Simulation and Control of C9-C10 Aromatics Splitter Column of Bouali Sina Petrochemical Company

M. Zivdar [a], S.M. Mirhosseini [b], M.A. Mokhtari [b], M. Abdollahi [c]

[a] Professor, Chemical Engineering Department, University of Sistan and Baluchestan, P.O. Box 98135-674, Zahedan, Iran

[b] MSc, Chemical Engineering Department, University of Sistan and Baluchestan, P.O. Box 98135-674, Zahedan, Iran

[c] Process Dept. Bouali Sina Petrochemical Company, Site 4, Petrochemical Special Economic Zone, Bandar-e Mahshahr, Iran

mzivdar@eng.usb.ac.ir; seyedmortezamirhosseiniusb@gmail.com; mokhtarimohammadamin94@gmail.com; mabdoullahi@gmail.com

Abstract. In this study, steady-state and dynamic simulations of the C9-C10 aromatics splitter column of Bouali Sina Petrochemical Company have been presented. C9-C10 aromatics splitter column has the task of recovering C9 aromatics fraction from the feed. The average pressure of the column is 1.4 bar, average temperature 200 °C, and has 62 equilibrium trays. After performing steady-state simulation, the results were compared with the operation data, and the average error of 0.15% for the top, and 1% for the bottom of the column were obtained. In the dynamic simulation, a PI controller has been used to control feed flow rate, temperature, pressure, and the reservoir levels of the column. The results of the dynamic simulation showed a decrease of 1.115 MW in the condenser, and a decrease of 0.154 MW in reboiler heat duty compared with available operation data. By disturbing the feed flow rate by ± 15%, and feed temperature by ±10%, implementation of two points control structures (LV), (DV), (V, L/L+D), (V/B, L/L+D) showed the column has returned to set points very quickly. The (V, L/L+D) control model was the best model for controlling the disturbances in feed flow rate and temperature, and (DV) was the worst model among four selected methods for controlling the disturbances in the column.

All rights reserved by the authors as per DA2022 copyright notice.

Keywords: C9-C10 Aromatics, Splitter column, steady-state simulation, Dynamic simulation, Pressure drop, Two-point control

Introduction

The C9-C10 distillation tower splitter is located in unit 600 of Bouali Sina Petrochemical Complex and is responsible for separating C9 heavy aromatics from C10 heavy aromatics. Figure 1 shows the C9-C10 splitter distillation process. In the C9-C10 splitter distillation tower, after recovering the C9 aromatic components from the heavier aromatic components, C9 was returned to the unit 700 alkylation complex, while the heavier components were sent to other units.

