Unisim Based Simulation and Analysis of Crude Oil Distillation

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Abstract. Crude distillation is the process of separating the hydrocarbons in crude oil based on their boiling point. Though refining process consists of a wide variety of units the major part is done in Crude Distillation Unit (CDU). In this study an attempt is made to make a train of heat integration network for the crude distillation process. Steady state simulations of cases with different arrangement of heat exchangers were studied in this work. Since the cost of energy has increased dramatically in last year's, the ability to optimize the use of resources and in particular of energy is becoming an extremely important skill for chemical engineers. Steady state simulation and dynamic simulation of crude plant with optimized heat exchanger design were then performed using Unisim software.

1. Introduction
Nowadays the process simulation can be applied in almost all the disciplines of chemical engineering and engineering in general. It is the inevitable part of the different disciplines such as the design of the process, the investigation and the development, the planning of the production, the optimization, the training and the education and the decision-making for a process [1]. The process of oil processing begins by geological and geophysical research of areas that are potentially rich with oil [2]. The modeling and simulation of the crude distillation process may be developed only using simulating software packages like Aspen Plus, Aspen HYSYS, Unisim Design, and PRO/II [3]. Crude distillation units (CDU) are the most strategic units for the processing of the crude oil [4]. The operation of a standard crude oil distillation column is as follows. Stored raw crude oil is partially heated in Preheat Train 1 and fed to preflash and further heated, in Preheat Train 2 and a fired heater, before being fed to the atmospheric distillation column. The preheat trains use heat recovered from the crude distillation unit, particularly the pump-arounds and product streams. The partially vaporized crude oil is fed to the atmospheric distillation column a few trays above the bottom stage. Stripping steam is supplied to the column at the bottom stage, which partly suppresses the boiling point of the crude mixture and further vaporizes the crude oil mixture [5]. It produces almost 16 different petroleum products such as LPG, Naphtha, Kerosene, Diesel, AGO, Fuel gas [6]. It is estimated that 7 to 15 % of the crude oil input is consumed in refinery processes, of which 35 to 45 % is used for crude oil distillation. Preflash units are useful for reducing the fired heat demand for crude oil preheating prior to distillation. The preflash unit removes some light components and some of light naphtha; the vapour stream bypasses the fired heater, helping to reduce its fuel consumption [7]. Many studies regarding the crude oil behavior and its distillation have been published recently and introduced a novel optimization scheme for crude oil selection in the refining[8]. Fouling of heat exchangers is one of the major concerns of the petroleum refining industry. It leads to operating problems, affects the efficiency of the heat recovery systems,
and can seriously alter the profitability of a refinery [9].

2. Oil Characterization

The first step for a successful simulation is correct choice of the thermodynamic method that will be used in the calculations of the state variables and the physical properties. The Peng-Robinson equation of state is normally accepted for the compounds in the crude distillation unit process stream [10]. Simulation includes adding both oil and non-oil components. Non-oil components are created by adding the hypocomponents to the component list. Here oil characterization of the oil (Petroleum Fluid) had done using the Assay data to create the hypocomponents. An efficient assay is derived from a series of test data that give an accurate description of petroleum quality and allow an indication of its behavior during refining [11]. The UniSim Design Oil Characterization procedure is used to convert the laboratory data into petroleum hypo-components. Results of oil characterization are composite curves, property plots, distribution plots etc…”Figure 1” represent Composite plot of property TBP distillation.

![Figure 1. Composite plot of property TBP distillation](image1)

Naphtha, Kerosene, Light Diesel, Heavy Diesel, Atmospheric Gas Oil, Residue are the straight run products which are shown in “Figure 2” Cut temperature of each product can be found from these plots.

![Figure 2. Cut Distribution of Straight Run products](image2)
3. Steady state simulation analysis
To realize the simulation diagram, the literature reflects some aspects. If Unisim simulator is used, it is recommended to use Refluxed Absorber model. To build the crude distillation unit simulation program using the Unisim simulator, the best practice is to build it step by step, making sure that after each step the model is convergent. First, the Refluxed absorption column model is configured without preheat train. Then the feed (crude oil partial vaporized) and the steam used in bottom column are defined. Also AGO steam, Diesel steam and trim duty are also defined. The steps for Refining simulation without preheat train are creating unit set, choosing property package, selecting the non-oil components, characterizing oil, creating and specifying the preheated crude and utility streams, installing and defining the unit operations in pre-fractionation train and finally installing and defining crude fractionation column. Unrefined petroleum is handled in a fractionation column to deliver kerosene, naphtha, diesel, AGO, and residue. Preheated crude (from an upstream preheat train) is taken care of to a pre-flash column where vapors are isolated from the fluids, which are heated in a heater. The pre-flash fumes sidestep the heater and are recombined with the hot unrefined from the heater. Four cases were done for steady state simulation.

3.1. Case 1 - without preheat train
A fluid package contains the components and property methods that UniSim Design will use in its calculations for a particular flow sheet. Depending on what is required, a fluid package can also contain other information, such as a petroleum fluid characterization. Peng Robinson is used as fluid package.

![Figure 3. Case 1- CDU without preheat train](image)

The crude column consists of a refluxed absorber with three side strippers and three cooled pump around circuits. The atmospheric crude column is to fractionate the crude into its straight run products. The main column consists of 29 trays plus a partial condenser. The Tower Feed enters on stage 28, while superheated steam is fed to the bottom stage. In addition, the trim duty is represented by an energy stream feeding onto stage 28. The Naphtha product as well as the water stream Waste H₂O, is produced from the three-phase condenser. Crude atmospheric Residue is yielded from the bottom of the tower. Each of the three-stage side strippers yields a straight run product. Kerosene is produced from the reboiled KeroSS side stripper, while Diesel and AGO (atmospheric gas oil) are produced from the steam-stripped Diesel SS and AGOSS side strippers, respectively. The vapor from the column is mixed with heated crude to give as a feed to atmospheric column. Two heaters are used for the simulation. The total heat duty is 1.12E+09(kJ/h).

