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Model of a crude oil distillation column

Juan Sebastian Useche, Angélica Orjuela, Darío Amaya

Mechatronics Engineering Program, Faculty of Engineering, Nueva Granada Military University, Bogotá, Colombia.

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Address For Correspondence:
Dario Amaya ,Mechatronics Engineering Program, Faculty of Engineering, Nueva Granada Military University, Bogotá, Colombia.
Tel:+51-6500000-1280; E-mail: dario.amaya@unimilitar.edu.co

ABSTRACT

The extracted oil reservoir does not have any practical application. It is necessary to separate it into different fractions themselves are useful. This process is done in refineries. Distillation is the fundamental operation for petroleum refining. Its aim is to separate the various components of crude oil by heating. The simulation of this process is especially important because it is one of the largest consumers of energy in industrial processes. This hinders accurate prediction of process results. In this paper the model of operation of the distillation column of oil, resulting from mass balances, energy and thermodynamic relations is presented. The most important result is the behavior of the distillation unit estimation, which enables the model to be evaluated according to the characteristics of crude, plus acontextualization of the elaborate models is performed and simulation allows the evaluation of model results very close to realit

KEYWORDS: Crude Oil Distillation, Simulation, MESH Equations, MATLAB.

INTRODUCTION

The distillation is to separate the components of a mixture, based on the different boiling points. This process is used mostly in petrochemical processes [1][2] . In oil refineries, crude oil is a complex mixture of components that need to be separated into groups according to a range of volatility [3][4]. The crude distillation systems include the distillation columns and heat recovery systems, it is the first process in an oil refinery [5]. It is a process that consumes an equivalent of 1% to 2% of processed crude [6][7]. Due to rising energy costs, it has made considerable efforts to reduce energy consumption [8].

Modeling and simulation of this process has been of great attention from industry and research entities, developing procedures and methods salient in recent decades [9][10]. The equations describing the steady-state process, although they represent a basic equilibrium model is extended to a highly nonlinear and interdependent [11]. Amundson in [12] first proposed set of equations, simultaneous nonlinear for processing multicomponent, through the matrix method, separating relations enthalpy and mass for each course, this provided an effective simulation became a reference point for developed works.

Due to technological and industrial development and increased products that require oil processes, it is necessary to identify the model, to make simulations that achieve represent the behavior of the distillation units used in industry, reducing research costs and development[13]. The presence of the different chemicals in the oil determine their chemical and physical characteristics, such as density, viscosity, etc. [14]. Given these differences can determine various classification systems. Mostly used criteria are its chemical composition, density, the presence of sulfur, geographical location[15][16].

Some of the work related, is the presented by [17] where the optimization of an oil distillation column is studied using linear programming, based on the model of the Port-Harcourt refinery, as main result validated solutions to improve the distillation process through validation Matlab. In [18] adjusting the parameters of the predictive control of oil distillation unit with real characteristics of the industry, so the approach stands out with the goal of addressing a real problem is done. The main result of simulation and analysis of the results obtained in applying this type of control is highlighted.

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Regarding the application of neural networks is [19], the Baiji oil distillation unit is modeled, using data from Aspen HYSYS main result implementation of the neural network using MATLAB toolbox is made, and identify the advantages of handling nonlinear models with strategies diffuse Control.

Furthermore, [20] where research on existing distillation unit was made, setting the low efficiency and the potential for improved performance. Techniques developed had an increase in efficiency of 1.6% and capital savings and a proportional reducing energy consumption. Based on the above, in this paper the modeling and simulation of a distillation column of oil with 7 compounds like outputs, but the mathematical model proposed can be implemented with n number of products with features concentration variables and relative volatility, and operating properties of the distillation unit variables.

MATERIALS AND METHODS

Crude oil distillation is a fundamental process in the refinery, so the development of the mathematical model is very important, which faithfully represents the characteristics of the separation unit, through which passes a preheated oil[21]. Given the size of the model according to the inputs and outputs of the system, choose to use the mathematical relationships from the MESH method, which consists of four series of mass equations (M), balance (E), conservation (S) and enthalpy (H). In addition to the considerations for this it is considered more rigorous and this makes it suitable for the type of process being modeled

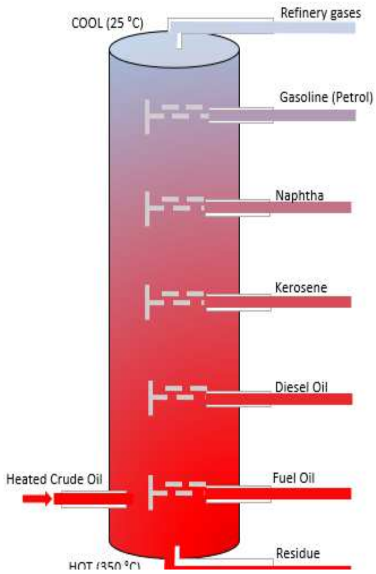

Fig. 1: Diagram of crude oil distillation

For a typical distillation column shown in Figure 1, is processed to implement the equations (MESH), mass and energy balance for each state i j each component steady state[22].

