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Refinery Configurations for Maximum Gasoline Production from Libyan Crude Oil

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Abstract

In this work, different refinery configurations are investigated for upgrading projects to increase gasoline production for local market demand. Different alternatives for the upgrading can be tackled. Either direct upgrading of the atmospheric residue, or first subject the atmospheric residue to vacuum distillation then upgrade the vacuum residue and vacuum gas oil to more valuable and lighter products. Obtained results show that, the scenario which included fluidized catalytic cracking (FCC) has shown the optimum in terms of both maximum gasoline and less capital cost compared with configuration that included the delayed coking process.

Keywords: Refinery; Gasoline; FCC; Delayed coking;Crude oil.

1. Introduction

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. In addition, small amounts of organic compounds containing sulphur, oxygen, nitrogen and metals such as vanadium, nickel, iron and copper are also present. The purpose of refining is to convert natural raw materials such as crude oil and natural gas into useful saleable product. Worldwide Crude oil refining (million bbl/cd) and number of refineries are shown in Figure 1.1.

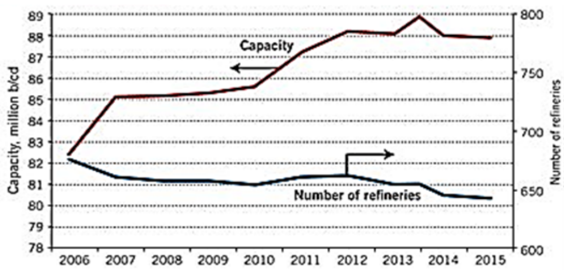

Figure 1.1: Worldwide Refining Consolidation

The overall economics or sustainability of a refinery depends on the interaction of three keys: the choice of crude oil used (crude slates), the complexity of the refining equipment (refinery configuration) and the desired type and quality of products produced (product slate). At the refinery, crude oil is treated and converted into consumer and industrial products. Three major refinery processes change crude oil into finished products: separation, conversion, and purification. Separation is performed in a series of distillation towers. The yield from a distillation tower refers to the relative percentage of each the separated components, known as product streams. Products from the distillation tower range from gases at the top to viscous liquids the bottoms. In all cases, these product streams are still considered unfinished and require further processing to become useful products. Distillation separates the crude oil into unfinished products. However, the products do

not naturally exist in crude in the same properties as the product mix that consumers demand. The biggest difference is that too little gasoline and too much heavy oil naturally occurring in crude oil. That is why conversion processes are so important. Their primary purpose is to convert low valued heavy oil into valued gasoline.
Modern refinery and petrochemical technology can transform crude oil into literally thousands of useful products, from powering our cars and heating our homes, to supply petrochemical feedstocks for producing plastics and medicines.
Refining performance is improved by consideration of the following factors:

- The ability to process crude oil into high-volume marketable products and generating high yields of those products.
- Selection of the crude feedstock from which the refinery can generate the highest product price differential or crack.
- Optimizing the selection of crude, timing of throughput, and matching the product slate to market demand.
- Tight control of both fixed and variable operating costs.

Kumari and Mateen [2] presented a study, for maximizing the refinery profit the optimization of selected refinery configurations, particularly the residue processing schemes. All selected configurations have "Zero Residue" and "Zero Fuel Oil" refinery producing Euro IV specification fuels. El-Temtamy and Gendy [3] studied seven different schemes for the upgrading of atmospheric residue produced in the Egyptian refineries. All the studied cases were identified as high diesel producing alternatives. The discounted cash flow method was used for the economic evaluation of the studied options. Sensitivity analyses have been performed on the most profitable scheme. They showed that all methods of analyses showed that the product sales price is the most influential factor for the project profitability. Carrillo and Corredor [4] visualized alternatives of producing synthetic crude from Castilla crude, compatible with the existing technologies available in the refineries, at the lowest possible cost and with the best cost/benefit ratio, using well-known technologies applied for the heavy crude oil upgrading in both Orinoco belt (Venezuela) and Alberta province (Canada).

