Process Simulation and Optimization of Crude Oil Stabilization Scheme Using Aspen-HYSYS Software

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Abstract— In this time of energy crises, low production rate against the increasing demand of oil and gas production regularly hampers both domestic and industrial operations. In addition, safety hazards arising from explosion and increase in the cost of production due to pumping cavitation has pose a great challenge on offshore Floating Production Storage and Off-loading (FPSO) terminals. In view of the above, the design of a computer base model for the simulation and optimization of crude oil stabilization scheme is highly desirable. Aspen HYSYS software (version 8.4) was used for the simulation and optimization processes and the fluid package employed was Peng-Robinson. Operational data used for the simulation was obtain ed from the aforementioned terminal. The model was based on gas product and liquid product flows. The simulation was performed to optimize the stabilization unit by manipulating various process variables, which was subject to a Reid vapor pressure (RVP) of gasoline as the constraint. The process flow diagram of the system was successfully developed. Furthermore, the optimizer tool of Aspen HYSYS was used to obtain the optimum operating conditions of the process and Sequential Quadratic Programming (SQP) algorithm was employed. The results of the base and optimized cases were compared and analyzed. Economic consideration showed an improvement of 31.11% (i.e. ₦ 42 billion) in net profit for the optimized case over the base case at optimal operating conditions. In addition, results showed that the effects of optimum feed conditions (flow rate, temperature and pressure) were between the ranges of of 6.0 e+03 to 8.0e+03 m³/h, 26 to 29°C, and 1.65 to 1.8 MPa respectively Therefore, it has been shown that the developed Aspen HYSYS model of this research work can be used to represent, simulate and optimize a crude oil stabilization system successfully.

Keywords—Stabilization, Simulation, Optimization, RVP, Aspen HYSYS.

I. INTRODUCTION

The economical challenge of modern technologies and customers’ satisfaction claims for a continuous optimization in every field of life. In chemical industry, products with precise quality values have to be produced while specific costs have to be on a minimal level. To fulfill these expectations, chemical process industries are renewed, redesigned, and rebuilt, i.e. modernized continuously to have the ability to operate complex, highly interconnected plants that are profitable and that meet quality, safety, environmental and other standards. Towards this goal, process modeling, simulation and optimization tools are increasingly being used industrially besides of the design process at every level of subsequent plant operations [11].

Crude oil contains complex mixtures which are very difficult to handle, meter, or transport. In addition to the difficulty, it is also unsafe and uneconomical to ship or transport these mixtures to refineries and gas plants for processing. However, environmental constraints exist for the safe and acceptable handling of hydrocarbon fluids and disposal of produced salt water. It is therefore necessary to process the produced fluids in the field to yield products that meet the specifications set by the customer and is safe to handle [1].
In order to maximize oil/gas production and increasing its market value, the oil and gas industry has shown keen interest in the development and optimization of separation efficiency between oil-gas-water in the crude stabilization process. Crude oil stabilization is a pre-treatment process which involve the removal of light hydrocarbons along with hydrogen sulphide and also reduces the vapor pressure. Dissolved gas in the crude oil must be removed to meet pipeline, storage or tanker Reid Vapor Pressure (RVP) specification. The presence of the most volatile hydrocarbon increases the RVP [5]. The impact of RVP is often referred to as the gasoline volatility. In this study, RVP has been set as a criterion for off-spec conditions of the product - that is, a maximum of 83 kPa.

Process simulation software packages are extensively used nowadays to estimate the product efficiency and enhance the performance of the system by optimizing operating parameters [12]. There have been few simulating software packages such as Aspen Plus, Aspen HYSYS and PRO/II for use in the oil and gas industries. In this study, Aspen HYSYS has been chosen as the suitable simulation software, in that it has vast importance for chemical engineers to simulate and optimize a process, which differs from many of the alternative commercial simulators in two main respects. First, it has the ability for interactively interpreting commands, as they are entered one at a time. Second, uses subroutines to model the process units, it has a unique feature that information propagates in both forward and reverse directions [2].


In this study, the model can provide an effective planning and operations tool. In view of the potential gains suggested by the results, modelling and optimization using computer simulator can bring new insight in the quest for a better crude oil stabilization system. In addition, it would significantly enhance recovery of stabilized liquid and reduce greenhouse gas emissions at the storage tanks and it would also be safe and economical to ship or transport the stabilized crude to refineries and gas plants. Furthermore, cost of production would be reduced by minimizing process system requirement due to pumping cavitation.

II. MATERIALS AND METHODS

A. Materials
The simulation software used in this study was Aspentech Hysys version 8.4 developed by Aspen Technology, Incorporation, Crosby Drive Bedford, Massachusetts, U.S.A. The data used for this study was obtained from Usan FPSO terminal. They include; detailed Process Flow Diagram of Usan FPSO terminal of crude oil stabilization system, inlet feed operating parameters, comprehensive crude oil compositions, equipment summary unit operation conditions and utilities.