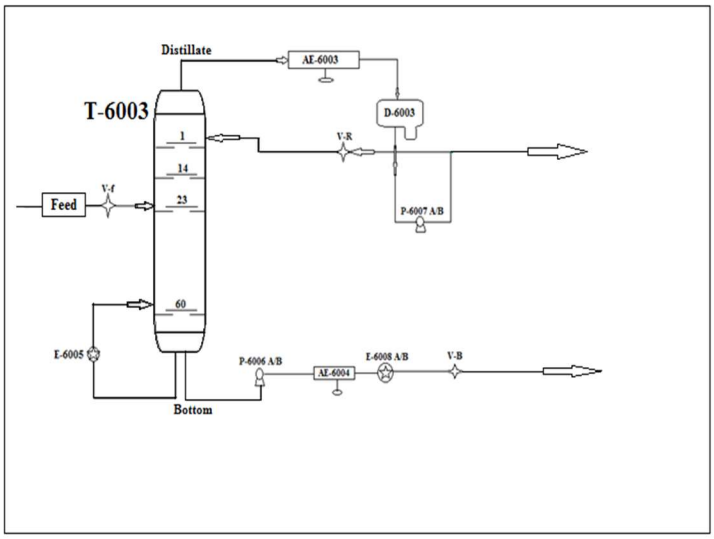


Fig. 1 C9-C10 splitter distillation tower flow diagram

Distillation is one of the most important and common separation method and is based on the distribution of components between two phases. In most steady-state simulations, the size of the equipment was not entered and only the possibility of changing operating conditions were considered. In addition, due to the lack of time involved in these simulations, it is not possible to predict and control the technical problems and the type of process response, all of which must be examined over time. In multi-component distillation towers, the goal is to minimize impurities except for the heavy key component in the top product of the tower and impurities except for the light key component in the bottom product of the tower. In controlling a distillation tower, it is ideal to measure both the top and bottom product concentrations of the tower and to control it by two input variables, so that the concentration of key components in both the top and bottom products are at its predefined values. Few distillation towers have this ideal control structure, as concentration analyzers are expensive and impose high maintenance costs on the system. Therefore, secondary variables such as the temperature of the tower trays are measured and controlled. Due to the relationship between concentration and temperature in distillation towers, the concentration can be estimated using the temperature of the tower trays and the estimated concentration can be used to control the quality of the tower products [1]. The researchers showed that to design an optimal controller, it is better to use all available data (measurements, process model, perturbation, etc.) and all controller variables to keep the output constant. So far, a lot of work has been done to obtain the best control structure of the distillation towers, which in many cases contradictory results were obtained, so to select the best control structure the designer must make a more detailed analysis of the system and be familiar with the system dynamics [2]. Luyben found to find the best feed tray in a multi-component distillation system. It was concluded that the optimal feed tray was the tray that minimizes energy consumption in the reboiler. For multiple feed trays, the method of trial and error was used to find the best feed tray [3]. Hossein Zadeh et al. investigated the importance of aromatic units responsible for the initial separation of benzene and toluene from xylene isomers in the Bouali Sina Petrochemical complex. It was shown that the UNIF-LBY, UNIFAC, Grayson, and Chao- Seader models gave the best results for the existing conditions [4]. Qi et al. reported a precise dynamic model in a distillation column to improve the computational performance of dynamic models. A linear regression algorithm for predicting vapor-liquid equilibrium data was proposed. Gear's method was used to solve the algebraic differential equations and the initial quantification was performed based on the steady-state model data. The simulation results with this dynamic model showed its compatibility with the values of the real experiment [5]. Zakwan Zayn et al. analyzed and improved the energy saving for the aromatic separation process by using the driving force method by Aspen Hysys software. The results of this work showed maximum energy reduction was 7.0% [6]. Silva Filho et al. developed a new distillation technology based on thermosyphon-based distillation at atmospheric pressure to improve the efficiency of the distillation process. Two compact pilot scales (1 m high distillation tube) were used to separate aromatic compounds. The results of this study showed that there was no difference between isothermal and non-isothermal conditions [7]. Although lot of researches have been done in recent years to improve the performance and increase the

quality and quantity of distillation unit products, more research is needed, especially in the areas of dynamic simulation and control of distillation towers. The study and simulation for the separation of C9-C10 aromatics are very limited and often exclusive and inaccessible. In this research, the C9-C10 splitter distillation tower of aromatic unit of Bouali Sina Petrochemical Complex has been simulated and controlled. Based on literature survey there was little information on aromatics units' simulation and control. Therefore, this research could be used as a guide for simulation and control of these units.

Simulation

Because the feed components in the C9-C10 tower are all non-polar or have very little polarity (feed composition is provided in appendix A), Peng- Robinson, CHAO-SEADER or BK10 equations can be used for the simulation. In this simulation Peng-Robinson equation was used. This model was chosen based on the minimum error in heat duties of condenser and reboiler simulation compared with operation data. Simulation and control in steady and dynamic modes have been done by Aspen plus and Aspen dynamics software.

Results and Discussion

Steady-state

Figure 2 shows the temperature profile of the C9-C10 splitter distillation tower. The vertical axis of this figure shows the temperature of each tower tray in degrees Celsius and the horizontal axis shows the number of trays (stages) of the tower. The important point about this figure is the relative increase in temperature after the feed entry stage, which is due to the temperature of the feed entering the tower. There is also a large change in temperature near the bottom of the tower due to the accumulation of heavy feed components that have a higher boiling point than other components.

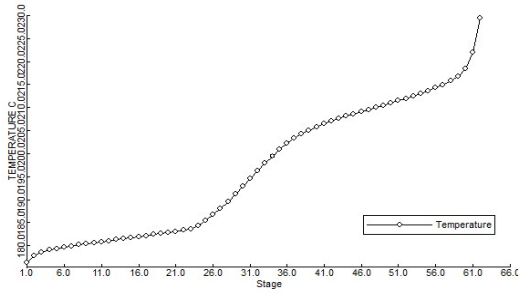


Fig. 2 C9-C10 splitter distillation tower temperature profile

Another result of the steady-state simulation is the pressure profile of the distillation tower trays, which is shown in Figure 3. The vertical axis in this figure is the pressure of the tower trays in terms of bar and the horizontal axis is the number of tower trays.

