Sudan University of Sciences and Technology

College of Petroleum & Mining Engineering

Department of Refining & Transportation

Economic Analysis for Extension of Port-Sudan Refinery

التحليل الإقتصادي للتوسعة مصفاة البحر الأحمر

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Supervisor:

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The project is accepted by college of Petroleum and Mining Engineering department of Refining and Transportation.

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Date: \ \2020

الإستهلال

بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

الْحَمْدُ لِلَّهِ رَبِّ الْعَٰلَمِينَ ١ الرَّحْمَٰنِ الرَّحِيمِ ٢

مَٰلِكِ يَوْمِ الدِّينِ ٣ إِيَّاكَ نَعْبُدُ وَإِيَّاكَ نَسْتَعِينُ ٤

اهْدِنَا الصِّرَاطَ الْمُسْتَقِيمَ ٥ صِرَاطَ الَّذِينَ أَنْعَمْتَ

عَلَيْهِمْ ٦ غَيْرِ الْمَغْضُوبِ عَلَيْهِمْ وَلَا الضَّالِّينَ ٧

Dedication

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This project is the first fruit of five years spent studding in university acquiring knowledge and skills. To those whom have been the most important inspiration for us in our education journey, thanks will not be enough for appreciating your great efforts.

Great love for the supporting that our parents, friends, and our respectable supervisor Dr. Mohammed Osman Khalil offered to us, regardless of all the circumstances of COVID-19.

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Abstract

This year and few years before the consumption of Diesel, LPG and Fuel oil increased sharply while the production from our domestic refinery are insufficient to cover this shortage so it’s been important to import product to felling this gap, thus this project aim to cover the local demand and export the surplus.

In this study an expansion was made to existing Port Sudan refinery to include farther units RFCC, VDU, CCR, and KDHT with total capacity of 55000bbl/day.

This project will be profitable after 12 years during which the initial cost will be returned with internal rate of return 20%, beside benefitting from PSR location to export the surplus.

التجريد

إزداد إستهلاك ال Diesel, LPG, and Fuel oil بصورة كبيرة في هذه السنة والسنوات القلائل الماضية بحيث لا يكفي الانتاج المحلي لتلبية الزيادة في الطلب لذلك كان من الضروري اللجوء الي استيراد منتجات

اضافية لتغطية هذا النقص. من هنا تكمن أهمية المشروع في تغطية هذا النقص في المنتجات المحلية وتصدير الفائض من بعض المنتجات.

في هذه الدراسة اجريت توسعة لمصفاة بورتسودان القديمة بإضافة بعض الوحدات الجديدة لتشمل: RFCC, CCR, VDU, KDHT, HT, and CDU بسعة تشغيل كلية تبلغ 55000 برميل يومياً .

تكلفة انشاء المشروع الكلية سوف تسترجع بعد 12 عام بمعدل IRR يساوي 20% من التكلفة الكلية، بالاضافة الي ذلك سوف يتم الاستفادة من موقع مدينة بورتسودان الاستراتيجي لتصدير الفائض من بعض المنتجات .

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CNPC	Chain National Petroleum Corporation
ORC	EL-Obaid Refinery Company
PSR	Port Sudan Refinery
Bbl/day	Barrel per day
t/y	Ton per Year
W %	Weight percentage
API	American Petroleum Institute
CDU	Crude Distillation Unit
VDU	Vacuum Distillation Unit
RFCC	Residual Flued Catalytic Cracking
KDHT	Kerosene Diesel Hydrotreating
CCR	Crude Catalytic Reforming
L D	Light Diesel
H D	Heavy Diesel
GO	Gas Oil
LPG	Liquefied Petroleum Gas
VGO	Vacuum Gas oil
LVGO	Light Vacuum Gas oil
HVGO	Heavy Vacuum Gas Oil
L R	Long Residue
Bit	Bitumen
MON	Motors Octane Number
PON	Posted Octane Number
KRC	Khartoum Refinery Company
TBP	True Boiling Point
IBP	Initial Boiling Point

FBP	Final Boiling Point
SG	Specific Gravity
N	Naphtha
TCC	Thermos Catalytic Cracking

Chapter (1)

Introduction

1.1. General about refining in Sudan*:*

Petroleum refineries are a very large complex that involve a great many different processing units, utilities, and energy system. And in Sudan there are three refineries which work to cover Sudan consumption for petroleum products and petrochemicals. The three refineries are:

1.1.1. Khartoum refinery.

1.1.2. El-Obaid refinery

1.1.3. Port Sudan refinery.

1.1.1. Khartoum refinery:

Khartoum refinery is a modern refinery. It is joint venture between china and Sudan, invested by china national petroleum corporation (CNPC) on 50% basis, the joint venture agreement was signed in March 1997. And the Construction is finished in 1998 and the production started in 2000, at capacity of 50,000bbl/day, in 2003 the refinery was expanded in order to process very severe crude production from block 6 in Fula and the total refinery capacity become 100,000bbl/day.

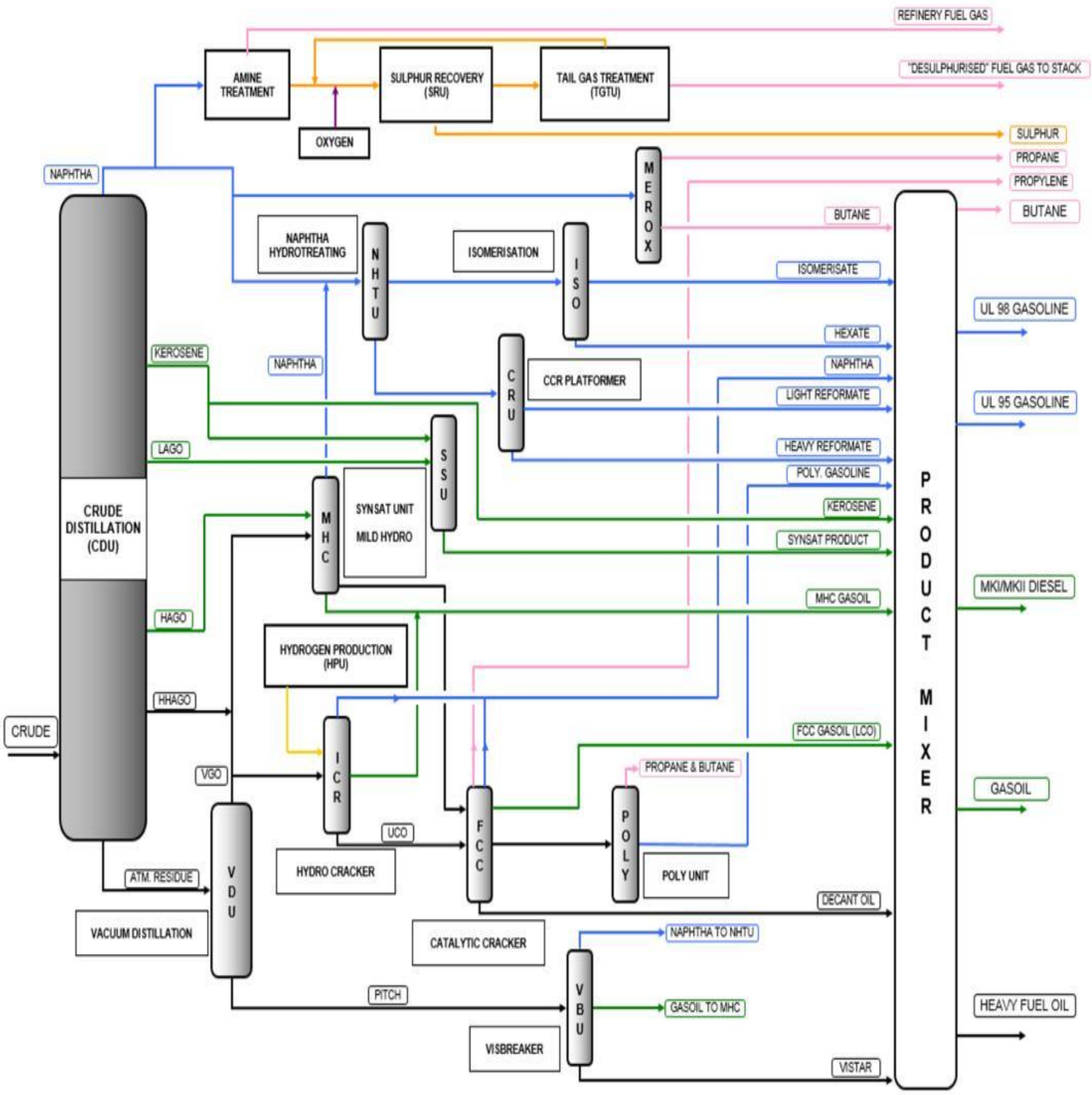

Fig (1.1): Khartoum refinery process flow diagram

1.1.2. El-Obaid refinery:

ORC was established in 1996 with capacity 15 kbbl/day, based on Nile Blend crude oil. A simple refinery, containing crude distillation unit. ORC located in West Sudan.

- ORC is processing Nile Blend crude oil.
- Processing Capacity = 2050 t/d (15,000 bpd)

Table (1.1): ORC product percentage

Products	Yield (Wt. %)
Naphtha	5 %
Kerosene	7 %
Gasoil	23 %
Fuel Oil	63 %
Fuel & Loss	2 %

1.1.3. Port Sudan refinery:

Port Sudan refinery is located near the red sea and it's the smallest refinery with capacity of 21700 bbl./d

It was published in 2005 to process Dar blend crude, which has high-acid content and found in Sudanese's Melut basin and started operation in 2009.

