Open Journal of Modelling and Simulation, 2022, 10, 340-348
https://www.scirp.org/journal/ojmsi
ISSN Online: 2327-4026
ISSN Print: 2327-4018

30,000 bpd Capacity Modified Modular Refinery Operations in Nigeria

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How to cite this paper: Michael, A.O. (2022) 30,000 bpd Capacity Modified Modular Refinery Operations in Nigeria. *Open Journal of Modelling and Simulation*, **10**, 340-348.
https://doi.org/10.4236/ojmsi.2022.104020

Received: May 23, 2022
Accepted: October 10, 2022
Published: October 13, 2022

Abstract

The study investigated and classified twenty Nigerian crude oil types based on their products recovery volume at true boiling point temperature of 370˚C using crude oil assay analysis data into Group A (crude oil with recovery volume above 80%), Group B (crude oil with recovery volume between 70% and 79%) and Group C (crude oil with recovery volume below 70%) respectively. Thus, twenty Nigerian crude oil types were simulated in a modified modular refinery (modified topping plant) of 30,000 bpd capacity and twenty-nine (29) column trays number using Aspen Hysys software. Furthermore, the residues from the conventional modular refinery were processed as feedstock or precursor into the hydrocracker reactor attached to the stripping section of the modified modular refinery to yield more valuable products of liquefied petroleum gas, naphtha, diesel and bottom (residue). The simulation results of the modified modular refinery were compared with conventional modular refinery in terms of their residual yield percentage as Nigerian Brass 2012 of API 40.62, recovery volume 88.78%, yielded residue of 11.22% and 1.29% for conventional modular and modified modular refineries respectively while Okoro 2012 of least API 23.54, recovery volume 57.84%, yielded residue of 42.16% and 4.92% for conventional modular and modified modular refineries respectively. Thus, the residual or bottom product issue associated with operational process of conventional modular refinery operations in Nigeria due to inefficient or non-operational conventional major refinery in Nigeria has been resolved to minimum or least amount with the operational process of modified modular refinery operations in Nigeria.

Keywords

Modified Modular Refinery, Hydrocracker, Topping Plant Residue, Simulation, Aspen Hysys

1. Introduction

Crude oil refining involves subjecting the feedstock to a series of physical and chemical processes as a result of which different products are generated. The amount of reserve from the petroleum reservoir, together with oil and gas prices, operating costs and taxes controls the cash flow of the industry [1]. Petroleum refining processes are chemical engineering processes and other facilities used in crude oil refineries (also referred to as oil refineries) to transform crude oil into useful products such as liquefied petroleum gas, gasoline, kerosene, jet fuel, diesel oil and fuel oils [2]. Crude oil refineries are very large industrial complexes that involve many different processing units 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 considerations [3]. In many ways, oil refineries technology is similar to a chemical plant and crude oil feedstock is processed in oil production plant before refining. There is usually an oil depot (tank farm) at or near an oil refinery for the storage of incoming crude oil feedstock as well as bulk liquid products, and oil refinery is considered an essential part of the downstream sector of the petroleum industry [4]. Raw or unprocessed crude oil is not generally useful in industrial applications, although light, sweet crude oil (low viscosity, low sulphur) has been used directly as a burner fuel to produce steam for the propulsion of seagoing vessels [5]. The lighter elements, however, form explosive vapours in the fuel tanks and are therefore hazardous, especially in warships. Thus, the different hydrocarbon molecules in crude oil are separated in a refinery operation into components that can be used as fuels, lubricants, and as feedstocks in petrochemical processes that manufacture products such as plastics, detergents, solvents, elastomers and fibers (nylon and polyesters) [6].

Oil refineries are large-scale plants, processing about a hundred thousand to several hundred thousand barrels of crude oil per day. Due to this high capacity, many of the units operate continuously as opposed to processing in batches, at steady state or nearly steady state for months to years. The high capacity also makes process optimization and advanced process control very desirable [7]. Once crude oil is extracted from the ground, it is transported and refined into petroleum products that have different values. These products are then transported to end-use consumers or retailers. The overall well-to-consumer supply chain for petroleum products is often described as being segmented into three components [8].

1) *Upstream Activities*: This involves exploring for crude oil deposits and the production of crude oil. Examples of firms that would belong in the upstream segment of the industry include companies that own rights to drill for oil such as ExxonMobil and companies that provide support services to the drilling segment of the industry such as Halliburton [9].

2) *Midstream Activities*: This involves the distribution of crude oil to refiners,

the refining of crude oil into saleable products and the distribution of products to wholesalers and retailers. Examples of firms that would belong in the midstream segment of the industry include companies that transport oil by pipeline, truck or barge such as Oando Plc and companies that refine crude oil such as the Nigerian National Petroleum Corporation [9].

