Scientific Research Publishing

World Journal of Engineering and Technology, 2020, 8, 443-455
https://www.scirp.org/journal/wjet
ISSN Online: 2331-4249
ISSN Print: 2331-4222

Simulation of Stripper Flooding Due to the Increase of Feed Flowrate

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How to cite this paper: Al Mehairbi, M.J., Al Mahri, S.A. and Dadach, Z.E. (2020) Simulation of Stripper Flooding Due to the Increase of Feed Flowrate. *World Journal of Engineering and Technology*, **8**, 443-455.
https://doi.org/10.4236/wjet.2020.83033

Received: July 13, 2020
Accepted: August 18, 2020
Published: August 21, 2020

Abstract

In this investigation, UniSim software and the Soave-Redlich-Kong (SRK) thermodynamic model were utilized to study flooding in a Naphta stripping column. The objective of this study was to evaluate the impact of increasing feed flowrate from a design load of 121 m^3/hr. to 165 m^3/hr. on the performance of the plate column. In order to study only flooding in the column, UniSim software was run by keeping the LPG (Liquefied Gas petroleum) and Naphta products within the required specifications. According to the original design specifications of the stripping column, it should not be operated at high feed rates and differential pressure must not exceed 600 mbar. For the purpose of simulation, this value corresponds to a maximum allowable flooding percentage of 85%. The simulation results show that the flooding percentage was 144.5% in the case under study and 83.7% for the design case. Flooding occurred in all parts of the column with diameters of 2 m and 2.7 m. For the case under investigation, the reflux to feed ratio was reduced from 0.45 (design case) to 0.2. The originality of this investigation is the utilization of the temperature profile in the column as a tool to detect the plates where flooding could take place. The column temperature profile during the case under study suggests instability in the plates between trays 5 to 15. It is therefore suspected that flooding takes place mainly between those plates.

Keywords

Flooding, Temperature Profile, UniSim, Naphta Stripper

1. Introduction

Distillation is a unit operation utilized to separate components in a feed stream based on their boiling points. Flooding is a common technical problem that negatively affects the efficiency of the separation process. Depending on the degree

of flooding, the maximum capacity of the column may be severely reduced. Flooding is detected by sharp increases in column differential pressure and significant decrease in separation efficiency. Column differential pressure in a distillation column is known as the difference of pressure between the lower and upper elevations of the column. The increase of differential pressure in distillation columns is mainly related to the high flowrate of vapor in the column. For example, an increase in differential pressure could indicate that the feed rate is too high. Indeed, a higher feed flowrate would overload the column. There would be a resultant increase in differential pressure and the tower would be unable to make the desired separation. An increase of vapor flowrate in the column could also be caused by excess of vaporization in the reboiler of the column or decrease of the efficiency of the condenser. If the problem of flooding continues, the pressure of the vapour can increase to a point where it forces liquid out of the top of the column. This condition is known as puking. In actual practice, distillation columns usually have numerous control loops, running in Auto, controlling process parameters like feed rate, column pressure, reboiler heat duty, reflux ratio, top and/or bottom product compositions, various temperatures, etc. The action and interaction of these control loops can make detection and diagnosis of flooding difficult [1]. There are many research investigations on flooding phenomena in distillation columns in the literature. Most studies have been conducted using packed columns since the probability of flooding occurring is much greater due to packing than between trays. One of the studies was performed by Emerson Process Management with the use of a differential pressure transmitter. According to the authors, the use of a transmitter to measure the differential pressure across the distillation column can help to detect when flooding starts. The research predicted flooding only in the case of a sharp increase in differential pressure [2]. Mathematical models were also developed to predict or estimate flooding capacity in a column using superficial flooding velocities of the vapor and liquid [3]. Other studies focused mainly on the pressure drop measurements on distillation columns [4] and computational fluid dynamics on the column trays [5]. The flooding phenomenon in the bubble-cap tray distillation column was also investigated. In an experimental investigation, flooding occurred at a vapor rate of 81 kg/hr. and before the production goals could be reached. Flooding was detected by an increase in differential pressure in the column, rising above 0.13 barg. According to the author, the reason for flooding to occur before production goals could be caused by the design flaw of the downcomers on some trays, which had double the tray spacing compared to the rest of the trays in the bubble-cap tray distillation column [6]. According to an investigation on crude oil distillation columns, flooding reduced crude distillation unit capacity by 20,000 to 25,000 bpd. Flooding occurred in plates between the top of the column and the kerosene side stripper vapor return tray but the exact location was unknown. The differential pressure in these plates increased from 0.22 psi to the range 0.24 - 1.75 psi [7]. The flooding situation caused the following technical problems:

1) An increase in pressure drop between the diesel side stripper vapor return tray and the top of the column.

2) An increase in kerosene draws temperature.

3) Loss of level in kerosene side stripper.

4) High column bottom's level.

The authors proposed a bypass line as a solution to the flooding problem. The function of this bypass line was to route a slipstream of top pump-around liquid onto the third tray below the pump-around collector. The bypass line increased the condensation rate of vapors below the pump-around collector tray which resulted in a high kerosene product rate. Hence, the diesel pump-around was reduced and the fractionation between the diesel and kerosene was improved.

In this investigation, UniSim software and the Soave-Redlich-Kong (SRK) thermodynamic model are utilized to study flooding in a forty-three-tray distillation column when the unit load was increased for investigation from a design load of 121 m^3/hr. to 165 m^3/hr. The Constraints of the simulation are:

1) Maintaining maximum light naphtha RVP of 0.75 Kg/cm^2 which is produced in Naphtha splitter located downstream the stripper column.

2) Maintaining maximum C5 in LPG Stripper to be 2% C5 and weathering test of 2˚C.

3) Processing more LPG (C3 and C4) than original design due to the variations in the crude feed quality.

Since flooding is more likely to occur in the smaller diameter, the part of the column having 2 m as the diameter of the column was a focus of this investigation. The originality of this investigation is the use of temperature profile in the column to detect the plates with potential flooding.

2. Background

2.1. Introduction to Mass Transfer by Diffusion

Diffusion mass transfer involves the movement of molecules from one phase to another for the purpose of achieving a desired concentration in one of the phases. The driving force of mass transfer is the difference in concentration. One of the important equations in the mass transfer process by diffusion is Fick's law

$$J = -D * \Delta C / \Delta x \tag{1}$$

where J is the Mass flux, D is the Diffusivity, ΔC is Concentration difference, and Δx is the distance for mass transfer.

2.2. Relative Volatility

The most important factor which determines the ease of separation of two components in a column is the relative volatility *aij*. It is a measure of the differences in volatility between the two key components, and hence their boiling points. The relative volatility of component "*i*" with respect to component "*j*" is defined as:

$$\alpha ij = \frac{yi}{xi} \Big/ \frac{yj}{xj} \tag{2}$$

where yi = mole fraction of component "i" in the vapour and xi = mole fraction of component "i" in the liquid

2.3. Vapor Liquid Equilibria

Distillation columns design is based on the boiling point properties of the components to be separated. Thus, the height and the number of plates of distillation columns are determined by the vapor liquid equilibrium (VLE) data for the mixtures (Figure 1).

2.4. Performance of Distillation Columns

The performance of a distillation column can be affected by many factors as follows:

1) Feed conditions;
2) State of Trays;
3) Vapor Flow Conditions;
4) Vapor velocity.

2.4.1. State of Trays

For most distillation columns, the weir holds a liquid level in each tray. The vapor must overcome this liquid head to move up the column. On the tray, the vapor and liquid are in contact and mass transfer by diffusion occurs (Figure 2). The actual number of trays required for a particular separation is determined by the individual efficiency of each tray. Thus, any operating condition that causes a decrease in tray efficiency will also affect the performance of the column.