1.2. Demand of Products in Sudan:

<u>% of Local Production</u>

Table (1.2): Local Refineries Production

Product	Annual Refineries production t/y	Annual Products Consumption t/y	Balance t/y	% of Local Production
LPG	302,144	547,500	-245,356	%55.2
Mogas	1,008,283	949,000	59,283	%106.2
Jet A1	122,027	219,000	-96,973	%55.7
Diesel	1,650,986	2,938,000	-1,287,014	%56.2

Heavy Diesel	270,426	500,163	-229,737	7777
Pet Coke	248,901	240,914	7,987	%103.3
Fuel Oil	290,196	1,002,450	-712,254	%28.9
Naphtha	23,070	23,070	0	%100.0
Kerosene	26,978	16,000	10,978	%168.6

Notes:

- The shortage in LPG is very high where the local production cannot cover almost half of the demand.
- The shortage in Jet A1, Diesel and Fuel oil is very excessive and need high supply to cover this shortage.
- There is no shortage in the production of Mogas, pet coke, naphtha.

1.3. Needs for new Port Sudan refinery

Table (1.3): PSR Production

Products	**PSR production(t/y)**	**Balance (t/y)**	**New Balance (t/y)**	**New local production**
LPG	186,450	-245,356	-58906	89.26 %
Mogas	690,690	59,283	2152.283	179.03 %
Jet A-1	174,570	-96,973	432.027	135.43 %
Gas oil (L.D)	881,100	-1,287,014	-405914	86.18 %
Fuel oil	25,410	-712,254	-686,844	31.48 %

Bitumen (H.D)	349,140	-229,737	119403	123.87 %

Notes:

- After using port Sudan refinery, the shortage in LPG and gas oil is almost covered and the gap between supply and demand become very small.
- The shortage in Jet A1 is covered and there is surplus which can be exported.
- There is big gap in production of fuel oil production and its demand so we need to maximize the capacity to fix it.

Chapter 2

Literature Review

2.1. TYPE OF REFINERY:

Introduction:

Petroleum refineries are very large industrial complexes that involve a great many different processing unit and auxiliary facilities such as utility units and storage tanks. Each refinery has its own unique arrangement and combination of refining processes largely determined by the refinery location, desired products and economic consideration. There are most probably no two refineries that are identical in every aspect.

But in general we can have categorized them according to their units in to three types:

2.1.1. Simple refinery.

It is the refinery which consist of Crude Distillation Unit, a catalytic reformer to produce high octane gasoline, and middle distillate hydrotreating units.

2.1.2. Complex refinery

It has in addition to the units of the simple refinery, conversion units such as hydrocracker and fluid catalytic cracking units.

2.1.3. Complicated refinery

This refinery has all of the above units in addition to deep conversion units which produce more light products. (MOHAMED A. FAHIM, 2010).

2.2. TYPE OF CRUDE OIL:

Crude oil is a complex liquid mixture made up of a vast number of hydrocarbon compounds that consist mainly of carbon and hydrogen in differing proportions.

There are three main classes of crude oil:

2.2.1. According to chemical compositions:

Crude oil samples can be classified on the basis of paraffinic, naphthenic, or aromatic content depending on the result obtain from distillation.

A. Paraffin's:

Paraffin refer to alkanes such as methane, ethane, propane, n and iso-butane, n and iso-pentane. These compounds are primarily obtained as a gas fraction from the crude distillation.

B. Naphthenes:

naphthenes or cycloalkanes as cyclopropane, methyl cyclohexane are also present in the crude oil, these compounds are not aromatics and hence do not contribute much to the octane number. Therefore, in the reforming reaction, these compounds are targeted to generate aromatics which have high octane numbers than the naphthenes.

C. Aromatics:

Aromatics such as benzene, toluene o/m/xylene are also available in the crude oil. These contribute towards higher octane number products and the target is to maximize their quantity in a refinery process.

2.2.2. According to the API:

Table (2.1): Types of crude according to API

API gravity	Description
Less than 10	Very heavy crude
Between 10 & 30	Heavy crude
Between 30 & 40	Medium crude
Above 40	Lite crude

2.2.3. According to the sulfur content:

Sulfur is present in the crude oil. Crude oil with high sulfur content is termed as sour crude, while the crude with low sulfur content is termed as sweet crude.

Table (2.2): types of crude according to sulfur content

Sulfur percent % .5wt %	Description Sweet crude
Sulfur content > .5wt%	Sour crude

2.3. CRUDE OIL CHARACTERISTICS:

A Petroleum refining stud starts with describing its feed stocks, the crude oil and the range of products that are produced by the various processes. Crude oil comes from different physical and chemical characteristics. On the other hand, the products that are produced have to meet market requirements and as such, should comply with certain specification.

2.3.1. API GRAVITY:

It is expression of the density of the petroleum rather than specific gravity. It is index of lightness or heaviness of the crude oil. And can be calculated from the specific gravity of oil at 60F by the following:

API= (141.5/specific gravity)-131.5

The light crude varies from 45 to 35 medium from 35 to 25 and the heavier crude is less than 25. API is range from 10 to 50 put most of the crudes fall Between 20 to 45. (Gary, 2001)

Sulfur Content:

Sulfur and API gravity are two properties which have had the greatest influence on the value of crude oil. Although nitrogen and metals contents are increasing in importance. The sulfur content is expressed as present sulfur by weight and varies from less than 0.1% to greater than 5%. crude with greater than 5% called sour crude and it is required more expensive processing than the sweet one which have sulfur less than 0.5%. The sulfur in the crude exists as dissolved hydrogen sulfide. (Gary, 2001)

2.3.2. Pour point:

The pour point is defined as the lowest temperature at which the crude sample will flow. It indicates how easy or difficult its flow, especially in cold weather.it also indicates the aromaticity or paraffin of the crude o or its products. A lower pour point means that the paraffin’s content is low. Pour point boiling above 232 C is determined by standard test like ASTM D97. (MOHAMED A. FAHIM, 2010)

2.3.4. True Boiling Point Distillation:

The boiling point distribution of crude oil is obtained through a batch distillation test ASTM2892. The distillation apparatus has 15-18 theoretical stages with 5:1 reflux ratio. For boiling point below 340 C the distillation is performed at atmospheric pressure. The residue is distilled under vacuum (1 to 10 mm Hg). The boiling points under vacuum are converted to normal boiling points. The distillation continues to a normal boiling point of 535 C. This test allows for the collection of sample cuts at different boiling points ranges. These cuts can be subjected to physical and chemical measurements. (MOHAMED A. FAHIM, 2010).

Carbon Residue:

Carbon residue is determined by distillation to a coke residue in the absence of air. The carbon residue is roughly related to the asphalt content of the crude and to the quantity of the lubricating oil fraction that can be recovered. In most cases the lower the carbon residue, the more valuable the crude. This is expressed in terms of the weight percent carbon residue by either the Rams bottom (RCR) or Conradson (CCR) ASTM test procedures. (Gary, 2001).

2.3.3. Salt Content:

The salt is undesirable in crude oil or products because it causes corrosion damage to the process equipment and poisoning the catalyst in the catalyst conversion processes. Desalting is used to remove salt from the crude. And the process is desirable at even small amount of salt. It is measured by ppm (part per million) and it is varying from 1 to 3 ppm. (Gary, 2001).

2.3.4. Nitrogen Content:

High nitrogen content is undesirable in crude oils because organic nitrogen compounds cause severe poisoning of catalysts used in processing and cause corrosion problems such as hydrogen blistering. Crudes containing nitrogen in amounts above 0.25% by weight require special processing to remove the nitrogen. (Gary, 2001).

2.3.5. Metals Content:

The metals content of crude oils can vary from a few parts per million to more than1000ppm, and despite of their low concentrations, are of considerable importance. Minute quantities of some of these metals (nickel, vanadium, and copper) can severely affect the activities of catalysts. Vanadium concentrations above 2 ppm in fuel oils can lead to severe corrosion to turbine blades and deterioration of refractory furnace linings and stacks. Distillation concentrates the metallic constituents of crude in the residues, but some of the organometallic compounds are actually volatilized at refinery distillation temperatures and appear in the higher-boiling distillates.

The metallic content may be reduced by solvent extraction with propane or similar solvents as the organometallic compounds are precipitated with the asphaltenes and resins. (Gary, 2001).

2.3.6. Molecular weight:

Most crude oil and petroleum fractions have average molecular weights from 100 to 500. Although there are several methods for measuring the molecular weight, the most suitable method is that based on freeing point depression. (MOHAMED A. FAHIM, 2010).

2.4. PRODUCTS SPECIFICATION:

2.4.1. Viscosity:

The viscosity of an oil is a measure of its resistance to internal flow and is an indication of its lubricating qualities. In the oil industry it is usual to quote viscosities either in centistokes (which is the unit for kinematic viscosity), Say bolt universal seconds, Say bolt Furl seconds, or Redwood seconds. These units have been correlated and such correlations can be found in most data books. In the laboratory, test data on viscosities is usually determined at temperatures of 100! F,130! F, or 210! F. In the case of fuel oils, temperatures of 122! F and 210! F are used.

2.4.2. Freezing point:

Freezing point is the temperature at which crystals of hydrocarbons formed on cooling disappear when temperature of fuel is allowed to rise. This method covers a procedure for the detection of separated solids in aviation reciprocating engine and turbine engine fuels at any temperature likely to be encountered during flight r or on the ground. (Agrawal, 2018).

2.4.3. Aniline point:

Aniline is a poor solvent for aliphatic hydrocarbons and excellent one for aromatics. This property is used in the aniline point test. Aniline point of oil is the lowest temperature at which the oil is completely miscible with an equal volume of aniline.

Equal volumes of the sample and aniline (5 ml each) are heated or cooled with stirring in a jacketed test tube and temperature at which complete miscibility occurs is noted. High aniline point indicates that the fuel is highly paraffinic and hence has a high diesel index and very good ignition quality. In case of aromatics the aniline point is low and the ignition quality is poor. (Agrawal, 2018).

2.4.4.Flash point and fire point:

Flash point and fire point can be taken as indirect measure- of volatility of the product. The flash point is the lowest temperature at which application of test flame causes the vapor above the oil to ignite. The fire point is the lowest temperature at which the oil ignites and continues to burn for 5 second.

The determination of flash point of petroleum products consists of heating a given volume of liquid at a standard rate of temperature rise until vapor is produced to such a degree as to give a flammable mixture with air in an enclosed space (i.e. closed flash point temperature) or with air in an open cup (i.e. the higher open flash point temperature), ignition resulting from the application of a small flame. At fire point, not only will the vapor-air mixture flash but the liquid will continue to burn.

