of simulation are obtained.

# Chapter 4

# 4. Result and discussion

In this research design criteria of a flare gas recovery system and simulation of the recovery system was studied for the gas sent to the flare in Khartoum Refinery Company. In this section, the results of simulation of gas flaring system will be presented, as well as the results of the economic evaluations.

## 4.1 Results of simulation:

In this section we will discuss the results of simulation of flare gas recovery system (figure 4.1).

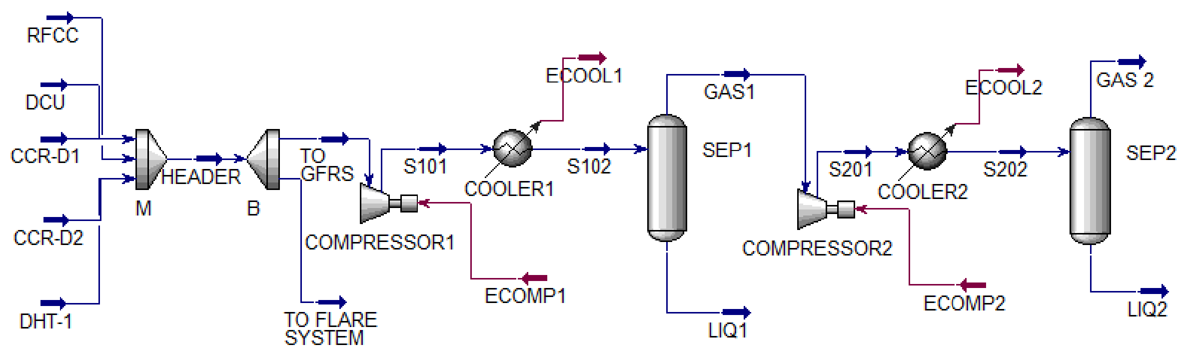



Fig 4.1 Flare Gas Recovery System

It was found that the amount of gases that were usually burnt in flare system in Khartoum Refinery were reduced from 41950 nm3/h (1893.49 kg mole/hr.) to 4195 nm3/hr. (189.349 kg mole/hr.).

Production of LPG increased by 2273 kg/hr. from first separator and 1133 kg/hr. from second separator. The total annual production of LPG from FGRS was 29,836 t/year. The total annual production of LPG from KRC is 300,000 t/year, the production of LPG increase by 9.9% after recovery (Figure 4.2).

The top stream of second separator contain 56.06% dry gas which can use as fuel in turbine to generate electricity also can use as fuel in furnaces.

The top stream of second separator contain 20.66% hydrogen which can use as feed of hydro treating unit. All these quantities of useful products are burned in KRC.

Because of growing interest in minimizing flaring, in part due to the pollution emissions generated by flaring and potentially significant emission sources within a refineries, fields and plants. The flaring reduction has high priority as it meets both environmental and economic efficiency objectives. Design of flare gas recovery system (Fig. 4.1) reduced the amount of emissions to 10%.

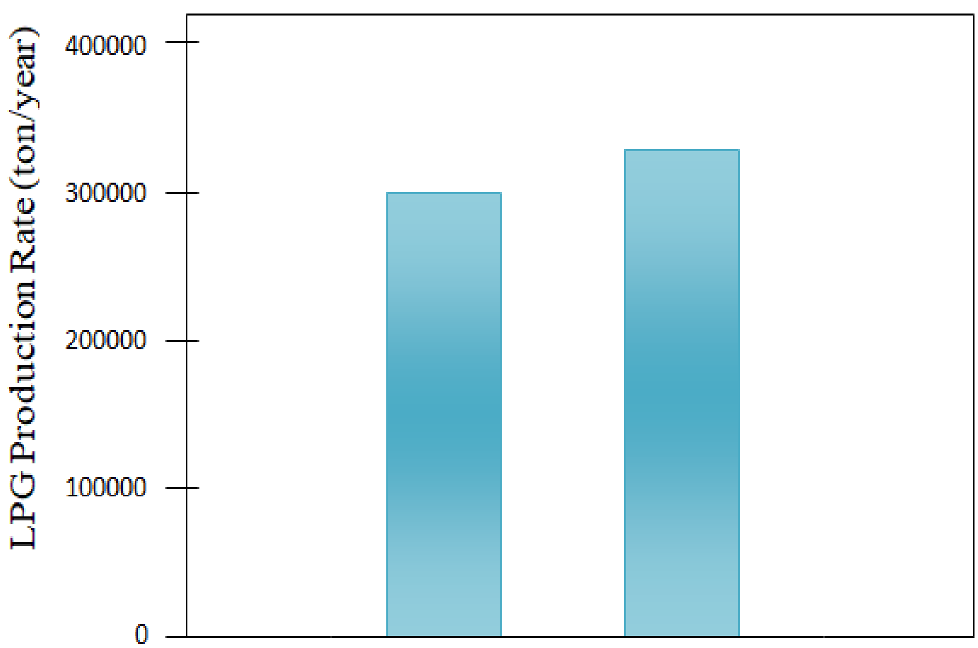



Figure 4.2 LPG production rate (ton/year) before and after FGRS

## 4.2 Economic Evaluation:

In this section we will discuss the results of economic evaluations of flare gas recovery system.