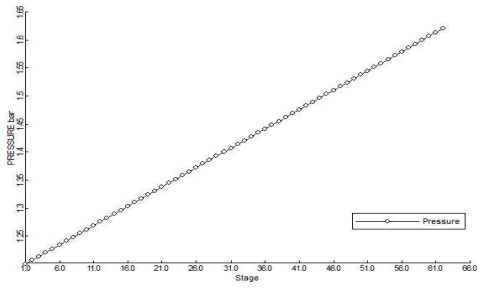


Fig. 3 Steady-state pressure profile of C9-C10 splitter column

The pressure gradient obtained in Figure 3 is the result of a pressure drop of 0.00689 bar, which was considered for each tray.

One of the key components of the distillation tower is 1,2,4-Trimethylbenzene. Its purity should be 37.23%. The percentage error for this component is 0.0016%, which indicates the accuracy of the simulation.

Table 1 shows the comparison between the thermal energy consumed by the condenser and the reboiler with the data available in Bouali Sina Petrochemical Complex. Case 1 is the petrochemical data and case 2 is the results obtained from the steady-state simulation.

Table 1.
Comparison of the thermal energy consumption of condenser and reboiler with operational data

	1	2	Error (%)
Condenser Heat Removal (MW)	5.63	5.66	0.532
Reboiler Heat Input (MW)	5.025	4.827	3.94

Dynamic Simulation

In this section, profiles of temperature, pressure, liquid, and vapor distributions in the steady and dynamic states on the trays of the C9-C10 splitter distillation tower are presented.

Figure 4 shows the temperature difference profiles of the tower trays in steady and dynamic states. The increase in temperature difference in the dynamic state compared to the Steady-state is due to the difference in pressure distribution between the steady and dynamic states.

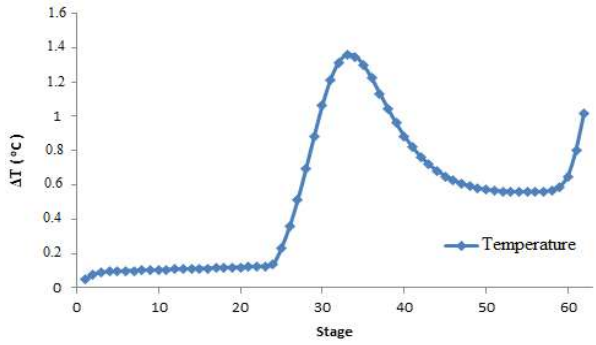


Fig. 4 Temperature difference profiles of the C9-C10 splitter distillation tower in dynamic and steady modes

Figure 5 shows the comparison of the difference in vapor distribution profile on the trays in steady and dynamic states, which indicates that the amount of vapor from the tower trays in the dynamic environment is higher than the steady-state.

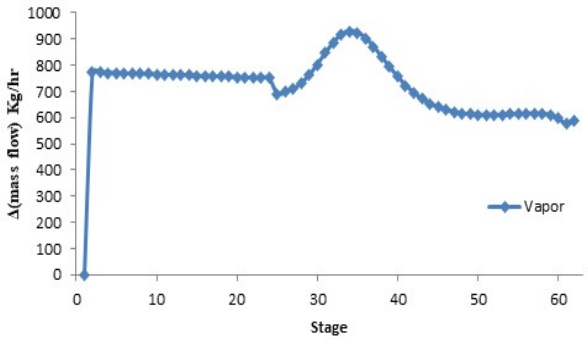


Fig. 5 Comparison between vapor load of C9-C10 splitter distillation tower trays in dynamic mode compared to steady-state

The performance of the control loops in re-establishing the tower stability was investigated, and the effect of disturbances on the feed flow rate of the C9-C10 splitter distillation tower was investigated. The perturbations were ±15% change in feed flow rate. The perturbations were controlled by four closed-loop control models (LV), (DV), (L / L + D, V) and (L / L + D, and V / B). Distillation of the C9-C10 splitter was controlled by two-point control models.