Abel apparatus is used for determining the closed cup flash point of petroleum products having flash points between 19°C and 49°C. Pensky-Martens apparatus is used for determining the flash point of fuel oils and lubricating oils, bitumen other than cutback bitumen having a flash point above 49 C. Cleveland apparatus is used for determining the flash and fire points of petroleum products except fuel oils and those products having an open cup flash point below 79°C.

Flash point measures the tendency of the fuel to form a flammable mixture with air under controlled laboratory conditions. This is the only property that must be considered in assessing the overall flammability hazard of a material. It is used in shipping and safety regulations that defined flammable and combustible materials. Petroleum products having low flash points are potential to fire hazards.

Flash point can indicate the possible presence of highly volatile and flammable materials in relatively nonvolatile or nonflammable material. (Agrawal, 2018).

2.4.5. Octane number:

An octane number is a measure of the knocking tendency of gasoline fuels in spark ignition engines. The ability of a fuel to resist auto-ignition during compression and prior to the spark ignition gives it a high octane number. The octane number of a fuel is determined by measuring its knocking value compared to the knocking of a mixture of n-heptane and iso-octane. Pure n-heptane is an assigned a value of zero octane while iso-octane is assigned value of 100 octanes. Hence an 80 vole c iso-octane mixture has an octane number of 80. Two octane tests can be performed for gasoline. The motor octane number (MON) indicates engine performance at high way conditions with high speeds (900 rpm). On the other hand, the research octane number is indicative of how speed city driving (600rpm). The posted octane number (PON) is the arithmetic average of MON and RON. (MOHAMED A. FAHIM, 2010).

2.4.6. Cetane number:

The cetane number measures the ability for auto ignition and essentially the opposite of octane number. The cetane number is the percentage of pure cetane number (n-hexadecane) in a blend of cetane and alpha methyl naphthalene which matches the ignition quality of a diesel fuel sample. This quality is specified for middle distillate fuels. One of the standard tests is ASTM D976. (Agrawal, 2018).

2.4.7. Smoke point:

Smoke point is the maximum flame height in mm at which the fuel will bum without smoking *hen determined in a smoke point apparatus under specified conditions. Smoke point apparatus comprises four main parts-lamp body, candle socket, candle and stand. The lamp body with chimney is fitted on the inside with a polished black engraved scale which is marked in white. A gallery is secured in the lower part of the body. The candle socket assembly is designed to give a smooth rise and fall over the total distance of travel. To ensure interchangeability the candle is finished to close tolerances. The assembly is mounted on a stand. The sample is burned in a standard lamp with a specified wick for five minutes. The height of the flame is read when it leaves no smoky tail. This is an important test for evaluation of illuminating oils (kerosene) for their ability to bum without producing smoke and the assessment of the burning quality of aviation fuels. Higher the smoke point better is its domestic use. It also serves as a guide to assess the aromatic content of kerosene. (Jones, 2015).

2.4.8.Raid Vapor Pressure:

The raid vapor pressure (RVP) of a product is the vapor pressure determined in a volume of air four times the liquid volume at 37.8 C. This property measures the vapor-lock tendency of a motor gasoline in which excessive vapors are produced in the fuel line causing interruption of the supply of liquid fuel to the engine. It also indicates the explosion and evaporation hazard of the fuel. One of the standard tests is ASTM D323. (MOHAMED A. FAHIM, 2010).

2.5. Unit process operation

2.5.1. Introduction:

Crude oil is the row material in the petroleum industry which consist mainly of a complex mixture of hydrocarbons and nonhydrocarbons.

The purpose of a refinery is to:

1. To separate the crude oil in to different fractions
2. Shift the original component ratio and properties to meet the customer's demand
3. Remove the impurities detrimental to increase product quality

The processing of crude oil is extremely complex due to its numerus and varied components and the range of products that are derived from it.

2.5.2. Refining process:

Table (2.3): types of refinery process unit

• Separation	• Crude oil desalting/dewatering • Atmospheric distillation • Vacuum distillation • Light ends recovery
• Conversion	• Thermal cracking-cocking-vis breaking • Catalytic cracking • Hydro cracking • Steam cracking • Catalytic reforming • Isomerization • Alkylation and polymerization

• Treating	• Hydrodesulphurization • Hydro treating • Extraction • Bitumen blowing • Lube oil manufacture (large or specialist only)
• Crude and product handling	• Unloading • Storage • Blending • loading
• Auxiliary facilities	• Boling/process heaters • Hydrogen production • Sulfur recovery and production • Cooling tower • Compressor engine • Power generation • Blow down system • West water treatment • Flares

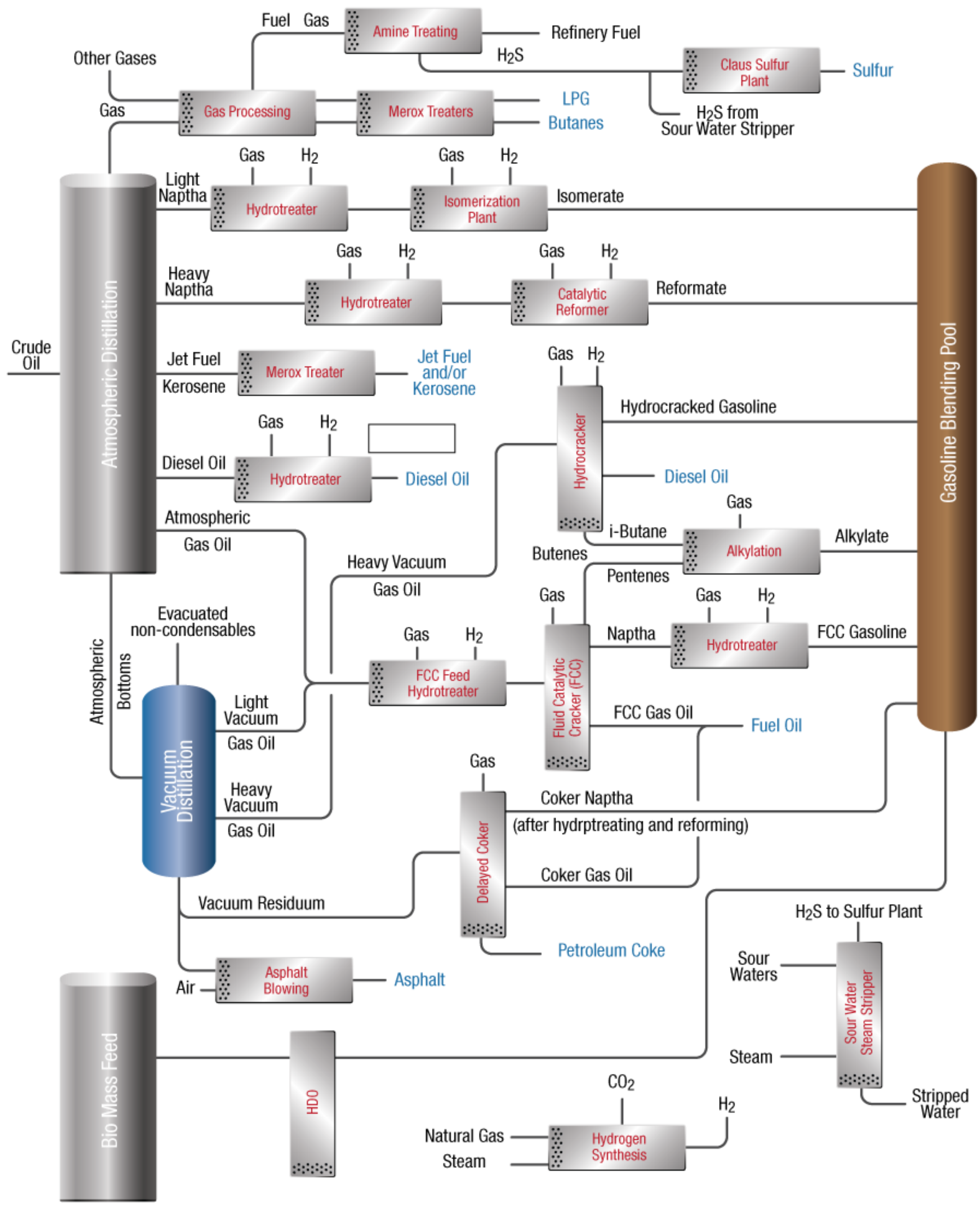

Fig (2.1): Refinery process unites (Coker, 2018)

2.5.3. Crude Distillation Units (CDU):

Crude distillation unit is the main unit in any modern refinery. It is the first process of converting crude oil to the main products which then are treated to remove poisonous and to increase its quality. And the refinery can be multiple feed or multiple distillation (many distillation).

The first step in petroleum refining is the fractionation of crude oil in atmospheric or vacuum distillation towers. Heated crude oil is physically separated into various fractions, or straight run cuts, differentiated by specific boiling point ranges and classified in order of decreasing volatility, as gases, light distillate, medium distillate, gas oil, and residuum (Agrawal, 2018).

Crude oil preparation:

Crude oil often contains water inorganic salt, suspended solid and water soluble trace metals. Firstly, it is important to remove these contaminates by desalting in order to reduce corrosion, plugging, and fouling of equipment, and to prevent poisoning the catalyst in processing units.

Desalting:

There are three typical methods of crude oil desalting:

I. Chemical desalting:

In this process we add chemicals surfactants and water to the crude then we heated (66-177C) so that the salt and other impurities dissolve in to the water then transferred to be settle in the tanks.

II. Electrostatic separation:

In this process we apply high voltage electrostatic charges in order to concentrate suspended water in the bottom portion of the settling tank. Surfactants are added only when the crude oil has a large amount of suspended solid.

III. Filtering:

This process involve filtering heated crude oil using medium filtration (diatomaceous earth) (Agrawal, 2018).