2.4.2. Tray's Efficiency

Tray's efficiency (E) is one of the most relevant column performance parameters. The most important condition for satisfactory tray performance is achieving close contact between the liquid and the vapor phases. Trays provide contact for the mass transfer by diffusion between the vapor and liquid phases and their overall efficiency (E) can be calculated using the following equation:

$$E = \frac{Nt}{Na} \tag{3}$$

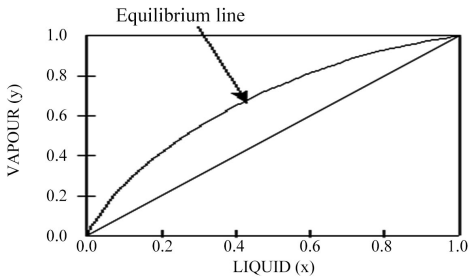

Figure 1. Vapor-Liquid-Equilibrium (VLE) curve [8].

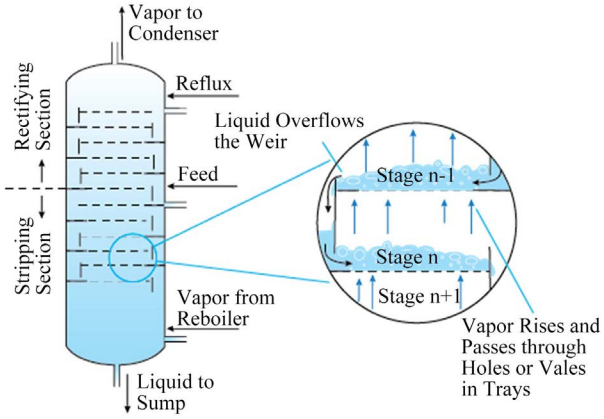

Figure 2. Liquid and Vapor flows through a column's plate [9].

where *Nt* is the theoretical number of trays and *Na* is the actual number of trays. Tray efficiency depends on the mass transfer by diffusion between the liquid and the vapor. Efficiency is achieved through adequate contact time between vapor and liquid. Thus, the higher the distribution height formed on the tray, the longer the contact time. The definition of plate efficiency given by Murphree is widely used in practice. Murphree tray efficiency is defined by comparing a real tray with an ideal tray approaching equilibrium. Since the contact time between the liquid and vapor in any plate affects the amount of light components to diffuse from the liquid to the vapor phase and the heavy components to diffuse from the vapor to the liquid phase, the Murphree tray efficiency can be approximately written with respect to the contact time between liquid and vapor in the plate as shown below:

$$E \propto \frac{tc}{tn} \tag{4}$$

where E is the tray efficiency, tc is the actual contact time between vapor and liquid and tn is the time needed for an ideal stage. Therefore, achieving a longer contact time between vapor and liquid will equate to a higher value of the efficiency of the plate. The residence time t_L of the liquid in a given tray is related to the volume of tray (V) which is constant and to the flow rate (FL) of the liquid as shown by the equation:

$$t_L = \frac{V}{FL} \tag{5}$$

On the other hand, the residence time t_V of the vapor in the same tray is related to the volume of the tray (V) which is constant and to the flow rate (FV) of the vapor as shown by the equation:

$$t_V = \frac{V}{FV} \tag{6}$$

It is evident that the vapor and liquid contact time increases when their flow rates decrease. Therefore, there is a maximum value of the flow rate of vapor and liquid in order to achieve the contact time that assures the required mass trans-

fer by diffusion of heavy and light components in that tray. The contact time considered to estimate the efficiency of the plate is the smaller one between t_V and t_L. Notably, tray efficiencies are affected by resistance, fouling, tear and corrosion. The rates at which these factors occur depend on the properties of the fluids being processed. Hence, appropriate materials should be specified for the choice of tray material and design.

2.5. Analysis of the Dynamics in a Distillation Column

It's clear from **Figure 3** that the area of satisfactory operation is sufficient and requires a certain value of liquid and vapor flow rates. As shown in **Figure 4**, when the limits of this area are exceeded, the problems below will occur:

1) The lower limit of the vapor flow is set by the condition of weeping. Weeping occurs when the vapor flow is insufficient to maintain a level of liquid in the plate.

2) Entrainment refers to the liquid carried by vapor up to the tray above and it is caused by the high vapor flow rates.

3) Coning occurs at low liquid rates, and is the term given to the condition where the vapor pushes the liquid back from the holes and jets upward, with poor liquid contact.