Table 2.1: Refinery configurations

Process Units	Sc1(existing unit)	Sc2	Sc3
Atmospheric Distillation	√	√	√
Vacuum Distillation	√	√	√
Catalytic Reforming	√	√	√
Fluidized Catalytic cracking		√	
Delayed Coking			√

Gupta and Gera [5] highlighted the upgrading of residue or heavy oil using thermal and catalytic hydrocracking processes such as visbreaking, Nanoparticles; Biological processing of heavy fractions. In the present study, optimization of the selected refinery configurations, particularly the residue processing schemes, were carried out so as to maximize the gasoline refinery yield.

2. Refinery Configurations

Refineries are classified according to the number of processes available for transforming crude into petroleum products such as: gasoline, diesel, and jet fuel. In general, refineries fall into three categories. The simplest is a topping plant, which consists only of a distillation unit and probably a catalytic reformer to provide octane. The next type of refining is a cracking refinery, which takes the gas oil portion from the crude distillation unit (a stream heavier than diesel fuel, but lighter than HFO) and breaks it down further into gasoline and distillate components using catalysts, high temperature and/or pressure. The third one of refining is called the coking refinery. This refinery processes residual fuel, the heaviest material from the crude unit and thermally cracks it into lighter product in a coker or a hydrocracker. The addition of a fluid catalytic cracking unit (FCCU) or a hydrocracker significantly increases the yield of higher-value products like gasoline and diesel oil from a barrel of crude. All investigated scenarios are shown in Table 2.1. A typical of refinery configuration processes is shown in Figure 2.1.

2.1. Catalytic Reforming Process

Reforming is an oil refining operation that produces reformate, a high-octane gasoline blending

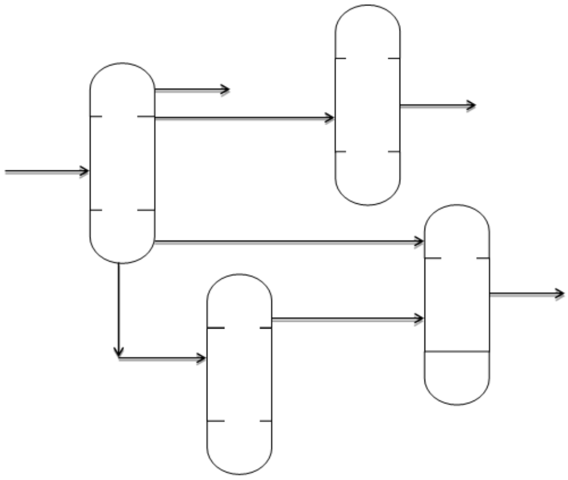

Figure 2.1: Refinery Configuration Process Scenario (Sc2)

component. The reforming process uses heavy naphtha, which is the second lightest liquid stream from an atmospheric distillation column, to produce reformate. In the reforming complex, a feed pre-treater removes sulfur from the reformer feed using hydrogen and a desulfurization catalyst. The pre-treated feed then is sent to the reformer reactor where a catalyst and heat are used to restructure or reform low octane naphtha into higher octane hydrocarbon molecules that are valuable gasoline blending components (see Figure 2.2). The process turns straight-chain hydrocarbons into cyclic compounds while removing hydrogen. The cyclic compounds have a much higher octane rating than the straight-chain feedstock and enable economic production of high-octane lead-free gasoline.

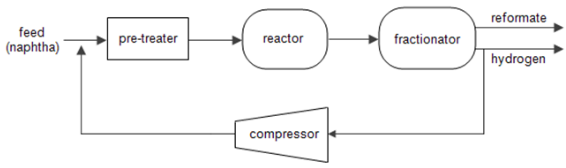

Figure 2.2: Typical reforming process diagram (Source: U.S. Energy Information Administration)

3. Refinery Economics

Petroleum projects as investment opportunities require huge funds and with a long time to construct and they are associated with a series of risks and uncertainties. Therefore, the economic evaluation can be a main tool and reasonable way to find out best petroleum investment opportunities in terms of cost, revenue and risks.

