CFD versus experiment: an investigation on liquid weeping of Nye tray

SADEGH ABBASNIA[1], Vali Shafieyoun[1], and Zarrin Nasri[1]

[1]Affiliation not available

May 8, 2020

Abstract

Weeping was investigated using some tests and a numerical model. The tests were performed within a 1.22 m-diameter pilot-scale column including two chimney trays and two Nye test trays by air-water system. The rates of weeping were measured in Nye trays with two heights of the weir and a 5% hole area. Moreover, the weeping rate in outlet half and inlet half of the Nye tray and the total weeping rate were calculated. Afterward, an Eulerian-Eulerian CFD technique was used in the current study. The results show good consistency between the attained CFD findings and the experimental data.

1. Introduction

To design a distillation tray, combining empirical and related theoretical findings is essential. An appropriate phase contact and an improvement in a tray's efficiency are achieved by a proper tray design. It has been proved that the trays possess suitable flexibility for operation in a satisfactory area of operation circumstances, which is called the tray's operation window or behavior diagram. This region is stated by the liquid and vapor rates. By a low vapor rate, tray efficiency declines by the liquid weeping; however, the force extends toward the above tray and the entrainment phenomenon takes place at a high vapor rate. Numerous distillation towers exist operating at a lower capacity compared to their design capacity. Hence, by determining the entrainment limits and liquid weeping of the trays, appropriate information can be obtained for enhancing the performance in towers. The weep fraction and dry tray pressure drop are two main hydraulic factors determining the lower operation limit for a tray[1-3]. The sieve trays are still the normal mass transfer tools in petroleum industries with their constant well features. The sieve tray's simple geometry results in the leakage of liquid within the deck holes at low vapor rates and decreases its normal operation window. Furthermore, the weeping is regarded as a usual reason for the trays' mal-functions in chemicals, olefins, refineries, and gas plants[4]. Lockett et al. [5]computed the reduction of tray performance caused by weeping. They attempted to prolong the former analyses' applicability [6-8] for industrial towers by attending the point where the gas phase is not combined between the trays. Fasesan [9] calculated the liquid weeping rate in absorption trays by two equal trays. His study focused on an absorption column with air-water system. The results were gained by two independent approaches of dye trace and weep-age catch tray method. Additionally, this researcher utilized a chimney tray for measuring the rate of weeping for valve trays and sieve through a direct volumetric technique. The findings illustrated that the liquid weeping is different between the trays. The obtained results indicated that by increasing the liquid load, the rate of weeping for a sieve tray working in the weeping trend increases linearly.

To utilize sieve tray towers for industrial uses more effectively, it is essential to have an enhanced theoretical understanding of the sieve tray hydraulics. In this regard, understanding some measurable and valuable parameters like pressure drop is essential but not enough. Hence, comprehending the detailed performances of instant liquid and vapor flows in the column is necessary. Previously, the mathematical models were developed to predict the liquid weeping and its rate [10-12] as alternative techniques to interpret a tray performance over weeping circumstances. A model was developed by Wijin [13] for lower operation limits of absorption and distillation trays. This author provided a novel technique to calculate the minimum gas flow rates of valve trays and sieve operating in the churn, bubble, and turbulent flow systems. Also, the researcher examined the association between tray efficiency and weeping.