3) *Downstream Activities*: This involves the retail sale of petroleum products. Gasoline stations commonly referred as filling or petrol stations in Nigeria are perhaps the most visible downstream companies, but companies that deliver heating oil or propane would also fall into this category [9].

Crude oil is essentially a mixture of many different hydrocarbons, all of varying compositions and complexities. In order to separate the crude oil into different components that make up the raw natural resource, crude oil must be refined (refinery process) so that components can be removed according to their temperature difference (Boiling points) [10]. Thus, the Nigeria government owns and operates four major refineries through the Nigerian National Petroleum Corporation (NNPC) namely, old and new Port-Harcourt Refining Company (OPHRC and NPHRC), Kaduna Refining and Petrochemical Company Limited (KRPC) and Warri Refining and Petrochemical Company Limited (WRPC). Despite these refineries, 80% of petroleum products consumed in Nigeria are based on importation as the refineries operate less than 20% to 25% of its original capacities [9] [11] [12]. Therefore, the dependency on importation of petroleum products in Africa's largest crude oil producer, Nigeria has led to incessant and continual scarcity of petroleum products. In addition, illegal refineries that feed on stolen crude oil abound in Nigeria with its associated operational and production hazards such as environmental pollution, crude oil theft, fire safety risk and poor quality petroleum products etc [13]. To curb the incessant and continual scarcity of petroleum products, environmental hazard associated with illegal (local) refineries, and reducing to minimal the importation of petroleum products, the existing refineries must be revamped and operated at full capacity, while new refineries are built by partnering with private sector thereby leading to deregulation of the sector [14]. Since construction of major refineries are capital intensive and time consuming, modular refineries have been licensed as a panacea to scarcity of petroleum products to meet local demands in Nigeria, thereby enhancing the availability of good quality products by eliminating illegal refineries and its associated environmental hazards.

A modular refinery can be built and operational within fourteen months of contract execution, thereby providing valuable fuels for host communities for vehicles, power generation, water treatment, and employment chances [10] The components of modular refinery include tankage, a distillation unit, facilities for gas recovery, and light hydrocarbons, and utility systems such as steam, power, and water-treatment plants. Topping refineries yield large amounts of unprocessed product (residue) and local markets determines its installation. The modular refinery process gives high quality control level, effective application of space and pre-delivery testing for efficient process functionality. Its available capacities ranges between 1000 and 30,000 barrels per day (bpd) [15] Topping refineries are hastily becoming a viable, flexible and cost effective scheme for petroleum producers especially where there is quick requirement to meet local need of crude oil products with relatively low investment cost, speed and construction period are some of the major advantages of a modular refinery [16] However, conventional modular refinery (topping plant) have been reported with associated issue of bottom product (residue) as my researches are silent with this stripping section residue or product [10] [12] [17] [18] [19] [20]. Therefore, pipeline networks and tankers are proposed or used in developed countries for transporting topping plant stripping section residue to conventional major refinery for further processing into more valuable end products. However, these are not obtainable in Nigeria due to the topography and inefficient operational condition of the conventional major refineries. Hence, this research study focused on improving valuable petroleum products yield from conventional modular refinery operations in Nigeria through the processing of the stripping section product (residue) of the conventional modular refinery as feedstock to hydrocracker reactor attached to the stripping section of the conventional modular (topping plant) refinery. In addition, the hydrocracker reactor is a catalytic hydrogenation process that applied nickel catalyst in converting atmospheric residue to more valuable desired products. The hydrocracking operation is enhanced as the required hydrogen gas is produced via steam-methane process since methane is the first product from the conventional or modified modular refinery. Thus, the modified modular refinery yielded more valuable petroleum finished products such as liquefied petroleum gas (which are required for domestic and heating purposes in Nigeria), naphtha (a useful precursor for petrochemical industry) and diesel (highly needed for automobile vehicle and also source of electricity supply to homes and industries due to low availability of electric power supply in Nigeria) in addition to the initial products from conventional modular refinery operations in Nigeria.

2. Materials and Method

The materials applied in this research study include twenty (20) different types of Nigerian crude oil, API values, modified modular refinery, residue, Aspen Hysys Version 10 etc. Therefore, the following procedures are applied in performing this research study.

2.1. Crude Oil Classification

Twenty (20) Nigeria crude oil types were classified using Aspen Hysys software based on crude oil assay analysis and products recovery volume percentage at 370˚C and the results shown in **Tables 1-3** respectively.

2.2. Modified Modular Refinery Process

Twenty-Nine (29) column trays number were applied in a modified modular refinery in which hydrocracker was attached to its stripping section as shown.