3.1. Factors Affecting Refinery Costs

Refining costs greatly depend on several factors:

- Refinery complexity
- Capacity utilization or stream factor
- Refinery size
- Quality of the crude
- Location
- Environmental constraints

In the oil refining business, the cost of inputs (crude oil) and the price of outputs (refined products) are both highly volatile, influenced by global, regional, and local supply and demand changes. The parameters will be take in account are: Profitability, Return of Investment (ROI), Gross Margin, Discounted Cash Flow,
The payout time is also referred to as the cash recovery period or years to pay out. It is calculated by the following formula and is expressed to the nearest one-tenth year [7]:

$$Payouttime = (originaldepreciable\ fixedinvestment)/(AnnualCashflow) \tag{3.1}$$

4. Results and Discussion

In this work, the existing refinery configuration (Sc1, 1125 bbl/day) and two upgrading scenarios (Sc2 and Sc3) included the FCC and delayed coking processes (Table 2.1) are simulated for refining of 220,000 bbl/day of Sarir-Messla crude oil which having a gravity of 37.6 °API (sp.gr 0.8368 @ 15.6/15.6 °C), Sulphur content of 0.128 wt % and the characterization factor of crude was calculated to be 12.2. It has a pour point +15 °C and a kinematic viscosity of 7.3991 and 6.2251 CSt at 100 and 122 °F respectively. Sarir-Messla crude oil has Nickel and Vanadium content of 2.781 and 0.157 ppm respectively and conradson carbon residue (CCR) content of 3.192 wt%.

4.1. Distillation and Analysis

The distillation of the sample was carried out in two major steps as per ASTM D 2892 (15 Theoretical plate column) & ASTM D-1160 method. The atmospheric residue was further distilled to obtain distillate fractions. Distillate fractions corresponding to true boiling point up to 550+°C were collected. The yield pattern of each fraction collected is tabulated in percentage weight and percentage volume and has shown in Table 4.1.

4.2. Catalytic Reforming Material Balance

In this case, the feed to the catalytic reformer consists of the heavy straight-run (HSR) gasoline (70 to 175°C) from the atmospheric distillation unit (10364.5 lb/day). Yield correlations for the reformer were developed by Maples [6]. The yields for the all products calculated based on the C5+ Vol. % correlation (Equation 5) which is depended on assumption of RONR = 94 and N + 2A = 44.7% respectively.

$$C5 + Vol. = 142.7914 - .077033 * RON_R + 0.219122 * (N + 2A)_F \tag{4.1}$$

Where RONR is research octane number of reformate; C5 Vol% is volume percent of reformate yield; N is Napthenes Vol. % and A is Aromatics vol. % (subscript F mean in the feed). The material balance for the reformer specific for gasoline yield (Sc2) is shown in Figure 4. The total gasoline yield for each scenario can be summarized in Table 4.2.

Table 4.2: Product Yield (%) for each Configuration

Product yield %	Sc1	Sc2	Sc3
Gasoline yield	14%	40%	17%

It can be seen from Table 4.2 that, scenario 2 (included FCC unit) converted wide range of feedstock from atmospheric and vacuum distillation units to produce more gasoline yield compared with scenario 3 which has the delayed coking process. Furthermore in the existing refinery configuration the gasoline yield was found 14 %.

4.3. Economic Evaluation for the Proposed Scenarios

The profitability of an industrial opportunity is a function ofmajor economic variables such as product selling price, raw materials prices, capital investment, energy prices and so on. The existing

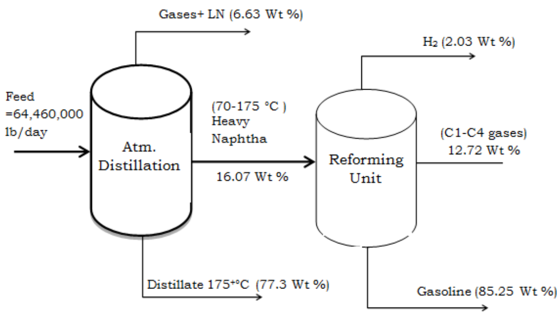

Figure 4.1: Gasoline yield Reforming Unit Material Balance (Sc2& Sc3)

refinery configuration and two scenarios schemes under consideration are evaluated using the discounting cash flow method. Feed and product prices for all units are shown in Table 4.5. Total capital cost ($) for each scenario can be summarized in Table 4.3 while the details percentage (%) parameters of total fixed cost for both FCC and delayed coking unit was estimated based on total capital cost and presented in Table 4.4 . Cumulative cash flow diagram for both scenario 2 and 3 are shown in Figure 4.2 and 4.3.
It can be seen from Table 4.5 that, 13 % increasing in total cash in Sc2 while 27.3 % increased for Sc3 (less yield gasoline produced) compared with the total capital cash in existing refinery process (Sc1).