System response to changes in feed flow rate

The first is the controllability of the tower at a flow rate of 40,000 Kg/hr. (15% reduction in feed flow rate) was investigated. Reducing the feed flow reduces the liquid on the lower trays of the column as well as reduces the liquid level at the bottom of the tower. By keeping the heat load of the reboiler constant, the vapor stream moves the heavier components to the top of the tower, thus reducing the purity of the product at the top of the tower. Having a proper control loop reduces the negative effects of this change and the tower returns to a stable state very quickly. Transient response of controllers of C9-C10 splitter column with four control models: (LV), (DV), (L / L + D, V), (L / L + D, V / B) are shown in Figures 6 and 7.

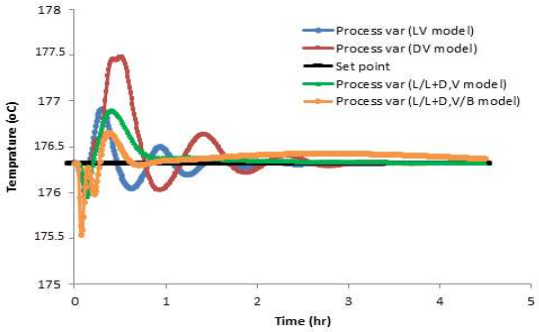


Fig. 6 Comparison of the transient response of top tower temperature with control models against a 15% reduction of feed flow rate

The tower's susceptibility to a flow rate of 55000 Kg/hr. (15% increase in feed flow rate) was investigated with the mentioned control models. As the feed flow increases, at constant reboiler load, the light components in the feed along with the heavy components come out of the bottom of the tower due to the reduction of vapor generated at the bottom of the tower. Transient response of controllers of C9-C10 splitter column with four control models: (LV), (DV), (L / L + D, V), and (L / L + D, V / B) is shown in Figure 7.

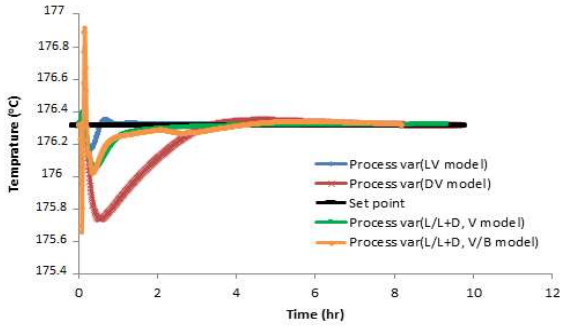


Fig. 7 Comparison of the transient response of top tower temperature with the control models against a 15% increase in feed flow rate

By increasing the feed rate by 15%, the transient response of the controllers showed that the control models (L / L +D, V) and (L / L+D, V/B) were able to bring the tower to a stable state in less than 1 hour. It should be noted that the LV model also performed very well to re-stabilize the tower against a 15% increase in feed flow rate except for controlling the liquid level. The DV control model took more than 4 hours to stabilize the tower and performed the worst among the two-point control models.

Conclusions

- Simulation of the C9-C10 splitter distillation tower of Bouali Sina Petrochemical Complex was performed and the results were compared with the designed values. The mean error percentages were 0.145% for the top tower products and 1.037% for the bottom products.
- In a dynamic simulation, PI controllers were used to control the feed flow rate, tower temperature, pressure, and level of tower reservoirs.
- A simple control structure was used to control the flow rate, pressure, and level of the tower tanks. However, in controlling the temperature of the tower, due to the complexity of its adjustment, the relay feedback control structure was used to find the gain and final frequency.
- To test the control performance of the distillation tower, perturbations such as changes in feed flow rate were performed and two-point control models (LV), (DV), (L/L +D, and V) (L/L +D and V/B) were used to reestablish the tower. The control model (L/L +D and V) was the best model for perturbation control and the (DV) model was the worst.

Acknowledgments

The authors would like to thank Bouali Sina Petrochemical Complex for providing the operational data.

References

1. P. Rafoei, M. Shahrokhi, *Inferential control of distillation tower prediction*, Journal of Chemical and Petroleum Engineering, Volume 44, Number 1, October 2010.