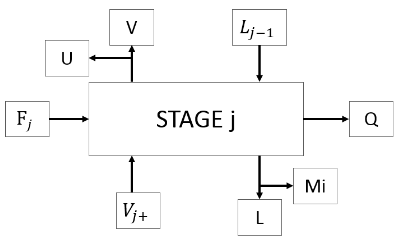

Fig. 2: General schematic representation of a stage j

To raise the balance of each plate the general diagram shown in Figure 2 follows.

Mass Balance equation (Equation M)

$$L_{j-1}X_{i,j-1} + V_{j+1}Y_{i,j+1} + F_j Z_{i,j} = L_{i,j}X_{i,j} + M_j X_{i,j} + V_j Y_{i,j} + U_j Y_{i,j} \quad (1 \leq j \leq NT,\ 1 \leq i \leq n) \tag{1}$$

The equation (1) is the general model to predict the mass flux of component i, in and out of the plate j.

$L_{j-1}X_{i,j-1} - (L_j + M_j)X_{i,j}$
$-(V_j + U_j)Y_{i,j} + V_{j+1}Y_{i,j+1} + F_jZ_{i,j} = 0$
(1≤j≤NT, 1≤i≤n) (2)

Rearranging the equation (1) equation (2) is obtained.

Phase equilibrium equation (Equation E)

$Y_{i,j} = K_{i,j}X_{i,j}$
(1≤j≤NT, 1≤i≤n) (3)

To estimate the behavior of the substance in the column is necessary verify the relationship of states, described in equation (3)

Sum of molar fraction (Equation S)

$\sum_{i=1}^{n} X_{i,j} = 1 \ , \sum_{i=1}^{n} Y_{i,j} = 1$
(1≤i≤n) (4)

Respecting the composition of the food that matches the products obtained equation applies (4)

Enthalpy balance (Equation H)

$L_{j-1}\mathrm{H}^1_{i,j-1} + V_{j+1}\mathrm{H}^v_{i,j+1} + F_j\mathrm{H}^f_{i,j} -$
$(L_j + M_j)\mathrm{H}^1_{i,j} - (V_j + U_j)\mathrm{H}^V_{i,j} - Qj = 0$ (5)

With equation (5) the heat balance equation arises considering enthalpies.

The model is developed according to some estimates.

$Y_n = K_nX_n$ (6)

The time of flow in each dish is sufficient to reach equilibrium between liquid and vapor according to the equation (6)

$K_n = K_{n+1} = K_{n-1}$
$Y_n = \mathrm{K}X_n$ (7)

Following the equation (7) It is considering the relative volatility on each plate as constant.

$T^v = T^i = T$ (8)

Considering the balance between the phases, the temperature of the liquid and vapor streams is the same, according to the equation (8).

$L_n = \mathrm{L}$
$V_n = \mathrm{V}$ (9)

The flow rate of liquid and steam are constant, as evidenced by the equation (9)

$H_n = \mathrm{H}$
$h_n = \mathrm{h}$ (10)

Since the flow rate of liquid and vapor into and out of each plate is constant, the retention of liquid and vapor will also be constant according to the equation (10). Furthermore it is considered that there is no heat loss through the column structure.

$\mathrm{H}^1_n = \mathrm{H}^1_{n+1} = H^1$
$\mathrm{H}^V_{n-1} = \mathrm{H}^V_n = H^V$
$\mathrm{H}^V_{i,j} = E_{i,j}\mathrm{H}^1_{i,j}$ (11)

Furthermore ideal systems for the molar heat of vaporization can be considered constant and independent of the fluid composition, temperature change also from one tray to another is small thus it arises equation (11)

$$L_{j-1}X_{i,j-1} - \left(L_j + M_j + \left(V_j + U_j\right) K_i\right)X_{i,j} + V_{j+1}K_{i+1}X_{i,j+1} + F_jZ_{i,j} = 0 \quad (12)$$

Taking into account the considerations and the equation (3), the simplified model shown in equation (12)

$$V_j + F_{j-1} + F_2 + F_1 = L_{j-1} + M_{j-1} + U_{j-1} + M_2 + U_2 + M_1 + U_1 + V_1 \quad (13)$$