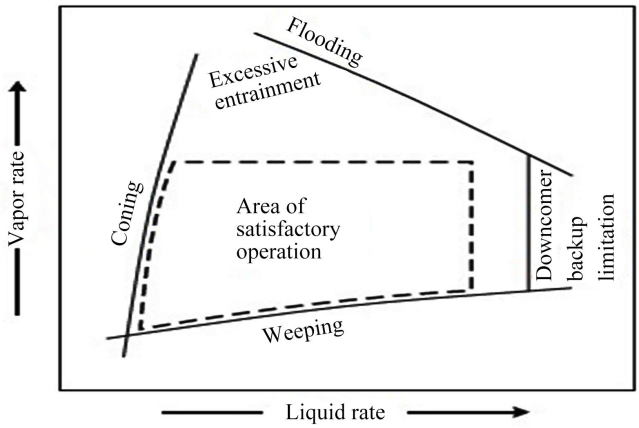

Figure 3. Sieve plate performance diagram [10].

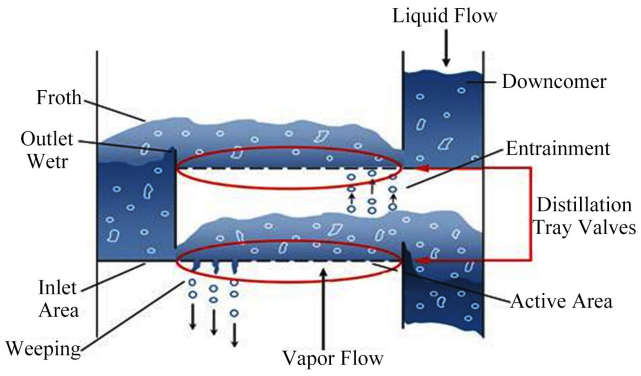

Figure 4. Conventional cross-flow distillation tray [4].

4) Flooding is brought about by excessive vapor and liquid flow, causing liquid to be entrained in the vapor up the column.

5) Excessive vapor results in an increase in pressure and it backs up the liquid in the downcomer, causing an increase in liquid holdup on the plate above.

2.5.1. Flooding

Flooding in a distillation column is a phenomenon whereby the rate of liquid coming into a tray from the tray above is higher than the rate of liquid leaving that tray through the downcomer, which causes the tray to fill up (become flooded) and the liquid is pushed to the tray above. It can be brought on either by excessive entrainment, where the rising vapor stream carries liquid to the tray above or liquid backup in the downcomer. The effective tray efficiency is lowered because liquid from a tray of lower volatility is carried to a tray of higher volatility, thereby diluting the effect of distillation. Moreover, the increased pressure from excessive vapor also backs up the liquid in the downcomer, causing an increase in liquid holdup on the plate above. Depending on the degree of flooding, the maximum capacity of the column may be severely reduced. Flooding is detected by sharp increases in column differential pressure (ΔP) and a significant decrease in separation efficiency. Also, the tower delta P is an indication of what level of liquid is in the trays. The tower's differential pressure is based on the amount of reflux that is added to the tower.

2.5.2. Vapor Velocity

As vapor flow increases in the column, its velocity will also increase. Hence, the flow rate is proportionally relational to the vapor velocity. Flooding determines the maximum vapor flow allowed, hence the column capacity. The vapor velocity (v) can be derived from the flooding velocity and the equation is defined as:

$$v = \frac{1.2}{\sqrt{\rho_G}} \tag{7}$$

where v is the vapor velocity, ρ_G is the density of the vapor. Flow, pressure, and temperature measurements allow the detection process of upsets, such as foaming, entrainment, weeping, and flooding. ΔP measurements offer the data required to better regulate the distillation process. When a distillation column is in a perfect state and operating consistently, the ΔP within the tower will remain stable. At a minimum, a single ΔP measurement should be made across the column. An even better solution is to additionally measure the ΔP across the stripping and rectifying sections, as well as individual trays. Pressure measurements can be implemented as needed across trays to further improve the operator's process insight.