B. Methods
The methods adopted in accomplishing this work, which was carried out to obtain the model, are outlined as follows.

1. Model development and process simulation procedure - Operational data for the simulation and optimization of the model were obtained from Usan Floating, Production, Storage and Offloading (FPSO) terminal. The simulation was performed in Aspen HYSYS (version 8.4) simulation environment. The components involved in the simulation process were characterized into pure and pseudo component and were selected from the simulator data base. The pseudo components (hentriacontanes to hexatriacontanes plus) which were not found in the data base of the component
library window, were created and added to the pure component as shown in Figure 1. Due to the presence of polar and non-polar hydrocarbons, as well as a three-phase system, Peng-Robinson was employed as the fluid package to predict the binary interaction and activity of the components in the liquid and vapor phase as shown in Figure 2.

The feed stream was defined by entering the feed conditions (flow rate, temperature, pressure and stream name) as shown in Figure 3. The streams were then connected to unit operations. The crude stabilization facilities consist of two three-phase separators, a flash drum, three heaters, two compressors, two valves, two mixers and a pump. After the input information and operating unit model were set-up, the process steady state simulation was successfully executed by the simulator as shown in Figure 4. The case was saved as “Base case” and a report was created.

![Figure 1. Choosing system components from data bank](image-url)
Figure 2. Selecting Peng-Robinson as the fluid Package

Figure 3. Schematic of feed stream conditions
2. **Process optimization** - After the model of crude oil stabilization process had been simulated, its optimization was carried out with the aid of the optimizer tool of the same Aspen HYSYS version 8.4 used for the model development and simulation, which was accessed upon the addition of the “Optimizer Spreadsheet” unto the developed model. The low and high bound for the primary (manipulated) variables were selected and set as shown in Figure 5. The criterion for the optimization was to maximize net profit subjected to a Reid vapor pressure of 83 kPa as the constraint as shown in Figure 6. The optimization equation is presented in equation (1). Sequential quadratic programming was the optimizer algorithm employed due to its ability in handling linear and non-linear algebraic functions as well as equality and inequality functions of constraint and unconstraint optimization problems. The optimization was then executed. The case was saved as “optimized case” and a report was created.

\[
\text{Net profit (\&/yr)} = (\text{flowrate}(i) \times \text{unit cost}(j)) - \text{(utilities)}
\]

where;

- \(i\) denotes the gas and liquid product,
- \(j\) denotes the unit cost of the gas and liquid product and utilities

involves the steam, compression and pump cost respectively.
III. RESULTS AND DISCUSSION

The summary of optimum results comparing the base and optimized cases of the model is presented in Table 1.
Table 1. Summary of optimum results of the base and optimized cases

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Base case</th>
<th>Optimized case</th>
<th>Difference between base and optimized cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel gas product flow (m³/yr_gas)</td>
<td>2.83 million</td>
<td>3.89 million</td>
<td>1.06 million</td>
</tr>
<tr>
<td>Gasoline product flow (bbl/yr)</td>
<td>9.87 million</td>
<td>13.00 million</td>
<td>3.13 million</td>
</tr>
<tr>
<td>Heater 1 heat flow (kJ/yr)</td>
<td>3.8 x 10⁹</td>
<td>1.8 x 10⁹</td>
<td>2.0 x 10⁹</td>
</tr>
<tr>
<td>Heater 2 heat flow (kJ/yr)</td>
<td>4.0 x 10⁹</td>
<td>3.0 x 10⁹</td>
<td>1.0 x 10⁹</td>
</tr>
<tr>
<td>Heater 3 heat flow (kJ/yr)</td>
<td>3.3 x 10⁹</td>
<td>2.3 x 10⁹</td>
<td>1.0 x 10⁹</td>
</tr>
<tr>
<td>Stage 2 Feed pressure (kPa)</td>
<td>680</td>
<td>680</td>
<td>0.00</td>
</tr>
<tr>
<td>Stage 3 Feed pressure (kPa)</td>
<td>338</td>
<td>324</td>
<td>14</td>
</tr>
<tr>
<td>RVP (kPa)</td>
<td>84.07</td>
<td>82.54</td>
<td>1.53</td>
</tr>
<tr>
<td>Net profit (₦ /yr)</td>
<td>135 billion</td>
<td>177 billion</td>
<td>42 billion</td>
</tr>
</tbody>
</table>