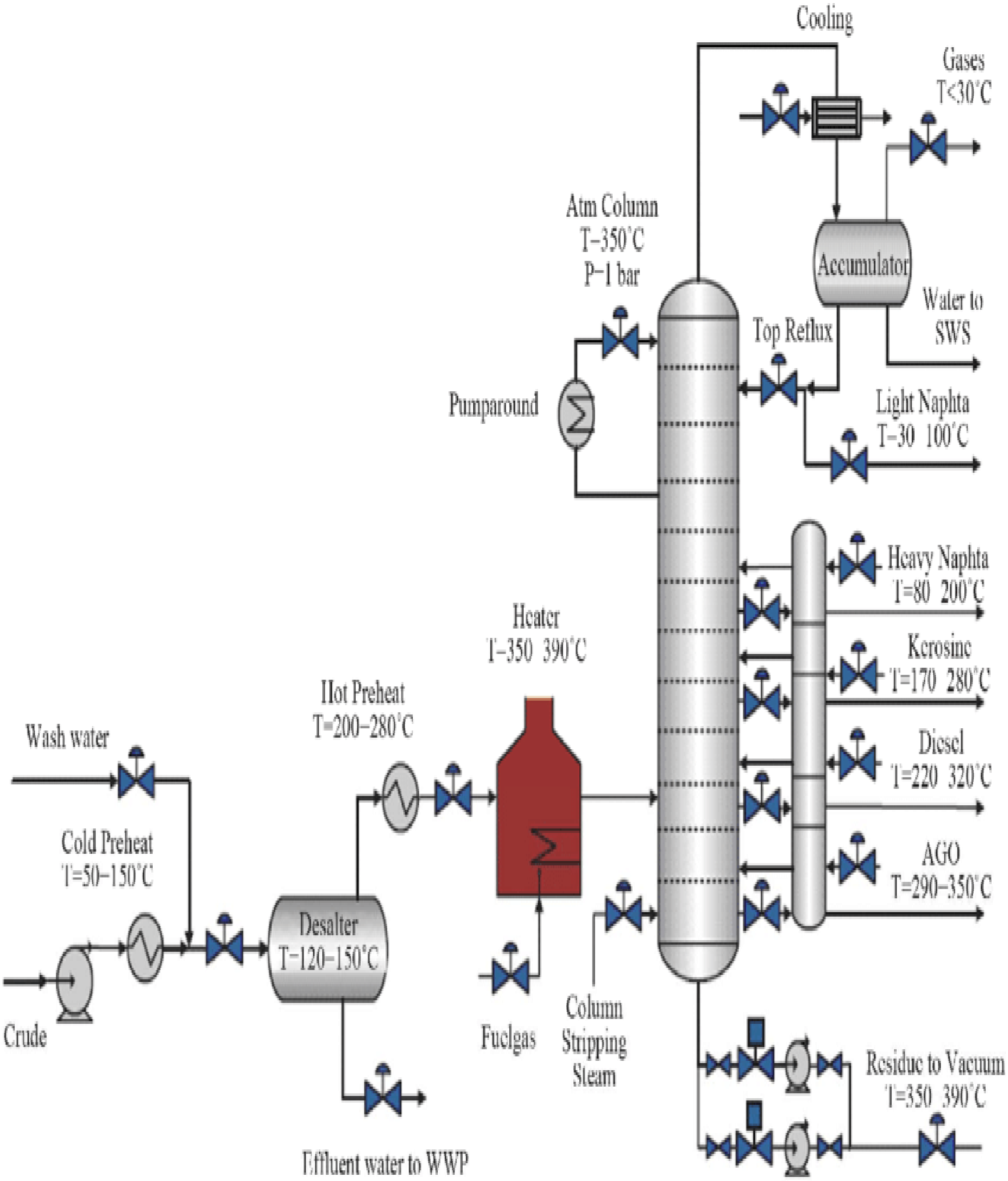

Fig (2.2): CDU process flow diagram

2.5.4. Residue Fluid Catalytic Cracking(RFCC):

Description:

Catalytic cracking breaks complex hydrocarbons into simpler molecules in order to increase the quality and the quantity of lighter, more desirable products and decrease the amount of residuals. This process rearranges the molecular structure of hydrocarbon compounds to convert heavy hydrocarbon feedstock into lighter fractions such as kerosene, gasoline, LPG, heating oil, and petrochemical feedstock.

Catalytic cracking is similar to thermal cracking except that catalysts facilitate the conversion of the heavier molecules into lighter products. Use of a catalyst (a material that assists a chemical reaction but does not take part in it) in the cracking reaction increases the yield of improved quality products under much less sever operating conditions that in thermal cracking. Typical temperatures are from 850-950 F at much lower pressures of 10-20 psi. the catalyst used in refinery cracking units are typically solid materials (zeolite, allomineium, hydro silicate, treated bentonite clay, fuller's earth bauxite and silica alumina) that come in the form of powders, beads, pellets or shaped materials called extradite.

There are three basic functions in the catalyst cracking process:

I. **Reaction**: feed stock reacts with catalyst and cracks in to different hydrocarbons
II. **Regeneration**: catalyst is reactivated by burning off coke and

III. **Fractionation**: crack hydrocarbon stream is separated into various product

The three types of catalytic cracking process are fluid catalytic cracking (FCC), moving bed catalytic cracking, thermos for catalytic cracking(TCC). The catalytic cracking process is very flexible and operating parameters can be adjusted to meet changing product demand. In addition to cracking catalytic activities include hydrogenation, dehydrogenation and isomerization. (the process of petroleum refiners. (Agrawal, 2018).

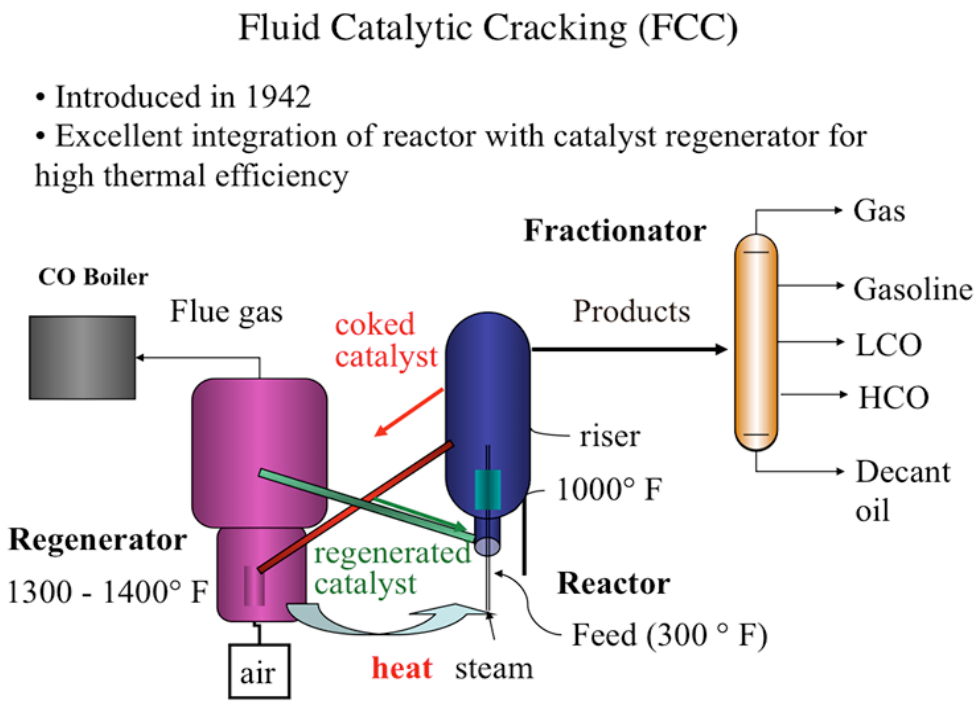

Fig (2.3): RFCC process flow diagram

2.5.5. Diesel Hydrotreating(DHT):

Hydro treating in the refinery is the term used to describe the process of removing sulfur, nitrogen and metal impurities in the feed stock (diesel or gasoline) by hydrogen in the presence of suitable catalysts.

Hydro treating is the process to catalytically stabilize petroleum products by converting olefins to paraffin's or removes objectionable from products or feed stocks by reacting them with hydrogen. Stabilization involve converting unsaturated hydrocarbons such as olefins and gum-forming unstable diolefins to paraffin's. elements removed by hydrotreating are: sulfur, nitrogen, oxygen, halides, and trace metals as nickel, vanadium, etc. when it's used to remove sulfur, it's referred to as hydro desulfurization. Further, to meet environmental, it also may be required to hydrogenate aromatic rings to reduce the aromatic content by converting it to paraffin's.

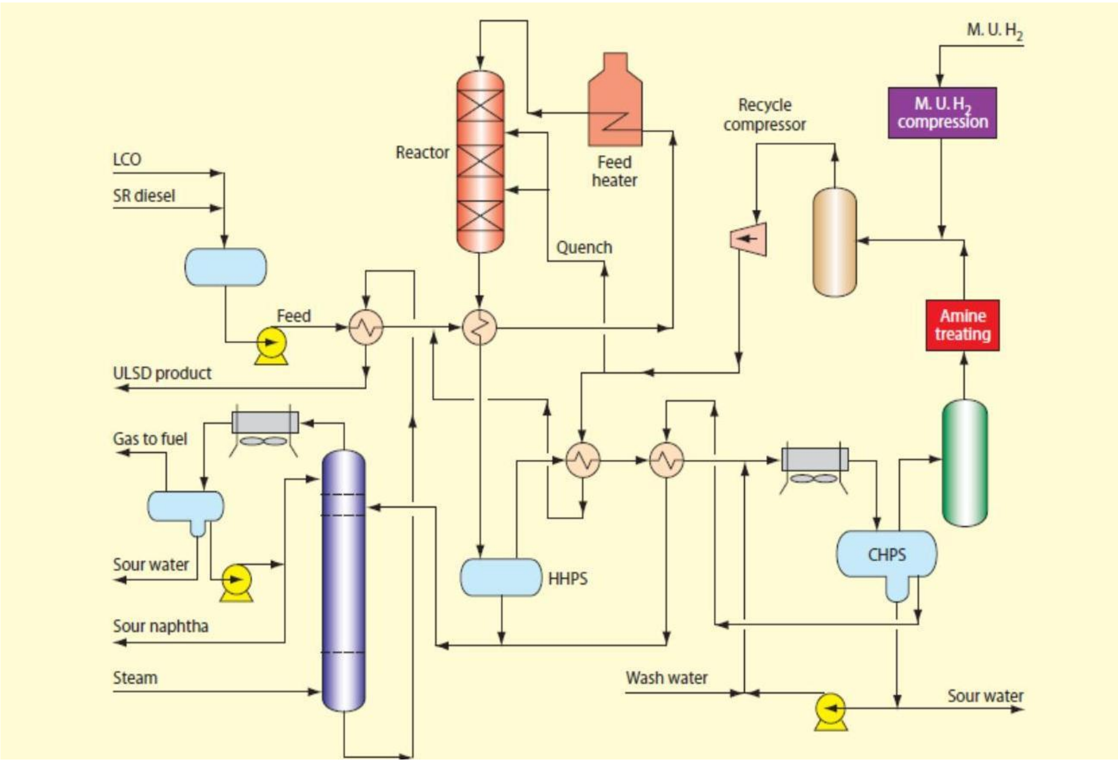

Fig (2.4): DHT process flow diagram

Process description:

The oil feed is mixed with hydrogen-rich gas either before or after it is preheated to the reactor inlet temperature. Most hydrotreating reactions are carried out below 800 °F (427 °C) to minimize cracking, and the feed is heated to 500–800 °F (260–427 °C). The oil feed combined with the hydrogen-rich gas enters the top of the fixed-bed reactor. In the presence of the metal-oxide catalyst, the hydrogen reacts with the oil to produce hydrogen sulfide, ammonia, saturated hydrocarbons and free metals. The metals remain on the surface of the catalyst, and the other products leave the reactor with the oil-hydrogen stream. The reactor effluent is cooled before separating the oil from the hydrogen-rich gas. The oil is stripped of any remaining hydrogen sulfide and light ends in a stripper. The gas may be treated to remove hydrogen sulfide and ammonia, and then recycled to the reactor. (Speight, 2006).

2.5.6. Crude Catalytic Reforming(CCR):

Catalytic reforming is the process of transforming C7-C10 hydrocarbon with low octane number to aromatics and iso-parafins which have high octane number. It is a highly endothermic thermic process requiring large amount of energy.

The catalyst reformer is one of the major units for gasoline production in refineries. It can produce 37wt % of the total gasoline pool. Other units such as fluid catalytic cracker(FCC), the methyl ter-butyl ether (MTBE)production unit, alkylation unit and isomerization unit, also contribute to this pool.

Reformer feedstock:

The feedstock to the reformer is straight run naphtha which coming from CDU. The feed is pre hydro treated to remove Sulphur, nitrogen and oxygen which can all deactivate the reforming catalyst. the hydro treated naphtha (HTN) is fractionated into light naphtha (LN), which is mainly C5-C6, and heavy naphtha (HN) which is mainly C7-C10 hydrocarbons. It’s important to remove C6 from the reformer feed because it will form which is considered carcinogenic upon combustion. Light naphtha is isomerized in the isomerization unit. Catalytic reformer is also considered to be the basic unit to produce hydrogen which can be recycled to naphtha hydrotreater and to the other units demanding hydrogen. (MOHAMED A. FAHIM, 2010).

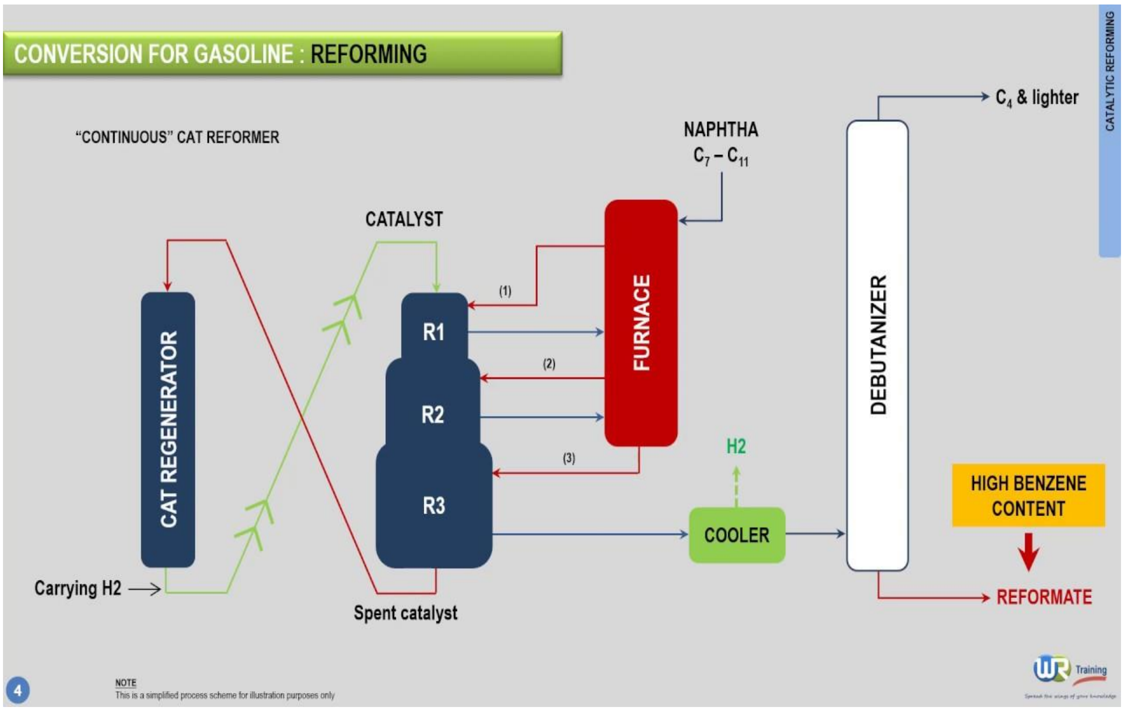

Fig (2.5): CCR process flow diagram

2.5.7. Delay Cocking Units(DCU):

Delay cock is a type of thermal cracking in which the heat required to complete the cocking reactions is supplied by furnace, while cocking itself takes place in drums operating continuously on 24h filling and 24h emptying cycles. The process minimizes residence time in the furnace, while sufficient time is allowed in the drums where cocking takes place (hence the "delayed coking") cock is rejected in the drums, thus increasing the H/C ratio in the rest of the product. However, these products are still unstable and unsaturated, and require further hydrogenation.

The feed to cocker is usually vacuum residue which is high on asphaltenes, resins, aromatics, Sulphur, and metals. The deposited coke contains must of the asphaltenes, Sulphur, and metals present in the feed, and the products are unsaturated gases (olefins) and highly aromatic liquids.

The feed to the delayed cocker can be any undesirable heavy stream containing high metal content. A common feed is vacuum residue but it can also accept fluid catalytic cracking slurry and visbreaking tar.

The products from the cocker are unsaturated gases (C1-C4), olefins (C2”-C4”) and iC4. The olefins are very desirable feed stocks to the petrochemical industry. Isobutene and olefins can be send to alkylation units, and the C3/C4 gases are send to LPG plant. The cocker is the only units in the refinery which produce cock.

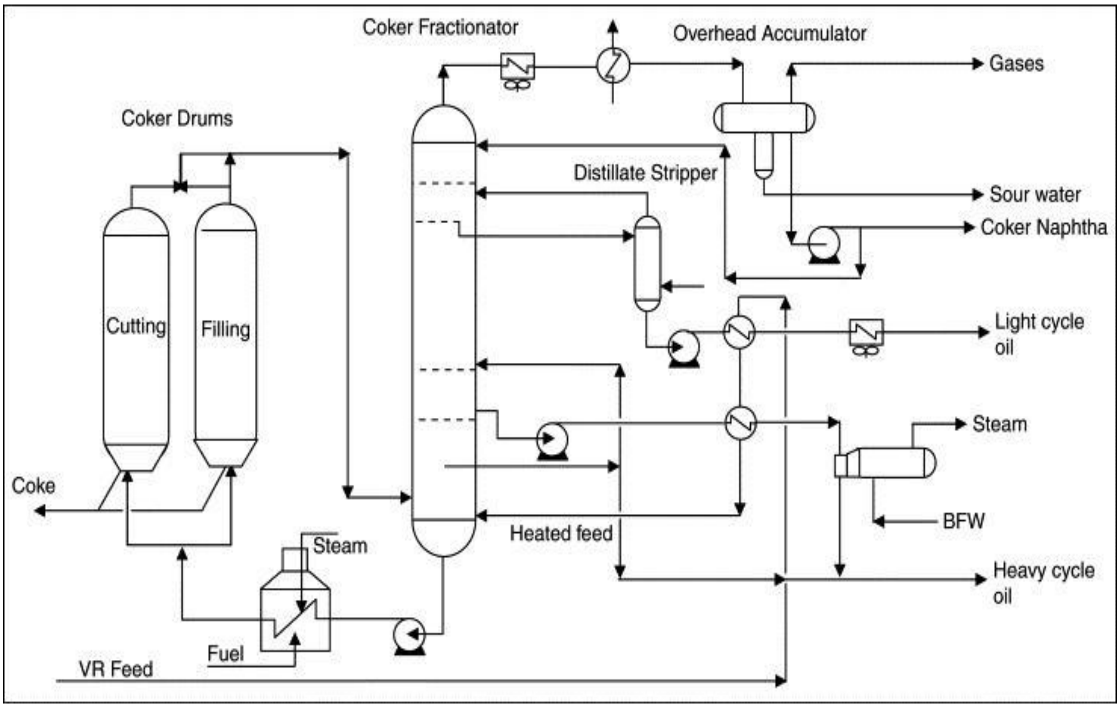

Fig (2.6): Delay cock unit process flow diagram (MOHAMED A. FAHIM, 2010)

Chapter 3

Block Diagram

3.1. Exiting Port Sudan refinery:

The existing Port Sudan Refinery was originally built and managed by Shell Oil Company and operated till late 1990 when it was shut down and then mothballed till now. The basic feedstock for the operation of the refinery was imported Arabia Arabian Light Crude Oil with the production of MO Gas, Kerosene, Diesel, LPG and Fuel Oil. The design processing capacity with Arabian Light was 25,000 BPD. The Refinery has following processing units.