The mass balance for the dish j-1 is brought into the equation (13)

$$L_{j-1} = V_j + F_{j-1} + F_2 + F_1 - M_{j-1} - M_2 - M_1 - U_{j-1} - U_2 - U_1 - V_1 \quad (14)$$

From equation (13) reorganizes for L_{j-1} leaving this as a subject, which corresponds to the equation (14)

$$L_{j-1} = V_j + \sum_{m=1}^{j-1}(F_m - U_m - M_m) - V_1 \qquad 2 \le j \le NT \quad (15)$$

The equation (14) is written generally in equation (15).

$$L_{j-1} = V_j + F_{j-1} + F_2 + F_1 - M_{j-1} - M_2 - M_1 - U_{j-1} - U_2 - U_1 - V_1 \quad (16)$$

Likewise the equation (15) extends to obtain expression to Lj, described in equation (16)

$$\left[V_j + \sum_{m=1}^{j-1}(F_m - U_m - M_m) - V_1\right] X_{i,j-1} - \left[V_{j+1} + \sum_{m=1}^{j}(F_m - U_m - M_m) - V_1 + M_j + \left(V_j + U_j\right)K_{i,j}\right]X_{i,j} + V_{j+1}K_iX_{i,j+1} + F_jZ_{i,j} = 0 \quad (17)$$

Substituting equations (15) and (16) in the equation (14) equation is obtained (17).

$$A_{i,j} = V_j + \sum_{m=1}^{j-1}(F_m - U_m - M_m) - V_1 \quad (18)$$

$$B_{i,j} = V_{j+1} + \sum_{m=1}^{j}(F_m - U_m - M_m) - V_1 + M_j + \left(V_j + U_j\right)K_{i,j} \quad (19)$$

$$C_{i,j} = V_{j+1}K_i \quad (20)$$

$$D_{i,j} = F_jZ_{i,j} \quad (21)$$

Considering the equations (18), (19), (20) and (21) Can rewrite the equation (17) compactly.

$$A_{i,j}X_{i,j-1} - B_{i,j}X_{i,j} + C_{i,j}X_{i,j+1} + D_{i,j} = 0 \quad (22)$$

In this way obtains the equation (22), and also the energy balance is simplified using assumptions.

$$L_{j-1}\mathrm{C}^1_{pi,j-1}\mathrm{T}^1_{i,j-1} - \left\{L_j + M_j + \left(V_j + U_j\right)E_{i,j}\right\} \mathrm{C}^1_{pi,j}\mathrm{T}^1_{i,j} + V_{j+1}E_{i,j+1}\mathrm{C}^1_{pi,j+1}\mathrm{T}^1_{i,j+1} + F_j\mathrm{C}^1_{pi,j}\mathrm{T}^1_{i,j} - Q_J = 0 \quad (23)$$

The equation (23) represents the general model that predicts the temperature of each plate due to temperature change through the column.

$$\left[V_j + \sum_{m=1}^{j-1}(F_m - U_m - M_m) - V_1\right] Cp_{i,j-1}T_{i,j-1} -$$

$$\left[V_{j+1} + \sum_{m=1}^{j} (F_m - U_m - M_m) - V_1 + M_j + F_j + (V_j + U_j)E_{i,j}\right] Cp_{i,j}T_{i,j} + V_{i+1}E_{i,j+1}Cp_{i,j+1}T_{i,j+1} - Q_J = 0 \quad (24)$$

Substituting equation (15) and (16) in equation (23) and ignoring the superscript and the equation is obtained (24)

$$P_{i,j} = \left[V_j + \sum_{m=1}^{j-1}(F_m - U_m - M_m) - V_1\right]Cp_{i,j-1} \quad (25)$$
$$R_{i,j} = \left[V_{j+1} + \sum_{m=1}^{j}(F_m - U_m - M_m) - V_1 + M_j + F_j + (V_j + U_j)E_{i,j}\right]Cp_{i,j} \quad (26)$$
$$S_{i,j} = V_{j+1}E_{i,j+1}Cp_{i,j+1} \quad (27)$$

Considering the equations (25), (26) and (27), can be replaced in the equation (24) to write this in a compact manner.

$$P_{i,j}T_{i,j-1} - R_{i,j}T_{i,j} + S_{i,j}T_{i,j+1} - Q_J = 0 \quad (28)$$

Thus arises the equation (28).