Table 1 presents summary of optimum results comparing the base and optimized cases of the model. The optimized case showed improvements in production of 37.46% (i.e. 1.06 million m³/yr) fuel gas product and 31.71% (i.e. 3.13 million bbl/yr) gasoline product over the base case. These can be attributed to decreased in heat flows of heaters 1, 2 and 3 from a high bound of 3.8 x 10⁹, 4.0 x 10⁹ and 3.3 x 10⁹ kJ/yr to a low bound of 1.8 x 10⁹, 3.0 x 10⁹ and 2.3 x 10⁹ kJ/yr respectively. This observation is in conformity with the findings of [4], who observed that increased heat supply breaks emulsions and resulted into excessive vaporization and loss of liquid product. Hence, it is pertinent to ensure that heat supplied at intervals does not exceed the high bound in order to ascertain good performance output. It can also be seen that the Reid Vapor Pressure (RVP) decreased from a high bound nof 84.07 kPa to a low bound of 82.54 kPa. These can be attributed to decrease in operating pressure at the final stage. This implied that operating pressure and temperature of the final stage dictates the vapor pressure of the liquid product, because at low operating pressure, the final stage heavy gas component will flash out from the liquid [3]. The net profit showed tremendous improvement from ₦ 135 billion to ₦ 177 billion, about 31.11% increase. The increased in the net profit can be attributed to high production rate of the desired products and this observation is in agreement with the finding of [7].

The effects of heaters 1, 2 and 3 heat flows on net profit is shown in Figures 7 – 9.
Figure 7 shows the effect of heat flow for heater 1 on net profit. It can be seen that the net profit decreased from 176 994 855 496.79 to N176 661 516 403.04 as the heat flow increased from 7.63E+07 to 2.90E+08 kJ/yr. Thus, in order to maintain an optimum net profit at the specified sales specification of product RVP of 83 kPa, the heat flow should be kept at 7.63 E + 07 kJ/yr. This implied that the decrease in the net profit was attributed to an increase in heat flow which reduced the volume of the fuel gas and gasoline product flow and thus, the net profit. According to [13], adding heat can cause a significant loss of the lower-boiling point hydrocarbons (light ends). This causes “shrinkage” of the oil, or loss of volume of the output. As a result, will lead to reduction of the net profit due to reduction in the output. Similarly, Figures 8 and 9 followed the same trend as above.

Figure 8. Effect of heater 2 heat flow on net profit

Figure 9. Effect of heater 3 heat flow on net profit

The effects of feed conditions on the product Reid vapor pressure for the simulated crude oil stabilization scheme is presented in Figures 10 – 12.
Figure 10. Effect of inlet feed temperature on product RVP

Figure 10 presents the effect of inlet feed temperature on product RVP. It can be seen that the product RVP decreased from 90.13 to 51.33 kPa as the inlet feed temperature increased from 10 to 100°C. This implied that, increase in the inlet temperature caused more portion of the light components to flash off from the crude and hence reduced the RVP of the product. Thus, the optimum temperature that the crude stabilization plant can tolerate in order to achieve the specified RVP (83 kPa) was between 26°C and 29°C. Hence, any temperature lower than 26°C or higher than 29°C would cause the stabilized crude to become off specification as it will require a higher heat duty to attain the required temperature before entering the pressure vessel. This observation is in agreement with the finding of [8] that RVP decreased as the feed temperature increased.

Figure 11. Effect of inlet molar flow rate on product RVP

Figure 11 shows the effect of feed molar flow rate on product RVP. It can be seen that the product RVP increased from 78.95 to 82.89 kPa as the molar flow rate increased from 10 000 to 80 000 m³/h_gas. This implied that increase in the molar flow rate would require more heat to flash off the volatile components. As a result, the RVP increased because of insufficient heat to maintain the RVP.
of the product. Therefore, for an acceptable RVP of 83 kPa, the optimum molar flow rate that can be processed by the crude stabilization plant was found to be in the range of 60 000 and 80 000 m$^3$/h_gas. This observation is in conformity with the finding of [6] who observed that increase in feed flow rate increased the product RVP.

Figure 12 presents the effect of inlet feed pressure on product RVP. It can be seen that the product RVP decreased from 82.96 to 82.27 kPa as the inlet feed pressure increased from 1000 to 9000 kPa. This implied that the high pressure drop in the pressure vessel led to high amount of volatile component flashed off to the stabilization gas header. Thus, the stabilized crude contained traces of light components which gave rise to lower RVP conducive for safe storage at atmospheric condition. Therefore, the optimum inlet feed pressure that can meet the required product specification was found to be in the range of 1 650 and 1 800 kPa. The above assertion is backed upon by the fact that, at high feed pressure the feed tends to change to the liquid phase while in the three-phase separator, the pressure should be as low as possible to flash-off the light ends [9].

IV. CONCLUSIONS
The process simulation and optimization of crude oil stabilization scheme of Usan FPSO terminal has been successfully performed and developed. The optimized case showed improvements in production of 1.06 million m$^3$/yr fuel gas product and 3.13 million bbl/yr gasoline product over the base case. Economic consideration showed an improvement of 31.11% (i.e. $ 42 billion) in net profit for the optimized case over the base case at optimal operating conditions. In addition, the optimum feed flow rate, temperature and pressure were between the ranges of 6.0 e+03 to 8.0e+03 m$^3$/h, 26 to 29°C, and 1.65 to 1.8 MPa respectively. Therefore, it has been shown that the developed Aspen HYSYS model of this research work can be used to represent, simulate and optimize a crude oil stabilization system successfully.

REFERENCES