3. Case Study: Flooding in Naphta Stripping Column

In this case study, naphtha was stripped off from light ends which are classified as LPG (C3 and C4) in a column that must be operated under certain required conditions. The forty-three plates are located in two parts of the column having

two different diameters of 2 m and 2.7 m. Column control does not allow simultaneous control of LPG quality and light naphtha RVP. According to the original design specifications of the stripping column, it should not be operated at high feed rates and differential pressure must not exceed 600 mbar (Table 1, Table 2).

Since the TBP (True Boiling Point) curve was not available, hypo component Naphtha* was assumed with specifications shown in Table 3.

3.1. The Design Operating Conditions (Design Case: 121 m³/hr.)

The design operating conditions of the stripper column were introduced as data in the UniSim software. The simulation results of the product specifications are shown in Table 4, Table 5.

Table 1. Column specifications.

Number of trays	43
Reflux feed ratio	0.45
Top Temperature, ˚C	82
Bottom Temperature, ˚C	138
Top Gauge Pressure, kPa	78.45

Table 2. Feed composition.

Naphtha Composition	
H2S	0.0002
Ethane	0.0016
Propane	0.0102
i-butane	0.0141
n-butane	0.0496
i-pentane	0.0445
n-pentane	0.0672
Naphtha*	0.8127

Table 3. Naphtha's Properties.

Base Properties	
Molecular weight	93.10
Normal boiling point, ˚C	75.00
Ideal liquid density, Kg/m³	698.0
Critical Properties	
Temperature, ˚C	245.0
Pressure, KPa	3024
Volume, m³/kg mole	0.3773
Acentricity,	0.2854

Table 4. LPG product specifications.

Temperature, ˚C	81.99
Pressure, Kpa	1569
Comp Mass Frac (i-Pentane)	**0.1267**
Comp Mass Frac (n-Pentane)	**0.1575**
Mass Flow, Kg/hr.	4189
Comp Mass Frac (Naphtha*)	0.1139

Table 5. Naphtha product specifications.

Temperature, ˚C	182.5
Pressure, Kpa	1589
Comp Mass Frac (i-butane)	**0.0087**
Comp Mass Frac (n-butane)	**0.0353**
Mass Flow, Kg/hr.	7.753e+4
Comp Mass Frac (Naphtha*)	0.8524

3.2. Operating Conditions under Investigation (Real Case: Feed Flowrate = 165 m^3/hr.)

The operating conditions of the stripper column were applied in the UniSim software. The feed flow rate was changed from 121 m^3/hr. to 165 m^3/hr. and the remainder of the operating conditions stayed unchanged. Most importantly, the flooding percentage was 144.5% which is far above the maximum allowable flooding percentage of 85%. Also, the reflux to feed ratio was reduced from 0.45 which is the design case to the actual reflux to feed ratio. The corresponding simulation data of the products specifications are shown in Table 6, Table 7.

Figure 5, Figure 6 show the difference in the column flow profile between the design and real cases. In both the design and real cases, the vapor and liquid curves were similar except that their molar flow rates are higher in the real case. The liquid in the column in the real case is twice as large as the liquid in the design case.

Another point is that the figures below showing a difference in the column temperature profile

Figure 7, Figure 8 are related to the temperature profile in the design case and the case under investigation. The temperature curve was standard in the design case while the increase of feed flowrate caused instability from trays 5 to 15.

4. Results Analysis and Discussion

Firstly, the simulation results show that the composition of i-Pentane in the LPG product was similar in both cases. However, the composition of n-Pentane de-

creased from 0.1575 (design case) to 0.0921 (real case). Regarding the quality of the Naphta product, the composition of i-butane decreased from 0.0087 to 0.0053 and the composition of n-butane decreased from 0.0353 to 0.0272. It should be noted that in order to study only flooding in the column, UniSim software was run by keeping the products within the required specifications, resulting in leaving large amounts of liquid inside the column.