Table 4.4: Total fixed cost details for both FCC and delayed coking units

Parameter	% (from Capital cost)
Depreciation	5%
Interest	3.5%
Process unites maintenance	5%
Off – sites maintenance	2.5%
General plant overhead	2.0%
Taxes and insurance	2.5%

It can be seen from Figure 5 that the payout time for Sc2 was found between 3-4 years while in Figure 6 Sc3 (included delayed coking) was found between 4-5 years. That means Sc 2 better than Sc3 in terms of cash recovery.

Table 4.1: Summary of product cut points and yields

Cut Point °C	Product	Yield on Crude (Wt. %)	Yield on Crude (Vol. %)
	Gases& LPG	1.03	1.55
C5-70	Light Naphtha	5.6	7.18
70-175	Heavy Naphtha	16.07	17.94
175-235	Kerosene	9.31	9.82
235-350	Atm. Gas Oil	19.85	19.97
350-550	Vac. Gas Oil	31.18	29.37
550+	Vac. Residue	16.95	14.33

Table 4.3: Total Capital cost for each scenario

Scenario	Total Capital Cost ($)
Sc1	3,081,737,888
Sc2	3,491,661,619
Sc3	3,924,552,788

Table 4.5: Prices of crude oil and products

Product	Price ($/ton)
LPG	444
Light Naphtha (atm)	504
Heavy Naphtha (atm)	510
Kerosene (atm)	529
Gasoil (Atm + V + FCC)	500
Gasoline (FCC)	546
C2& Lighter	100
Propane (C3)	345
Propylene (C3")	345
Butylene (C4")	277
H2 (lb/day)	400
Gas C4 (lb/day)	277
Coke	334
Crude oil price ($/bbl)	45

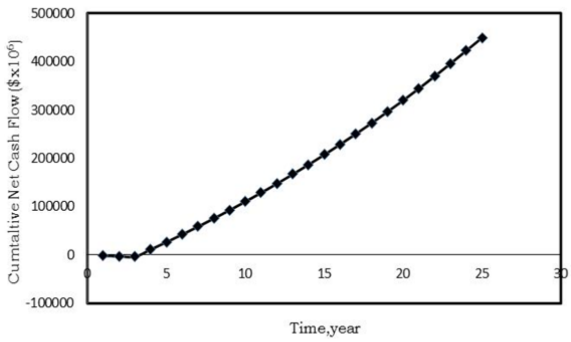

Figure 4.2: Cumulative Cash for diagram for Sc2

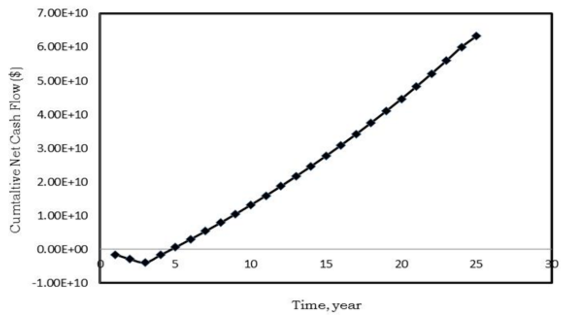

Figure 4.3: Cumulative Cash for diagram for Sc3

5. Conclusion

The purpose of refining is to convert natural raw materials such as crude oil into useful saleable product. A Comparison between the existing and proposed upgrading refinery processes included FCC or Delayed coking units in terms of techno-economic feasibility study is the main outcome of this work. Obtained results show that, the scenario which included the FCC unit has shown the best in terms of both gasoline production improved by 28% and the capital cost decreased by 12% compared with that included the delayed coking process. Generally, each refinery's configuration is determined primarily by the refinery's location, preferred crude oil slate, market requirements, and quality specifications for refined products.

6. Acknowledgment

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