Table (3.1): processing units and its capacity

SN	Processing Unit	Capacity
1.	Crude Distillation Unit	25,000 BPD
2.	Kero Minus Hydro-treating unit	10,000 BPD
3.	Plat-forming Unit	2500 BPD
4.	LPG Treating Unit	500 BPD

Introduction:

PSR Located 8 Kilometers South of Port Sudan. Construction Started Mid 1963 (Joint Venture Between Shell International and British Petroleum (B.P)).

Initial Commissioning Started October 1964.With a capacity of 2800 MT/SD

Utilities:

Two MP (Medium Pressure) Fired Steam Boilers 20t/hr,10t/hr.

- One MP Waste Heat Boiler 3 t/hr.
- One LLP Steam Generator 2.5 t/hr.
- 3*1.5 MW Total Condensing Turbo alternators.
- 1*1.4 MW Diesel Generator.
- 1*0.4 MW + 1*0.2 MW Auxiliary Diesel Generators.
- Recirculating Cooling Water (Induced Draft Tower) Circulation Rate 36,000 T/D. Makeup 700 T/D, Softened Town Water (Evaporation + Blowdown Loss).
- 2*15 T/Hr. Sea Water Distillers – Under Replacement by Reverse Osmosis.
- Two Zeolite Softeners for Cooling Water Makeup.
- Town Water and Sea Water Supply Facilities.
- Instrument Air and Tool Air Facilities.
- Service Water System

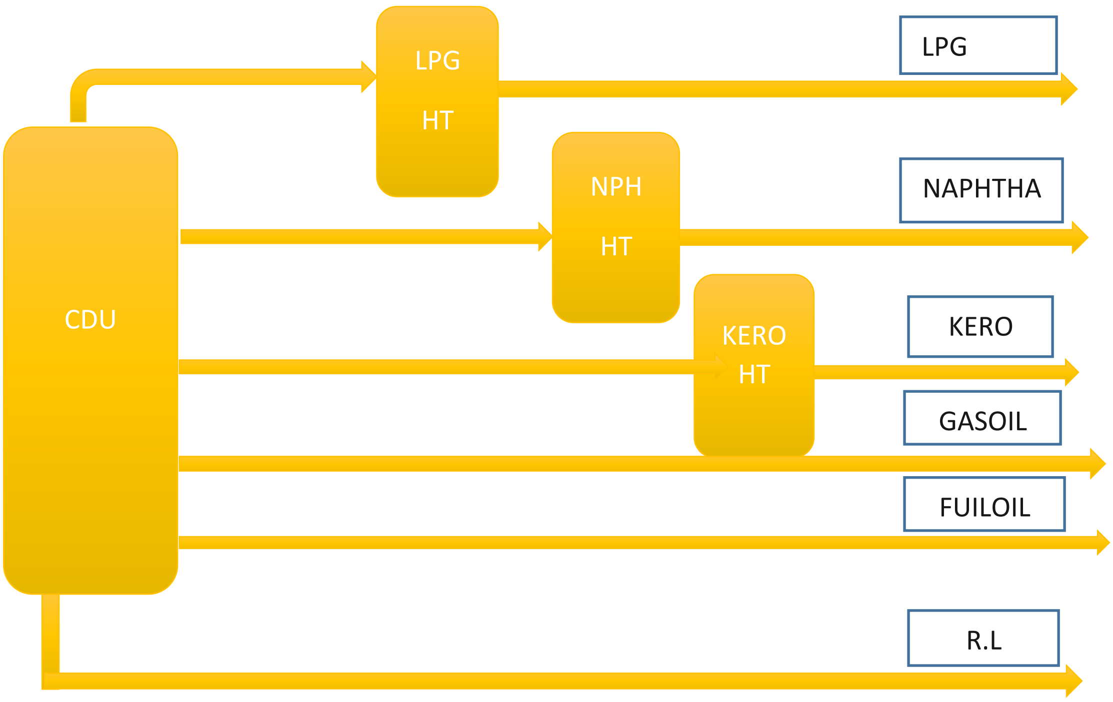

Fig (3.1): Exist PSR blog diagram

PROUCTS

Package_feed 3500 T/D

Table (3.2): Exist PSR production

PRODUCTS	T/D	Wt%
LPG	40	1.1
MOGAS	450	12.9
JET A1(DPK)	250	7.1
A.GASOIL	1120	32.0
FUEL OIL	1500	42.9
RFL	140	4.0
TOTAL	3500	100.0

3.2. Economic Analysis for Extension of Port-Sudan Refinery:

PSR Project Objectives: -

A- Economic utilization of the existing costal facilities.

B- To Maximize Gasoil Production.

C- Energy Security (Strategic Backup to KRC).

Basis of The Project:

- Feed Stock: Arabian Heavy Crude Oil
- Products: LPG, Mogas, Jet A-1, Gasoil, Fuel Oil & Bitumen
- Products Quality: Local Specifications
- Prices: Market Prices Netted Back to Port Sudan

Project to be studied:

Project’s feed: 55,000bpd (Existing-Arab H. +New – Dar)

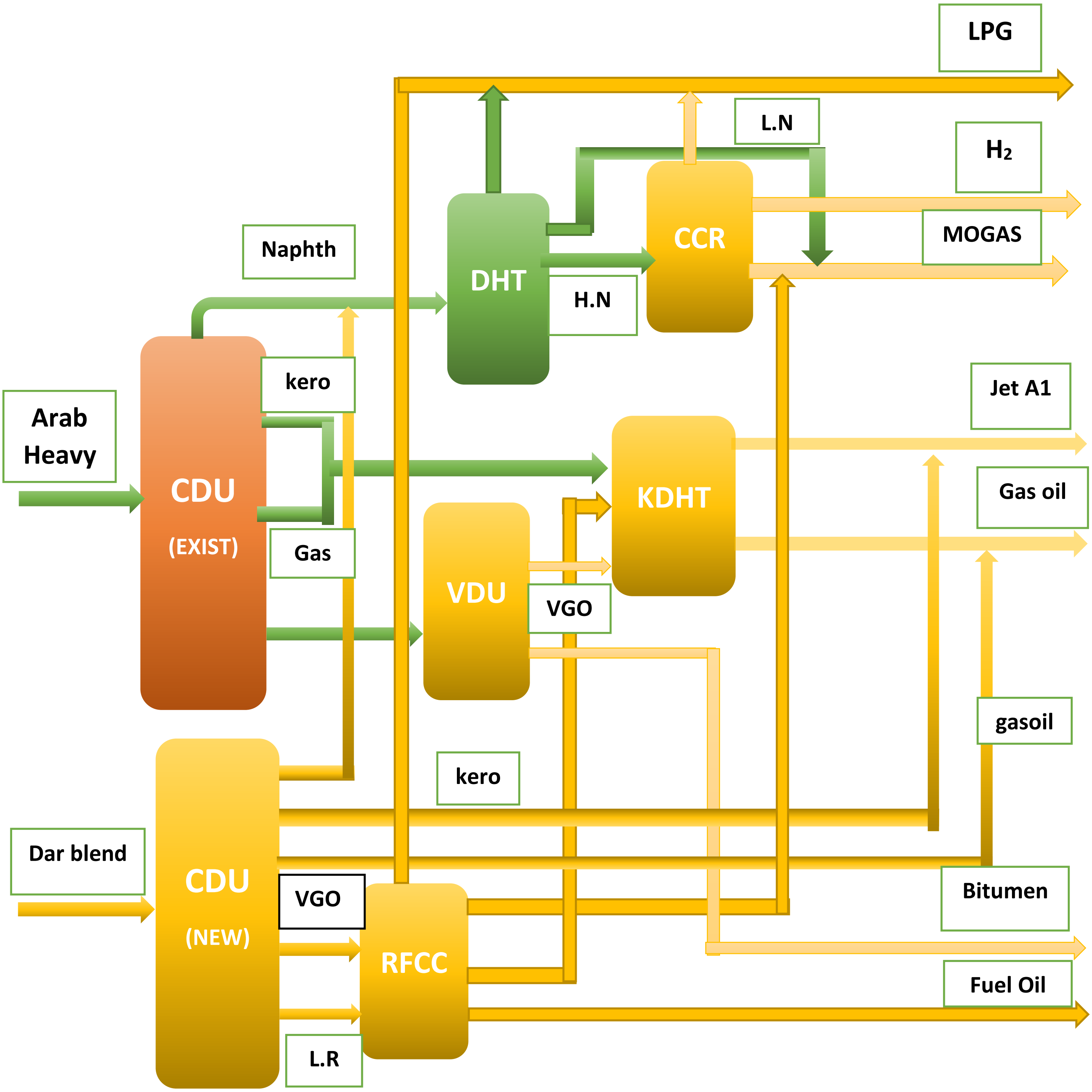

Fig (3.2): new PSR blog diagram

Chapter 4

Material Balance

4.1. Introduction:

Material balances are important first step when designing a new process or analyzing an existing one. They are almost always prerequisite to all other calculations in the solution of process engineering problems.

A petroleum refinery mass balance is required for number of purposes.

These are:

a) To understand the primary processing operations in various sub-processes and units.

b) To estimate the flow-rates of various intermediate streams using which final product flow rates can be estimated.

c) To serve as the initial data for the elementary process design of sub-processes and units.

Material balance can be applied by application of the low of conservation, which states that mass can neither be created nor destroyed. So mass entering a unit shall be equal to the mass leaving the unit.

Fig (4.1): general mass balance

A balance (or inventory) on a material in a system (a single process unit, a collection
of units, or an entire process) may be written in the following general way:

. **Input + generation - output - consumption = accumulation**

(Enter (produced (leave (consumed (buildup
Through within through within within
System) system) system) system)
system)

The general balance equation
may be simplified according to the process at hand. For steady state process the accumulation equal to zero.