2. A. Mohammadi Doust, *Simulation of distillation unit of Kermanshah refinery in steady-state and dynamics*, MSc. thesis in Chemical Engineering, University of Sistan and Baluchestan, September 2011.

3. W. L. Luyben, *Feed-Stage Multiplicity in Multicomponent Distillation*, Ind. Eng. Chem. Res., 49, 3980–3982. 2010, https://doi.org/10.1021/ie1001108.

4. M. Hossein Zadeh, A. Samadi, M. Zivdar, *Simulation of BTX Distillation Tower of Bu Ali Sina Mahshahro Petrochemical Presenting a suitable thermodynamic model to create optimal conditions*, The first process engineering conference in oil, gas, petrochemical and energy industries, Tehran, 2013, HTTPS: //civilica.com/doc/200075.

5. L. Qi, B. Wei, S. Cheng, *Dynamic simulation for gas distillation column based on an improved mechanism model*, Control Conference (CCC), 29th Chinese, 2010.

6. M. Zakwan Zaine, M. Faris Mustafa, I. Norazana, I. Kamarul Asri, H. Mohd. Kamaruddin Abd. *Minimum Energy Distillation Columns Sequence for Aromatics Separation Process*, Energy Procedia, Volume 75, August 2015, Pages 1797-1802, https://doi.org/10.1016/j.egypro.2015.07.146.

7. V. Francisco da Silva Filho, J. L. Francisco Alves, G. Francisco Reus, R. A. Francisco Machado, C. Marangoni, A. Bolzan, *Experimental evaluation of the separation of aromatic compounds using falling film distillation on a pilot scale*, Chemical Engineering and Processing - Process Intensification, Volume 130, August 2018, Pages 296-308, https://doi.org/10.1016/j.cep.2018.06.026.

APPENDIX A: Feed composition

Table 1. C9-C10 Splitter tower feed

	Component Name	Component ID in Aspen Plus	Kg/h	Wt%
1	Para-Xylene	P-XYL-01	1	0.00
2	Meta-Xylene	M-XYL-01	3	0.01
3	Ortho-Xylene	O-XYL-01	118	0.25
4	Isopropyl benzene	ISOPR-01	531	1.12
5	N-Propyl benzene	N-PRO-01	1292	2.72
6	Methyl-3-Ethylbenzene	1-MET-01	7671	16.15
7	Methyl-4-Ethylbenzene	1-MET-02	3490	7.35
8	1,3,5-Trimethylbenzene	1:3:5-01	5596	11.78
9	Methyl-2-Ethylbenzene	1-MET-03	2768	5.83
10	1,2,4-Trimethylbenzene	1:2:4-01	16612	34.97
11	1,2,3-Trimetylbenzene	1:2:3-01	3154	6.64
12	Indane	INDAN-01	379	0.80
13	1-Methyl-3-Isopropylbenzene	1-MET-04	92	0.19
14	1-Methyl-3-N-Propylbenzene	1-MET-05	457	0.96
15	1,3-Dimethyl-5-Ethylbenzene	5-ETH-01	657	1.38
16	1,4-Diethylbenzene	1:4-D-01	145	0.31

17	1,4-Dimethyl-2-Ethylbenzene	2-ETH-01	346	0.73
18	1,3-Dimethyl-4-Ethylbenzene	4-ETH-01	471	0.99
19	1,2-Dimethyl-4-Ethylbenzene	4-ETH-02	576	1.21
20	1,3-Dimethyl-2-Ethylbenzene	2-ETH-02	21	0.04
21	Mindane	MINDANE	185	0.39
22	1,2-Dimethyl-3-Ethylbenzene	1:2-D-01	117	0.25
23	1,2,4,5-Tetramethylbenzene	1:2:4-02	638	1.34
24	1,2,3,5-Tetramethylbenzene	1:2:3-02	709	1.49
25	1,2,3,4-Tetramethylbenzene	1:2:3-03	267	0.56
26	Naphthalene	NAPHT-01	288	0.61
27	C_{11} Aromatics (Butyl-Benzoate)	N-PEN-01	907	1.91
28	2-Ethyl-Meta Xylene	2-ETH-03	7	0.01
29	C_{10} Paraffines Heavy	N-DEC-01	12	0.03
	TOTAL		47510	100
Feed Temperature		203 °C		
Feed pressure		10.5 bar		