3.2. Case 2a - series connection with distillation column
The CDU system has the capacity to process 100,000 bbl/day of mixed crude oil. After preheating to about 260°C, the crude oil is fed to the bottom of pre-flashing column (Distillation column is modeled
as preflashing column). The operation conditions of the column are 230 kPa. The heavy crude at the bottom of pre-flashing column is sent to the CPT to heat upto 377.8°C, where the crude get further vaporized. LPG and Light Naphtha were obtained from the distillation column.

As the main equipment in ADU, the distillation column consists of 29 theoretical stages with three pump-arounds and three strippers. Three pump-arounds are located from 2th stage up to 1th stage, from 17th stage to 16th stage, and from 22th stage to 21th stage, respectively. The liquefaction temperatures of three pump-arounds are maintained at 195.64 °C, 366.76 °C, 445.57 °C, respectively. The product of heavy naphtha (HN) is distilled at the top of the distillation column in the ADU. Meanwhile, products of the kerosene, diesel, and atmospheric gas oil (AGO) are respectively withdrawn in the first side stripper (Str-1), the second stripper (Str-2), and the third stripper (Str- B3). The three side strippers all consist of three equilibrium stages. The feed flow rates and heat duty of the furnace are reduced when a part of crude oil is pre-flashed. Feeding the vapor from pre-flashing directly to the column can effectively improve the distribution of temperature and components along the entire column. The total heat duty is 7.445E+08 kJ/h and overall heat transfer coefficient is 2.575E+06kJ/Ch.

Figure 4. The flow sheet of case 2a with preflash modeled as distillation column and atmospheric column series connection

3.3. Case 2b- series connection with separator
Case studies were done to find out the temperature effect on vapor molar flow. It concludes that upto a certain temperature the molar flow of vapor is zero. That is upto 300 °C molar flow of vapor is zero. At 342.7 °C the molar flow of vapor is 273.6 kmole/h. Total heat flow is 7.312E+08 kJ/h. The overall heat transfer coefficient (UA) is 2.118E+06 kJ/C.h. The flow sheet of case with preflash modeled as separator and atmospheric column is shown in “Figure 5”.

Figure 5. The flow sheet of case 2b with preflash modeled as separator and ADU in series connection

3.4. Case 2c- parallel connection with distillation column
A distillation column is modeled as prefractionating column. The operation conditions of the column are 260 °C and 220 kPa. The operation conditions of the condenser are 50 °C and 120kPa. At the top of the pre-flashing column, the liquefied petroleum gas (LPG) and light naphtha (LN) are recovered as products at 50°C. The flow sheet of case with preflash modeled as distillation column and atmospheric column is shown in Figure 6.

Figure 6. The flow sheet of case 2c with preflash modeled as distillation column and ADU in parallel connection

The case studies for the temperature of prefractionator were done. From the case studies 260 °C is concluded. The condenser products are lights and Light Naphtha. Lights have C3-C4 carbon cuts. In order to find out the temperature at which give more amount of these cuts case studies were done. The case studies of mole fraction of four components against temperature were done.

3.5. Case 2d- parallel connection with separator

Figure 7. The flow sheet of case 2d with preflash modeled as separator and ADU in parallel connection

Total heat flow is 8.307E+08 kJ/h. The overall heat transfer coefficient (UA) is 2.051E+06 kJ/C.h.
The flow sheet of case with preflash modeled as separator and atmospheric column is shown in Figure 7.

4. Optimizing overallUA
Optimization of the crude oil separation process becomes increasingly important because of the high energy costs and ecological requirements for quality oil products [12]. The Optimizer determines the optimum Tee flow ratio by minimizing Overall UA. “Figure 8” shows variables tab to enter the variable description. Here total UA is minimized by optimizing TEE split ratio. Initially feed is split into two equal ratios. Low bound and high bound value of ratio need to be input. Low bound value is 0.1875 and high bound value is 0.7500.

![Image of Variables tab](Image)

Figure 8. Variables tab

Import the Heat Exchanger overall UAs to the Optimizer spreadsheet in Unisim. Sum of UA of heat exchanger is found out in a cell of spreadsheet. Initial value of total UA is 2.700e+006 kJ/C.h. The initial value of flow ratio is 0.5000. After optimization the flow ratio of second stream reduces to 0.4639. The minimized value of sum of UA is 2.642e+006 kJ/C.h. The SPQ scheme is used for the calculation procedure. This is the minimized value of UA obtained by optimizing flow split of TEE.

5. Conclusion
Simulation software is one of the best tools for a crude oil refinery. Process in crude oil distillation column is studied. A refinery tutorial is done in Unisim software. Crude oil assay is studied and analyzed using the refinery problem. TBP (True Boiling Curve) is used to characterize the crude oil. Here naphtha, kerosene, AGO were the products. Three side stream strippers are used in order to meet the characteristics of fuel (flash point). Kerosene is taken as first side stream. After that diesel and AGO are withdrawn. Also three pumps-around are used in order to maintain cuts (draw off temperature/composition). Comparison between steady state simulation between a plant with preflash modeled as separator and plant with prefractionator modeled as distillation column were done. Heat flow is more for separator model. The plant with prefractionator is taken as good model. UA minimized by optimizing the flow through TEE. The optimized value of flow ratio is 0.4639. The minimized value of UA is 2.642e+006 kJ/C.h. The SPQ scheme is used.

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