Table 1: Properties of Crude Oil

	STAGE	FLOW (m3/h)	Mole Fraction	Kij
Feed	40	1092.4		
Gases	65	81.2	0.312	0.13
Petrol	58	110.2	0.047	0.2
Naphtha	43	190.1	0.122	0.39
Kerosene	35	167.1	0.139	0.39
Diesel	25	215.3	0.190	0.24
Fuel Oil	12	52.3	0.1	1.0
Residue	1	276.2	0.09	0.44

The proposed model equations are described for any component that is of interest to a system of algebraic equations Nt (Nt be the number of dishes). The benchmark performance data are taken from the plant oil refinery Port-Harcourt[23], shown in Table 1, in which the flow and characteristics of each component are described, which are used to obtain the unknowns in the modeling.

Table 1 shows the characteristics of the crude oil that is processed in the most important refinery in Nigeria are specified. Stressing that the proposed model poses obtaining 7 products considering that most distillation processes aim five compounds.

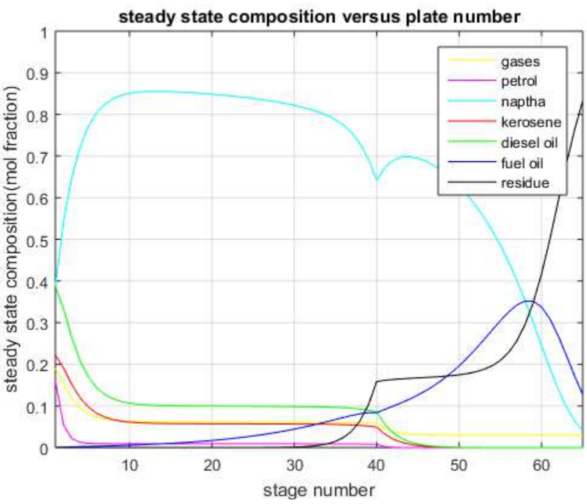

Fig. 3: Graph showing the operation of the column described steady state responses obtained by the proposed model.

The proposed model is solved by Matlab software and so the behavior at steady state is obtained from the distillation column. The graph representing the trend shown in Figure 3. Representing the composition according to the plates of the column.

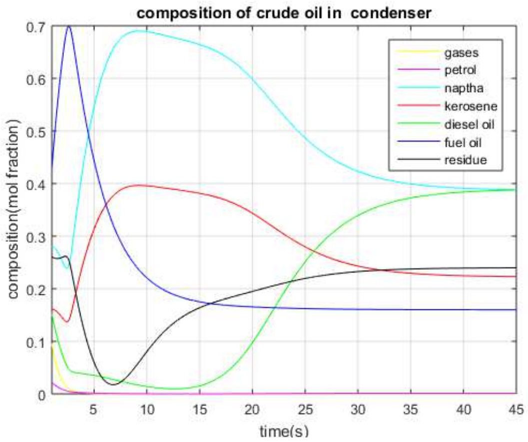

Fig. 4: Graph of the composition of the compounds in the capacitor oil through time.

Considering that the objective are all products individually further condensation of the compounds is simulated for this composition it is plotted against time, especially important in the condensation because it is responsible for obtaining the final product from the more volatile elements of crude which is evident in Figure 4.

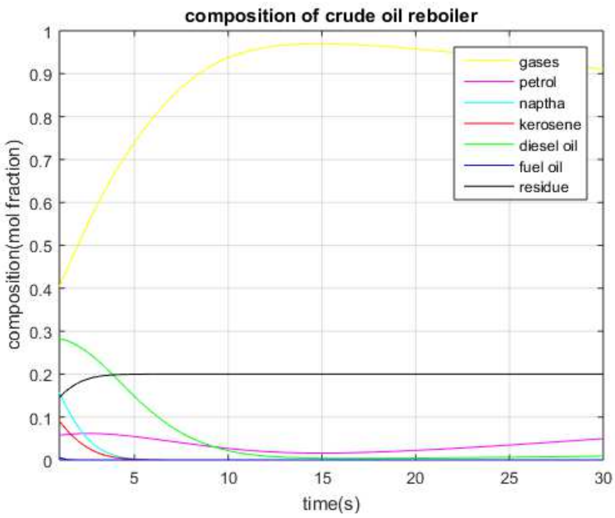

Fig. 5: Graph of the composition of the compounds in the reboiler oil over time.

Furthermore in Figure 5 the dynamic component in the reboiler shown, through this graph shows the process over time and as behavior difference components of crude.

Conclusions:

The MESH method by which the model is proposed, allows for more dynamic characteristics of the column so the simulation obtained corresponds to the behavior of these units in the industry.

Due to the relative volatility between more than two substances by the oil composition, it is important recognition of the steady-state performance of each dish to distinguish the difficulties of the separation process and designate the best way the products leaving.