Input + generation = output + consumption

For physical process, since there is no chemical reaction, the generation and
consumption terms will become zero, and the balance equation for steady-state
physical process will be simply reduced to:

Input = Output

4.2. Crude input:

The crude used in these refinery is Arab Heavy and Dar Blend

Arab heavy specification:

Table (4.1): Arab Heavy specification (Ministry of Oil and Mining)

Specification	**Crude**
Specific Gravity	0.886
API	28.2
Sulfur content w%	2.84 %
Viscosity cst	18.9 cst

4.3. Products output:

The refinery produces sex types of product which are: LPG, Mogas, Jet A1, Gas Oil, Bitumen, fuel oil.

4.4 Units Material Balance:

4.4.1. Mass Balance across the CDU:

a. CDU(Exist):

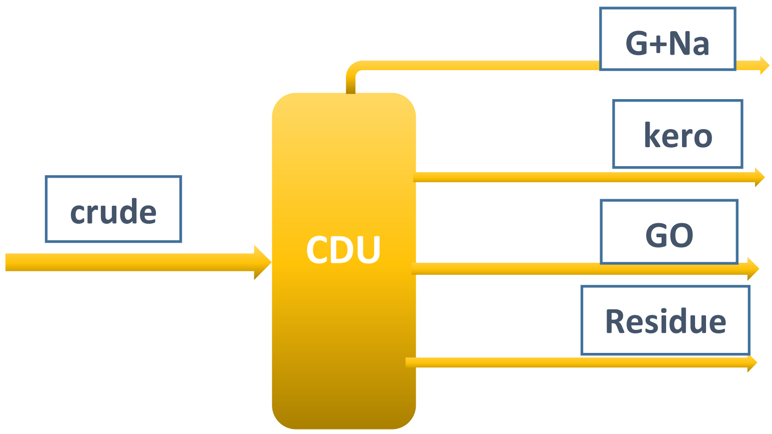

Fig (4.2): Exist CDU blog diagram

The exist CDU which work with Arab Heavy crude produce four products namely gas + naphtha (GN), kerosene (k), gas oil (GO), residue(R).

The steady volumetric balance for the CDU is defined as:

$$F_{crude} = F_{GN} + F_K + F_{GO} + F_R$$

Where F refers to the volumetric flow rates of various streams (crude, GN, K, GO, and R) balance for the CDU is defined as:

$$MF_{crude} = MF_{GN} + MF_K + MF_{GO} + MF_R$$

Where MF refers to the mass flow rates associated to the feed and product streams

The basic calculation for design units of refinery is 25000bb/d

Table (4.2) bbl/day –ton/day conversion

25000 barrel	M^3	886 Kg	Ton
Day	6.29 Barrel	M^3	1000 kg

= <u>3521.46 ton/day</u>

The specific gravity of the crude oil from table specification at temperature 15.7 ℃ is 0.886.

$$SG_{oil} = \frac{\mathcal{P}oil}{\mathcal{P}H2O}$$

The specific gravity of the crude is determined by crude assay, And the specific gravity of the product evaluated as a function of the product TBP and crude SG assay.

$$MF_{GN} = F_{GN} * SG_{GN} * \mathcal{P}_{H2O}$$

The percent of each product in the crude oil calculated by using the relationship
between temperature range (I.B.P and FBP) and percent volume (V%).

The calculation is mentioned below:

Gas + Naphtha from 20 ⟶ to 167 C

V_{GO} % $= \frac{Vi+Vf}{2} * Factor\ Steam$

Kerosene from 143 ⟶ to 242 C

V_K % $= \frac{Vi+Vf}{2} * Factor\ Steam$

Gas Oil from

$V_{GO} = \frac{Vi+Vf}{2} * Factor\ Steam$

Residue from

$V_R = \frac{Vi+Vf}{2} * Factor\ Steam$

The specific gravity of the product evaluated as a function of the product TBP and crude SG assay.

The calculation of the specific gravity of all products is done by using Figure that shows the relation between percent of volume of the product (V%) and the specific density.

Table (4.3): Shows the product specific weight and TBP test for Arab Heavy crude

Products	V%	SG
Gas + Naphtha	18	0.703
Kerosene	12.5	0.787
Gas Oil	16.4	0.846
Residue	53.1	0.984

Material balance for CDU:

Table (4.4): material balance across existing CDU

Stream	**V%**	**SG**	**Flow bbl/day**	**Flow ton/day**	**Sulfur (w%)**	**Sulfur ton/day**
Gas + naphtha	18	0.703	4500	502.9	0.0208	0.1046
Kerosene	12.5	0.787	3125	390	0.19	0.741
Gas Oil	16.4	0.846	4100	551.45	1.38	7.61
Residue	53.1	0.984	13275	2076.7	4.35	90.336
Crude	100	0.886	25000	3521.46	2.84	100.009

b. CDU(NEW):

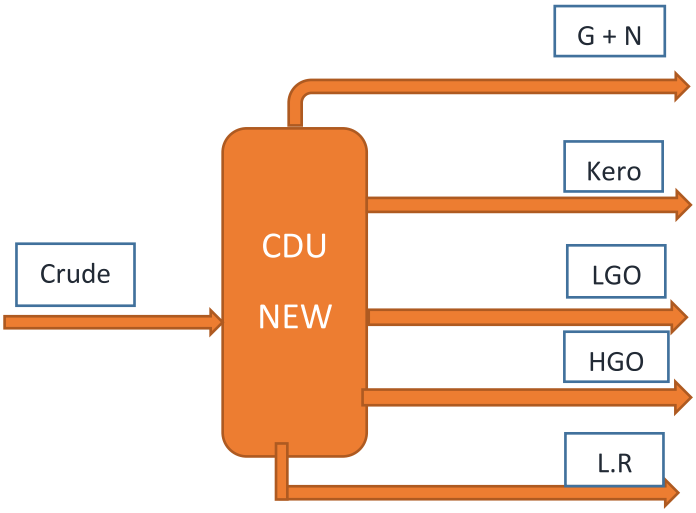

Fig (4.3): CDU blog diagram

The New CDU is working by Dar Blend crude and produce gas + naphtha (GN), Kerosene(K), L Gas Oil (LGO), H Gas Oil (HGO), and Long Residue (R).

The steady volumetric balance for the CDU is defined as**:**

$$\mathbf{F_{crude} = F_{GN} + F_{K} + F_{LGO} + F_{HGO} + F_{R}}$$

Where F refers to the volumetric flow rates of various streams (crude, GN, K, LGO, HGO, and R).

balance for the CDU is defined as:

$$\mathbf{MF_{crude} = MF_{GN} + MF_{K} + MF_{LGO} + MF_{HGO} + MF_{R}}$$

Where MF refers to the mass flow rates associated to the feed and product streams

The basic calculation for design units of refinery is 30000bbl/day.

30000 barrel	1 M^3	914 kg	1 Ton
Day	6.29 Barrel	M^3	1000 Kg

= 4359.3 Ton/day

The specific gravity of the crude oil from table specification at temperature 15.7 °C is 0.914.

$$SG_{oil} = \frac{\mathcal{P}oil}{\mathcal{P}H2O}$$

The specific gravity of the crude is determined by crude assay

$$MF_{GN} = F_{GN} * SG_{GN} * \mathcal{P}_{H2O}$$

The percent of each product in the crude oil calculated by using the relationship

between temperature range (I.B.P and FBP) and percent volume (V%).

Table (4.5): Show volume percentage(TBP) and the specific gravity of products (Ministry of oil and Mining)

Products	V%	SG
Gas + naphtha	2.21	0.719
Kerosene	4.03	0.781
Light Gas Oil	14.48	0.842
Heavy Gas Oil	13.24	0.866
Residue	19.4	0.914

Table (4.6): material balance across new CDU

Stream	V%	SG	Flow bbl/day	Flow ton/day	Sulfur (w%)	Sulfur ton/day
Gas + naphtha	2.21	0.719	663	75.786	0.0075	0.0057
Kerosene	4.03	0.781	1209	150.116	0.0083	0.0124
Light Gas Oil	14.48	0.842	4344	581.502	0.0106	0.0616
Heavy Gas Oil	13.24	0.866	3972	546.86	0.1143	0.6251
Residue	66.04	0.914	19812	2878.882	0.1721	4.9545
Total	100	0.914	30000	4770	0.3128	

4.4.2. Mass Balance Across VDU:

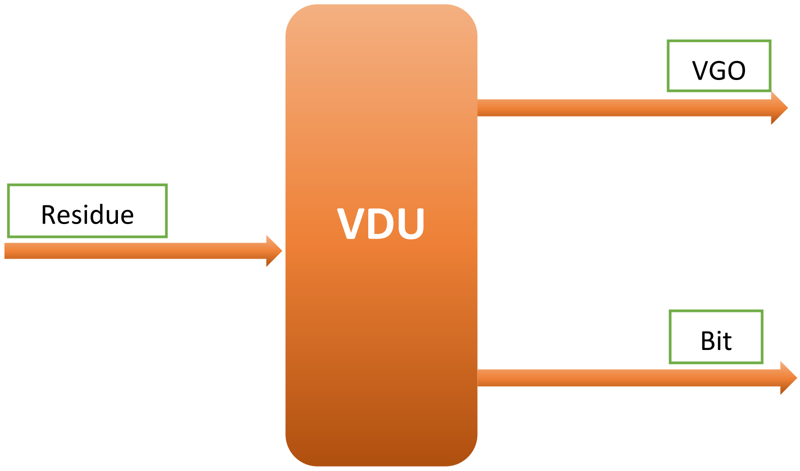

Fig (4.4): VDU blog diagram

The atmospheric residue from CDU(Exist) is directed to the VDU which provides the reduced pressure required to prevent thermal cracking when distilling the residuum. the vacuum tower is used for farther conversion of atmospheric residue and provides the catalytic cracking feed stocks (HGO) from the surplus residuum. The expected yields are VGO (HGO & LGO) and Bitumen. Mass balance expressions for the VDU are presented as follows:

$$F_R = F_{VGO} + F_{Bit}$$

$$F_R \, SG_R = F_{VGO} \, SG_{VGO} + F_{Bit} \, SG_{Bit}$$

The volumetric flow rate of the LVGO and HVGO can be obtained from their respective yields that is evaluated using the range of the cut temperatures on the crude TBP assay. The cut temperatures corresponding to these products is taken as follows:

a)LVGO:343.33-398.89C^{O}

b)HVGO:398.89-498.89C^{O}

c) Vacuum Residue: 498.89C^{o}

The specific gravity and sulfur content of LVGO and HVGO are evaluated with the TBP curve data of these products and crude SG and sulfur assay curves.