Table 1. Group A nigerian crude oil with over 80% recovery volume.

Crude Oil Type	Recovery Volume (%)	Residue (%)
Nigerian Brass 2012	88.78	11.22
Brass River 2011	88.65	11.35
Oso Condensate 2016	88.17	11.83
Agbami 2012	87.91	12.09
Erha 2012	83.66	16.34
Akpo 2014	83.41	16.59
Akpo Blend 2011	82.84	17.16
Forcados Blend 2014	81.49	18.51

Table 2. Group B nigerian crude with recovery volume between 70% and 79%.

Crude Oil Types	Recovery Volume (%)	Residue (%)
Nigerian Brass 2015	76.25	23.75
Okwori 2011	75.62	24.38
Amenam Blend 2011	74.56	25.44
Bonny Light 2011	73.19	26.81
Qua Iboe 2012	72.55	27.45
Okwuibome 2014	72.04	27.96

Table 3. Group C nigerian crude oil with recovery volume below 70%.

Crude Oil Type	Recovery Volume (%)	Residue
Nigerian Forcados 2012	69.70	30.30
Bonga 2012	68.53	31.47
Bonga 2014	67.55	32.45
Usan 2013	66.34	33.66
Usan 2015	63.81	36.19
Okoro 2012	57.84	42.16

Hence, the twenty (20) crude oil types were simulated in a modified modular refinery at operating temperature of 370˚C to yield product components as off gas, naphtha, kerosene, diesel, atmospheric gas oil and residue. In optimizing or enhancing production from conventional modular refinery, the residue was further processed as feedstock to hydrocracker reactor of the modified modular refinery in a catalytic hydrogenation process. Thus, the feedstock is processed in the hydrocracker reactor in the presence of nickel supported catalyst at operating conditions of 380˚C and 183 bar respectively, and hydrogen gas is produced and introduced into the hydrocracker reactor via steam-methane reforming process. The steam-methane reforming process is applied in this study for the hydrogen gas production as methane, which is the first light product of