Through time-dependent modeling of the critical stages of condensation and reboiling energy expenditure and the proper use of the equipment for the process to exit the distillation column is analyzed, so estimating techniques and solutions for improvement current behavior of the unit.

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REFERENCES

1. Ebrahimzadeh, E., J. Matagi, F. Fazlollahi and L.L. Baxter, 2016. "Alternative extractive distillation system for CO2–ethane azeotrope separation in enhanced oil recovery processes," Appl. Therm. Eng., 96: 39-47.
2. Gil, I., J. Gómez and G. Rodríguez, 2012. "Control of an extractive distillation process to dehydrate ethanol using glycerol as entrainer," Comput. Chem. Eng.
3. Królikowski, A.R., 2012. "Distillation profiles in ternary heterogeneous mixtures with distillation boundaries: Staged columns," Chem. Process Eng. - Inz. Chem. i Proces., 33: 207-219.
4. Kiss, A.A., 2014. "Distillation technology - still young and full of breakthrough opportunities," J. Chem. Technol. Biotechnol., 89(4): 479-498.
5. Hou, J., X. Li and H. Sui, 2015. "The optimization and prediction of properties for crude oil blending," Comput. Chem. Eng., 76: 21-26.
6. Mohayeji, M., M. Farsi, M.R. Rahimpour and A. Shariati, 2015. "Modeling and operability analysis of water separation from crude oil in an industrial gravitational coalescer," J. Taiwan Inst. Chem. Eng.
7. Enríquez-Gutiérrez, V.M., M. Jobson, L.M. Ochoa-Estopier and R. Smith, 2015. "Retrofit of heat-integrated crude oil distillation columns," Chem. Eng. Res. Des., 99: 185-198.
8. Agudelo, J.R., A. Álvarez and O. Armas, 2014. "Impact of crude vegetable oils on the oxidation reactivity and nanostructure of diesel particulate matter," Combust. Flame, 161(11): 2904-2915.
9. Luo, Y., L. Wang, H. Wang and X. Yuan, 2015. "Simultaneous optimization of heat-integrated crude oil distillation systems," Chinese J. Chem. Eng., 23(9): 1518-1522.
10. Cortez, L.C.S. and A.A. Pessoa, 2016. "A new model and a reformulation for the crude distillation unit charging problem with oil blends and sequence-dependent changeover costs," Comput. Chem. Eng., 84: 49-62.
11. Yang, Y. and P.I. Barton, 2015. "Refinery Optimization Integrated with a Nonlinear Crude Distillation Unit Model," IFAC-PapersOnLine, 48(8): 205-210.
12. Amundson, N.R. and A.J. Pontinen, 1958. "Multicomponent Distillation Calculations on a Large Digital Computer," Ind. Eng. Chem., 50(5): 730-736.
13. Fingas, M., 2013. "Modeling oil and petroleum evaporation," J. Pet. Sci. Res.
14. Tao, L., C. Li, X. Kong and F. Qian, 2012. "Steady-state identification with gross errors for industrial process units," in Proceedings of the 10th World Congress on Intelligent Control and Automation, pp: 4151-4154.
15. Behrenbruch, P. and T. Dedigama, 2007. "Classification and characterisation of crude oils based on distillation properties," J. Pet. Sci. Eng., 57(1-2): 166-180.
16. Speight, J., 2014. "The chemistry and technology of petroleum.
17. Popoola, L., A. Susu, A. Lateef and A. GREMA, 2015. "Application of Linear Programming in Profit Optimization of Crude Oil Distillation Column of Port Harcourt Refinery, Nigeria," IJASM.
18. Yamashita, A.S., A.C. Zanin and D. Odloak, 2015. "Tuning the Model Predictive Control of a Crude Distillation Unit.," ISA Trans.
19. Ahmed, D. and A. Khalaf, 2015. "Development of Artificial Neural Network Model of Crude Oil Distillation Column," Tikrit J. Eng. Sci.
20. Waheed, M.A. and A.O. Oni, 2015. "Performance improvement of a crude oil distillation unit," Appl. Therm. Eng.,75: 315-324.
21. Ansari, R .and M. Tadé, 2012. "Nonlinear model-based process control: applications in petroleum refining.
22. Gunorubon, J., O. Diepriye and R. State, 1983. "Simulation of a Multi-component Crude Distillation Column Rivers State University of Science and Technology , Kerosene (SRK) Light Diesel oil," pp: 366-377.
23. Oladimeji, T. and J. Sonibare, 2015."Environmental Impact Analysis of the Emission from Petroleum Refineries in Nigeria," Energy.