Below we illustrate the procedures for mass balance across the VDU

Table (4.7): Material balance across VDU

Yield	Volume %	Flow rate (bbl/day)
VGO	49.75	6604.31
Bitumen	50.25	6670.69
L.R	100	13275

4.4.3. Mass Balance Across RFCC:

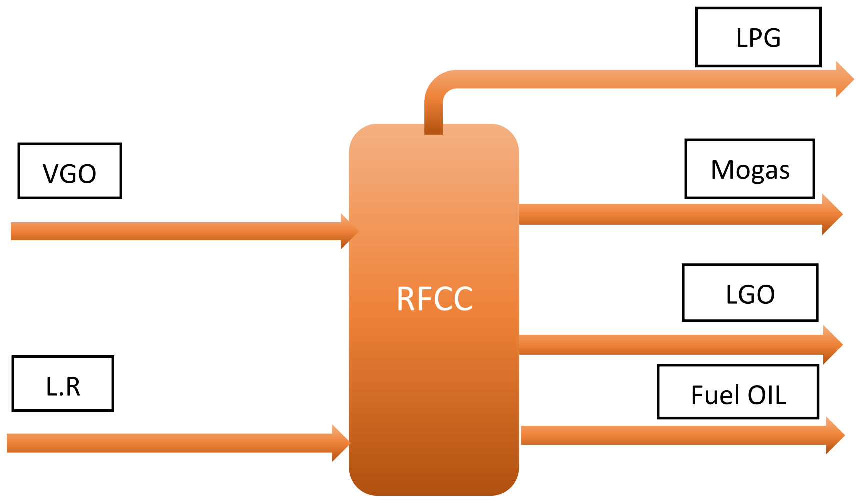

Fig (4.5): RFCC blog diagram

According to the blog diagram the RFCC unit produce four different products namely:

a. LPG.
b. Mogas.
c. LGO.
d. Fuel Oil.

For these products, conducting mass balances requires many data such as conversions, liquid volume yield (with respect to the feed), specific gravity and sulfur content.

Table (4.8): Material balance across RFCC

Yield	Volume %	Flow rate (bbl/day)
LPG	23	787.75
Mogas	48	1644
LGO	14	479.5

Fuel Oil	15	513.75
Feed (L.R+VGO)	100	3425

Mass Balance equations of Residue Fluid Catalytic Cracking(RFCC) is as following:

$$F_{VGO} + F_{L.R} = F_{LPG} + F_{Mogas} + F_{LGO} + F_{Fuil\ oil}$$

$$F_{VGO} * SG_{VGO} + F_{L.R} * SG_{L.R} = F_{LPG} * SG_{LPG} + F_{Mogas} * SG_{Mogas} + F_{LGO} * SG_{LGO} + F_{Fuel\ oil} * SG_{Fuel\ oil}$$

4.4.4. Material Balances across the Continuous Catalytic Reforming(CCR):

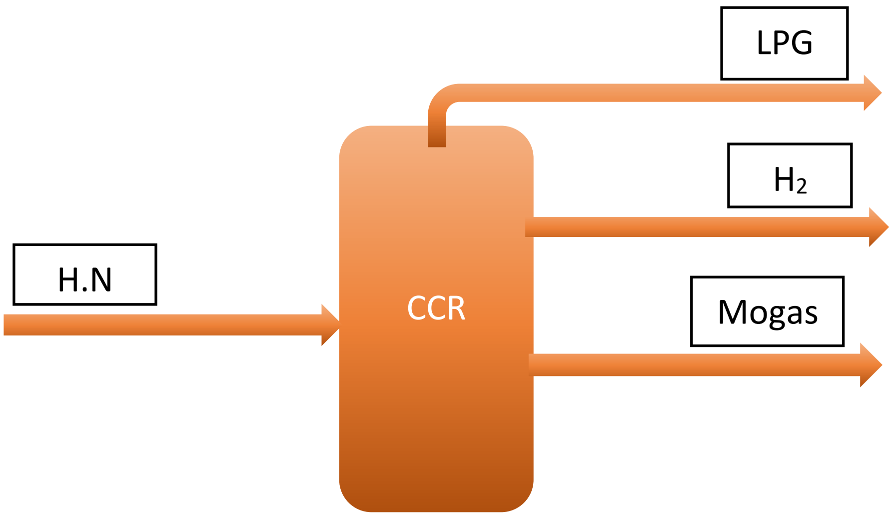

Fig (4.6): CCR blog diagram

The catalytic reformer unit is fed with the heavy naphtha generated from HDT. The properties of the reformer feed will be similar to the heavy naphtha fraction consolidated from various source units. Since catalytic reformer produces H2 along with lighter hydrocarbons along with the highly desired reformate product, it is essential to know the product flow rates as well as compositions of the lighter stream from the reformer.

The mass balance equations of CCR is expressed as following:

$$\mathbf{F_{H.N} = F_{Mogas} + F_{LPG} + F_{H2}}$$

Table (4.9): Mass balance across CCR

Yield	Volume %	Flow rate (bbl/day)
LPG	3	135
Mogas	90	4050
Hydrogen	7	315
Naphtha	100	4500

Chapter 5:

Economic evaluation

Economic evaluations are generally carried out to determine if a proposed development of Port Sudan Refinery (PSR) meets the profitability criteria.

5.1. Definitions

5.1.1. Capital Cost:

The capital cost is the cost which comprises of cost of process unites, utilities, security and environmental facilities, storage and handling facilities, civil work, building and infrastructure.

5.1.2. Operating Cost:

There are two types of operating cost:

5.1.2.1. Variable cost:

Is the cost which consist of chemicals (corrosion prevention, oxygenate for octane number improvement, cetane number improvers, or any other additives), catalysts, fuel cost.

5.1.2.2. Fixed cost:

Is consist of the following:

Manpower (is the number of technical and administrative staff needed to operate the refinery). Maintenance cost which depends on design of units, quality and reliability of the equipment, and operation practice. Overhead cost which consist of administrative cost, taxes, insurance, quality control cost, and community service.

5.1.3. Initial Investment:

Is the amount required to start project which equals capital expenditure + working capital + taxes**.**

5.1.4. Internal Rate of Return:

The internal rate of return is the discount rate that makes the net present value of all cash flows equal to zero in discounted cash flow analysis. IRR is ideal for analyzing capital budgeting projects to understand and compare potential rate of annual return over time.

5.1.5. Pay Back Period:

Pay Back Period is the time required to recover (Pay Back) the initial cost. So the shorter payback period means more success of the project.

5.1.6. Net Present Value

Is the difference between the present value of cash inflows and the present value of cash outflows over period of time. Net present value is used in capital budgeting and investment planning to Annalise the profitability of the project.

5.1.7. Gross Margin:

Is the difference between the value of refined products and cost of the crude oil delivered to the refinery.

Gross margin = $\sum^{N}_{i}$ (price of product I * yield of product I) – crude price

Table (5.1): Economics 2016 Prices (Ministry of oil and mining)

Total capex (MM US$)	1054
Working capital (MM US$)	54
Initial investment (MM US$)	1098

After scaling by using inflation equation:

$$E_{2020} = E_{2016} * (1.05)^n$$

n=4 years

assumes that the refinery will operate as a private company and its revenues come from the processing fees according to the assumptions below.

Assumptions:

1. Daily intake crude oil 55000 bbl/d.
2. Feed stoke Dar crude and heavy Arab crude.
3. Processing days 330 day per year.
4. Estimated life time 15 years.
5. Exchange rate 5.7 per dollar.
6. Discount rate 10%.
7. Business profit tax 15%.
8. Zakat 2.5%.
9. Annual fuel cost (4% of refine crude) MM$26.34.
10. Annual Excise Duties (as in KRC) MM$21.09.

Table (5.2): Economic Evaluation for 2020

Capital cost (MM US$)	1.28114
Working cost (MM US$)	0.06564
Initial cost (MM US$)	1.33463
IRR	20 %
Payback Period (years)	12

Chapter 6

Conclusion & Recommendations

6.1. Conclusions:

1. The shortage of the petroleum products in Sudan (LPG, Diesel, Fuel oil) has always been a major issue in energy demand, thus affecting negatively in the economic by losing hard currency to import products. So our study can assist in solving this problem.

2. This study applied Material Balance and Excel Sheet to estimate the production capacity for the units (CDU, DHT, VDU, RFCC, CCR, KDHT).

3. This study can increase LPG from 55.2% to 89.26%, Diesel from 55.7% to 86.18%, Fuel oil from 28.9% to 31.48%, to cover the local need and have surplus in Mogas 179.03%, Jet A1 135.43% and Bitumen 123.87% which can be exported to gain hard currency

4. The cost of expansion of existing PSR will returned in 12 years, with 20% IRR.

6.2. Recommendations:

1. This study focused on covering the increasing demand for petroleum products. Besides the surplus as (Mogas, jetA1 and bitumen) can be imported to gain hard currency.
2. A possible extension for Port Sudan refinery will cover this shortage by adding new units: (CDU operating with Dar blend, CCR unit, RFCC, KDH, VDU).
3. The optimum design and material balance for each unit was made to calculate the in and out flow rates. Thus, enables to predict the capacity of each unit.
4. Making the maximum benefit from Port Sudan refinery's strategic location (costal refinery) and use regional treaties as the common market for eastern and southern Africa (COMESA).
5. There are few shortages in these products demand (LPG, Gasoil, Fuel oil) which can be filled by increasing the feed stock of the Dar Blend.

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