- These results were obtained based on 0.58 $/liter for LPG (average world price of LPG – 02 Nov 2020(GlobalPetroPrices.com)). The lowest price is 0.07 (Algeria) and highest price is 1.14 (Sweden).
- The FGRS consist of mixer, tee, two compressors, two coolers and two two-phase separators. The cost analysis provided by economic analyzer module of Aspen HYSYS.

### 4.2.1 Unit operation cost:

The cost of each equipment and its installed cost, equipment weight and installed weight are presented in table 4.1.

Table 4.1 Unit Operation cost

| Name | Equipment Cost [USD] | Installed Cost [USD] | Equipment Weight [LBS] | Installed Weight [LBS] | Utility Cost [USD/HR] |
|---|---|---|---|---|---|
| SEP1 | 23,000 | 117,700 | 5100 | 15237 | 0 |
| COOLER2 | 19,700 | 115,800 | 3800 | 20019 | 2.83191 |
| COOLER1 | 43,300 | 165,100 | 11200 | 35635 | 25.253 |
| M | 0 | 0 | 0 | 0 | 0 |
| SEP2 | 24,900 | 119,200 | 6300 | 16366 | 0 |
| COMP1 | 7,362,200 | 7,767,200 | 133700 | 199491 | 404.705 |
| COMP2 | 964,700 | 1,126,500 | 15100 | 31746 | 40.4705 |
| B | 0 | 0 | 0 | 0 | 0 |

### 4.2.2 Utility cost:

The cost of electricity needed to operate the compressors and cost of refrigerant fluid to coolers in USD are presented in table 4.2.

Table 4.2 Utility cost

| Name | Fluid | Rate | Rate Units | Cost per Hour | Cost Units |
|---|---|---|---|---|---|
| Electricity | | 5841.28 | KW | 452.699 | USD/H |
| Refrigerant - Freon 12 | Refrigerant | 330.411 | KLB/H | 28.0849 | USD/H |

The investment summery of the flare gas recovery system in KRC is presented in table 4.3

Table 4.3 Summery of investment

| | |
|---|---|
| Total Capital Cost [USD] | 13,883,800 |
| Total Operating Cost [USD/Year] | 6,596,060 |
| Total Raw Materials Cost [USD/Year] | 0 |
| Total Product Sales [USD/Year] | 34,595,400 |
| Total Utilities Cost [USD/Year] | 4,214,550 |
| Desired Rate of Return [Percent/'Year] | 20 |
| P.O.Period [Year] | 1.68078 |
| Equipment Cost [USD] | 8,441,700 |
| Total Installed Cost [USD] | 9,415,600 |

- Total capital cost 13,888,800 $.
- Equipment cost 8,437,800 $.
- Total installed cost 9,441,700 $.
- Operating cost 6,596,060 $/year.
- Total utility cost 4,214,550 $/year.
- The total initial costs [USD] 31,741,100 [USD]
- Operating cost and utility cost [USD/Year] 10,810,610
- Total Product Sales [USD/Year] 34595400
- The total sales of two years is 69,190,800 USD and the total cost of two years is 53,362,320 USD we notice the project begins to realize profits in period of less than two years.

# Chapter 5

# 5. Conclusion and Recommendations

## 5.1 Conclusion:

This research was done to simulate a flare gas recovery system in Khartoum Refinery Company. The simulated unit consists of mixer, tee, two centrifugal compressors, two coolers and two two-phase separators. The unit has been added and simulated by aspen hysys and the result of simulation conducted based on data obtained from Khartoum refinery the production of LPG increased by 9.9%. The amount of gases that were usually burnt in flare system in Khartoum Refinery were reduced from 41950 nm3/h (1893.49 kg mole/hr.) to 4195 nm3/hr. (189.349 kg mole/hr.). Also the harmful emissions reduced by 90%

Study of economic evaluation found the total initial costs [USD] 31,741,100, Operating cost and utility cost [USD/Year] 10,810,610, Total Product Sales [USD/Year] 34,595,400, payback period 20 month

## 5.2 Recommendations:

- Production data has not been updated in KRC since 2010, so updates must be made
- More studies should be done to study if any harmful reaction could happen at low temperatures and find methods to reduce them.
- More studies should be done to study the possibility of separate hydrogen from dry gas (gas stream in second separator) and make an economic evaluation to this product
- More studies should be done to study the possibility of reduced the utility cost of compressors

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