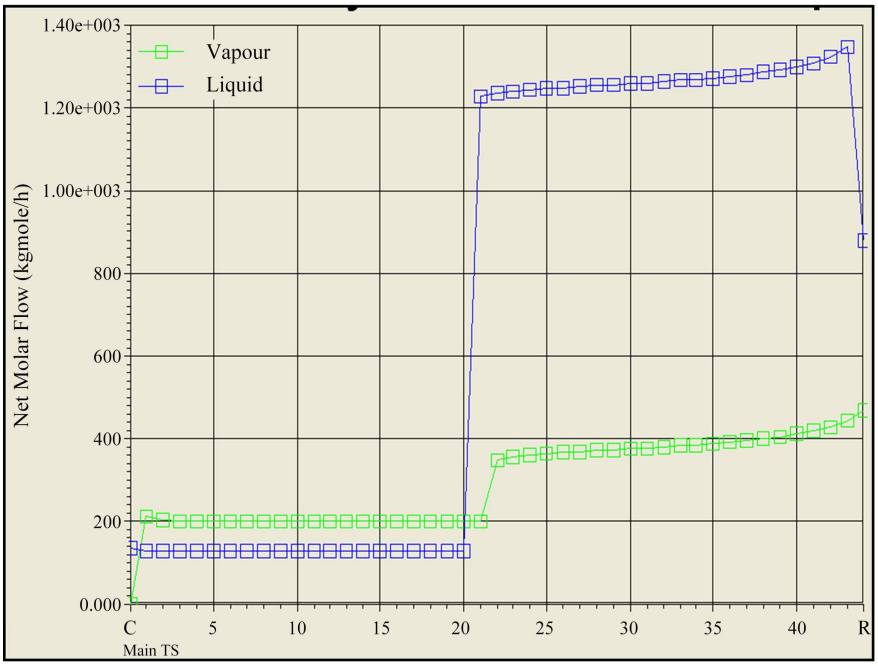

Figure 5. Column flow profile (Design Case).

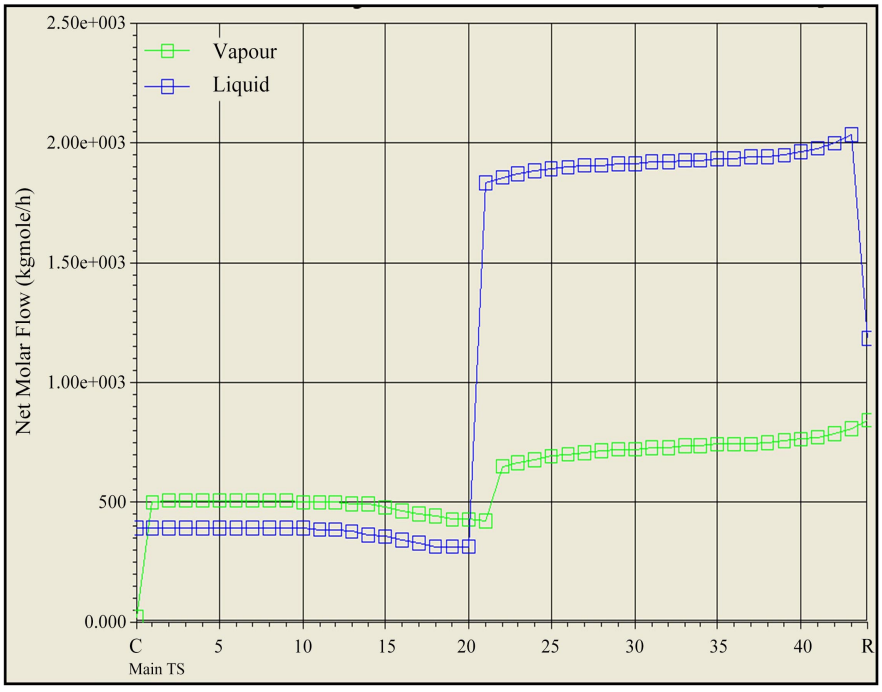

Figure 6. Column flow profile (Real Case).