Mehta et al.[14] Used the numerical method to investigate the hydrodynamic of perforated trays and presented detailed information in this regard. Furthermore, Yu et al. [15] and Liu et al. [16] assessed the hydrodynamic of tray by two- dimensional model through CFD. They presented models focusing on the variations and ignored the liquid phase hydraulics along with the gas flow in the direction of the dispersion height. A transient three-dimensional CFD model was presented by Quarini and Fischer [17] to investigate about the hydrodynamic of perforated tray.in foresaid model, drag coefficient was constant and equal to 0.44 . Moreover, the hydraulics of a sieve tray was enhanced by Krishna et al. [18] and Krishna and Van Baten [19] by approximating a novel drag coefficient for the large bubbles swarm in terms of the association of Bennett et al. [20]. A three-dimensional model was presented by Gesit et al. [21] for predicting the flow patterns and hydraulics of the sieve tray by CFD device utilizing Colwell [22] association for the liquid holdup working well in the force direction. A three-dimensional CFD simulation was presented by Teleken et al. with the mathematical homogeneous biphasic model [23-25] for evaluating the effect of electrical resistance of heaters over the sieve tray surfaces and its hydrodynamics. Moreover, Teleken et al. [24, 25] assessed a falling liquid film's flow via a distillation column via an Eulerian-Eulerian CFD technique. They aimed to provide a better interpretation of the feed distribution system. Patwardhan and Yadav [26] and Ud Din et al. [27] presented CFD models for comprehending the sieve's hydrodynamics and pulsed-sieve plate extraction column utilizing Eulerian-Eulerian method and the standard$k$ -ε turbulence model. Zarei et al. [28] studied the weeping phenomena in a circular sieve tray by experimental and CFD methods. The experiment was performed in a pilot-scale column with a diameter of 1.22 m including two chimney trays and two test trays. Some hydraulic parameters and weeping rates were calculated in sieve trays with a hole area of 7.04%. Overall, there was good consistency between the attained CFD findings and the experimental data. A 3D and biphasic model was presented by Yang et al [29] for the tray without a downcomer (Ripple tray) using the CFD. The model was homogenous following Euler-Euler interaction. They compared some elements like the clear liquid's height in the tray with the sieve tray and reported that the Ripple tray without downcomer experiences a rather small pressure drop compared to the sieve tray. Moreover, its operational flexibility was enhanced in comparison to the sieve tray. In [30], the hydraulics and flow patterns of a valve tray were predicted utilizing computational fluid dynamics simulation and experimental method. A three-dimensional CFD model was presented in the Eulerian frame work. Experimental findings of the average liquid holdup, froth height, clear liquid height, dry pressure drop, and total pressure drop were investigated and compared with the CFD results. The CFD results were in good consistency with experimental results. CFD simulation and experimental study on bubble cap tray were done in ref [31], Simulations were performed in industrial range of gas and liquid rates. Some hydrodynamic parameters were calculated and predicted. The gained results were in agreement with experiment. Abbasnia et al. [32] investigated the efficiency and mass transfer for the Nye tray and sieve tray. The system in their investigation was methanol-normal propanol. The distributions of methanol compositions on the trays were obtained for four average methanol compositions. The results revealed that the liquid composition profile on the Nye tray is enhanced compared to the sieve tray and more resembling the rectangular tray. Nye tray's Murphree efficiency was almost 10% higher than the sieve tray.

2. Experimental work

According to Fig. 1, the flow sheet design consists of a column with two chimney trays and two Nye trays. Three sight glasses are included in the column for facilitating the hydrodynamic phenomena observation over the trays. The air is blown by a blower through the column and water is pumped by a pump from a storing container inside the column to measure the water flow rate by a calibrated flow meter. Given the studied air/water system, the air outlet effluents to the surrounding. Inlet downcomer of the upper Nye tray, is filled with rings. Table 1 represents the specifications of the trays. Besides, the gas velocity is measured utilizing a calibrated pitot tube located at the blower's exit and a chimney tray placed under the test tray gathers the liquid weeping from the test tray then it is brought back to the tank. The height of the separator baffle is crucial for determining the liquid wept from two halves of the tray. To prevent any effect on the gas distribution, the height of the separator baffle must be lower than the chimney caps, as well as it must prevent from overflowing between two sides [33, 34].

The comparison between the experimental data and numerical predictions was limited to the relatively restricted set of available computational power and experimental data in the literature. In this regard, the current experimental data can be useful for the readers concerning Nye trays.