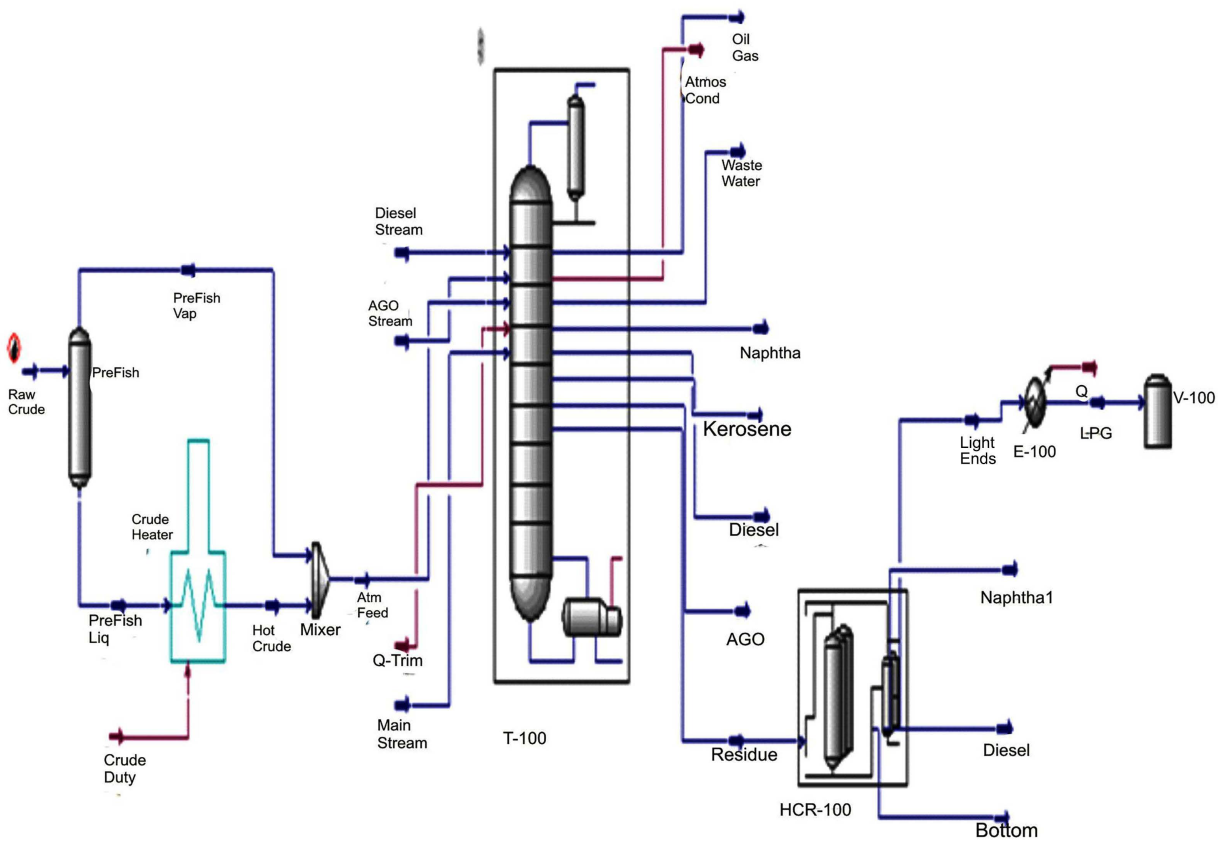

Figure 1. 30,000 BPD capacity modified modular refinery.

both conventional and modified modular refinery is the main feedstock or precursor for the process. Hence, more valuable products produced via the hydrocracker process are liquefied petroleum gas (LPG), which is cooled and stored at temperature below −42˚C (−43.6˚F), naphtha, diesel and bottom. Thus, the simulation processes were carried out for crude oil on the basis of 30,000 barrel per day (902.1Kgmol/hr) (**Figure 1**).

3. Result and Discussion

The results of this research study are discussed thus.

3.1. Crude Oil Classification

The results of the crude oil classification on twenty (20) Nigerian crude oil types using Aspen Hysys comprises of the crude oil assay results and their products recovery volume percent at true boiling point of 370˚C. Thus, the twenty (20) Nigerian crude oil types were classified into three groups namely: Group A, Group B and Group C as shown in **Tables 1-3** respectively. Therefore, Group A Nigerian crude oil types yielded high recovery volume of eighty percent (80%) and above and relatively low sulphur contents. Also, Nigerian crude oil types with recovery volume percent between 70 and 79 are categorised as Group B as shown in Table 2, while Nigerian crude oil type with recovery volume less than seventy (70%) are categorized as Group C as posited in Table 3

3.2. Modified Modular Refinery Simulation

The simulation process results of the twenty (20) Nigerian crude oil types in a modified modular refinery were compared with the simulation results of conventional modular refinery as presented by Adeloye, 2022 as highlighted in Table 4. Thus, Table 4 showed the residual percentages of the twenty crude oil types from conventional modular refinery and modified modular refinery simulation process respectively. It can be deduced that there is huge reduction in residual percentages of individual crude oil type when subjected to conventional and modified modular refineries respectively.

Hence, Okoro 2012 with the least API value among the twenty crude oil types yielded residual percent of 42.16 and 4.92 in conventional and modified modular refinery respectively

Table 4. Residual product percent of modular and modified modular refinery.

Crude Oil Type	Residue (%)	
	Modular Refinery	Modified Modular Rrefinery
Nigerian Brass 2012	11.22	1.29
Brass River 2011	11.35	1.30
Oso Condensate 2016	11.83	1.27
Agbami 2012	12.09	1.39
Erha 2012	16.34	1.85
Akpo 2014	16.59	1.77
Akpo Blend 2011	17.16	1.84
Forcados Blend 2014	18.51	2.15
Nigerian Brass 2015	23.75	2.71
Okwori 2011	24.38	2.62
Amenam Blend 2011	25.44	2.54
Bonny Light 2011	26.81	3.08
Qua Iboe 2012	27.45	3.14
Okwuibome 2014	27.96	3.22
Nigerian Forcados	30.30	3.54
Bonga 2012	31.47	3.66
Bonga 2014	32.45	3.78
Usan 2013	33.66	3.95
Usan 2015	36.19	4.22
Okoro 2012	42.16	4.92

4. Conclusion

Twenty (20) Nigerian crude oil types were analysed and classified for modified modular refinery operations as panacea to resolve the residue or bottom issue associated with conventional modular refinery in Nigeria. The resulting residues of these crude oil types were processed as feedstock in a hydrocracker reactor attached to the conventional modular refinery stripping section to yield more valuable products such as liquefied petroleum gas, naphtha, diesel and bottom. Thus, the modified modular refinery yielded a very low residual percentage volume in comparison to the conventional modular refinery, thereby resolving the residue or bottom product issue associated with conventional modular refinery operations in Nigeria due to inefficient operational level of conventional major refinery in Nigeria. Thus, the study recommends the naphtha product as precursor or feedstock for petrochemical operation while the bottom product of the hydrocracker reactor can be utilized as feedstock for further refining operational process for recovery of more useful and valuable products.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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