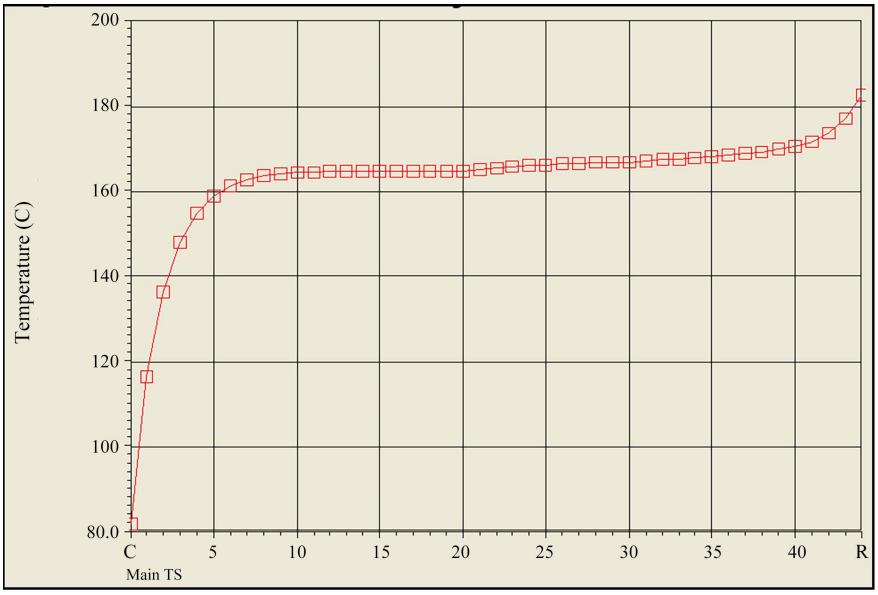

Figure 7. Column temperature profile (Design Case).

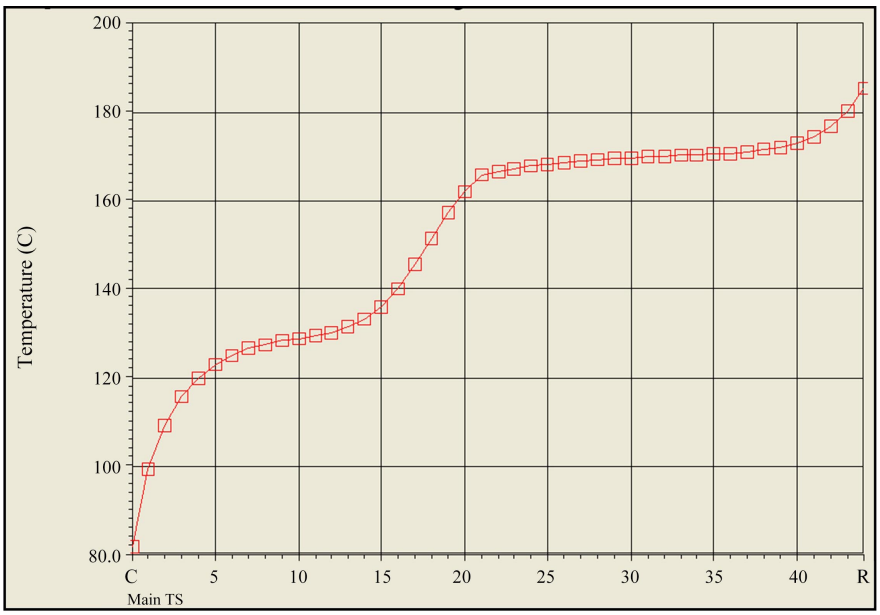

Figure 8. Column temperature profile (Real Case).

Table 6. LPG product specifications.

Temperature, ˚C	82.02
Pressure, Kpa	1569
Comp Mass Frac (i-Pentane)	**0.1329**
Comp Mass Frac (n-Pentane)	**0.0921**
Mass Flow, Kg/hr.	5009
Comp Mass Frac (Naphtha*)	0.000

Table 7. Naphtha product specifications.

Temperature, ˚C	185.3
Pressure, Kpa	1589
Comp Mass Frac (i-butane)	**0.0053**
Comp Mass Frac (n-butane)	**0.0272**
Mass Flow, Kg/hr.	1.054e+5
Comp Mass Frac (Naphtha*)	0.8609

Under the design operating conditions, the results were satisfactory as expected, while noting that the flooding percentage in the stripper was 83.7% which is below the maximum allowable flooding percentage of 85%. However, in the case under investigation, the flooding percentage was 144.5%. This percentage of flooding was found even in the part of the column having 2.7 m as diameter. According to the simulation results, it is evident that the stripper column is flooded with a large quantity of liquid caused by the high naphtha feed and reflux flow rates. It was noticed that in the design case, flooding did not occur when the diameter of the column was 2 m and 2.7 m respectively while in the real case, flooding occurred in the column with both diameters of 2 m and 2.7 m.

According to a similar investigation [7], flooding in an atmospheric distillation column occurred in plates between the top of the column and the kerosene side stripper and the differential pressure in these plates increased from 0.22 psi (design case) to the range 0.24 - 1.75 psi. The originality of this simulation project is the use of temperature profile in the column to detect the plates with potential flooding. Analyzing the temperature profile of both situations, the real case indicates instability from trays 5 to 15. It is therefore suspected that flooding takes place mainly between plates 5 and 15 of the column.

5. Conclusion

In this investigation, UniSim software and the Soave-Redlich-Kong (SRK) thermodynamic model were utilized to study flooding in the Naphta stripping column when the unit load was increased from a design load of 121 m^3/hr. to 165 m^3/hr. In order to study only flooding in the column, UniSim software was run by keeping the products within the required specifications, resulting in large amounts of liquid being deposited inside the column. Since flooding is more likely to occur in the smaller diameter, the part of the column with a 2 m diameter was selected in this investigation. The temperature profile in the column was also identified as a tool to detect the location of the potential flooding of plates. Firstly, the simulation results showed a small change in the composition of the LPG and Naphta products. Secondly, the flooding percentage was 144.5% in the case under study and 83.7% for the design case. The maximum allowable flooding percentage is 85%. It should be noted that for the case under investigation,

the reflux to feed ratio was reduced from 0.45 which is the design case to the actual reflux to feed ratio of 0.2. Finally, comparing the difference in the column temperature profile between the design and real cases suggests instability in the plates between trays 5 to 15. It is therefore suspected that flooding takes place between plates 5 and 15.

Acknowledgements

The authors wish to thank Higher Colleges of Technology, UAE for supporting this research work.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Liebermann, N.P. (1991) Troubleshooting Process Operations. 3rd Edition, Pennwell Publishing Co., Tulsa, 256-280.

[2] Emerson Process Management (2008) Distillation Column Flooding Diagnostics with Intelligent Differential Pressure Transmitter. http://www2.emersonprocess.com/siteadmincenter/PM%20Rosemount%20Documents/3051S_ASP_Distillation_Column_Flooding.pdf

[3] Piche, S., Larachi, F. and Grandjean, P.A. (2001) Flooding Capacity in Packed Towers: Database, Correlations, and Analysis. *Industrial & Engineering Chemistry Research*, **40**, 476-487. https://doi.org/10.1021/ie000486s

[4] Cai, T.J. and Resetarits, M.R. (2009) Pressure Drop Measurements on Distillation Columns. *Chinese Journal of Chemical Engineering*, **19**, 779-783.

[5] Liu, C.L. and Yuan, X.G. (2002) Computational Fluid-Dynamics of Liquid Phase Flow on Distillation Column Trays. *Chinese Journal of Chemical Engineering*, **10**, 522-528.

[6] Ozkaya, M. (2012) Determining the Operation Limits of Two Distillation Columns. A Thesis Submitted to the Faculty of the University of Tennessee at Chattanooga in Partial Fulfillment of the Requirements for the Degree of Master of Science in Chemical Engineering.

[7] Ruoss, S. (2001) Diagnose Flooding Columns Efficiently, Hydrocarbon Processing.

[8] Tham, M.T. (1997) Vapor-Liquid Equilibria, Distillation. https://www.rccostello.com/distil/distilvle.htm

[9] Duss, M. and Taylor, R. (2018) Predict Distillation Tray Efficiency, AIChE. https://www.aiche.org/resources/publications/cep/2018/july/predict-distillation-tray-efficiency

[10] Hebert, S. and Sandford, N. (2016) Consider Moving to Fixed Valves, AIChE. https://www.aiche.org/resources/publications/cep/2016/may/consider-moving-fixed-valves