3. CFD simulation

3.1. Framework

In the present research, two imperative multiphase models of Eulerian-Eulerian and volume of fluid (VOF) are utilized. The VOF method is a proper numerical technique to simulate the two-phase flows. The gas-liquid interface is a critical feature of this modeling. The model can be utilized to make the interface between the phases (a free surface reconstruction technique). This technique is also employed for mass and heat transfer in two-phase flows. In the present work, it was tried to assess the weeping rate of a column armed with Nye trays for the whole system not mainly for the gas-liquid interfaces. Consequently, an Eulerian-Eulerian method was chosen for this work. Here, two sets of transient CFD models in the 3D framework were established to investigate the single and two-phase flows via a full three-dimensional geometry of the circular distillation column. The Eulerian-Eulerian multiphase flow was utilized where the phases are treated as interpenetrating continua. Furthermore, the pressure velocity coupling was incorporated using the SIMPLE algorithm. To solve the transient equations prior to reaching the quasi mode, the time period of 0.002 s was considered. The upwind technique was also used for the advection discretization scheme and second-order backward Euler for integrating the time. The equations of momentum balance, species conservation, and mass conservation were solved but the energy conservation was neglected due to the isothermal system.

3.2. Basic equations

Modeling of two phases were carried out by transport equations. The transport equations (continuity, mass transfer and momentum) were carried out concerning two phases numerically. the continuity equation is expressed as follows:

$$\frac{\partial(\varepsilon_L \rho_L)}{\partial t} + \nabla.\left(\varepsilon_L \rho_L u_L\right) = -S_{\mathrm{GL}} \quad (1)$$

$$\frac{\partial(\varepsilon_G \rho_G)}{\partial t} + \nabla.(\varepsilon_G \rho_G u_G) = S_{\mathrm{GL}} \quad (2)$$

Where S_{LG} shows the mass transfer rate from the liquid phase to the gas phase and vice versa. The local balance condition must be satisfied by the mass transfer between the phases, soS_{LG}= -S_{GL}.

The equation of momentum is as follows:

$$\frac{\partial(\rho_L \varepsilon_L u_L)}{\partial t} + \nabla.\left(\rho_L \varepsilon_L u_L u_L - \mu_L \varepsilon_L \left(\nabla u_L + (\nabla u_L)^T\right)\right) = -\varepsilon_L \nabla p - M_{G,L} + \rho_L \varepsilon_L g, \text{ and} \quad (3)$$

$$\frac{\partial(\rho_G \varepsilon_G u_G)}{\partial t} + \nabla.\left(\rho_G \varepsilon_G u_G u_G - \mu_G \varepsilon_G \left(\nabla u_G + (\nabla u_G)^T\right)\right) = -\varepsilon_G \nabla p + M_{G,L} + \rho_G \varepsilon_G g. \quad (4)$$

Here, $\varepsilon_G$and ε_L the volume fractions of the liquid and gas phases, respectively. As well as:

$$\varepsilon_G + \varepsilon_L = 1. \quad (5)$$

The interphase momentum transfer (drag force), i.e., M_{GL} , is evaluated as follows:

$$M_{\mathrm{GL}} = \frac{3}{4}\rho_L \frac{\varepsilon_G}{d_G} C_D \left(u_G - u_L\right) \left|u_G - u_L\right|, \quad (6)$$

Where

C_D is the drag coefficient:

$$C_D = \frac{4}{3} \frac{\rho_L - \rho_G}{\rho_L} g d_G \frac{1}{V_{\mathrm{Slip}}{}^2}, \quad (7)$$

V_{slip} is slip velocity:

$$V_{\mathrm{slip}} = \frac{U_G}{\varepsilon_G{}^B}, \quad (8)$$

And ε_G^B and ε_L^B are the average volume fractions:

$$\varepsilon_L^B = \exp\left[-12.55\left(U_G\sqrt{\frac{\rho_G}{\rho_L - \rho_G}}\right)^{0.91}\right], \text{ and} \quad (9)$$

$$\varepsilon_G^B = 1 - \varepsilon_L^B. \quad (10)$$

Finally by replacing:

$$M_{\mathrm{GL}} = \varepsilon_G \left(\rho_L - \rho_G\right) g \frac{\varepsilon_G^B}{U_G^2} \left(u_G - u_L\right) \left|u_G - u_L\right|, \quad (11)$$

Ultimately, k -ε model was utilized concerning dispersed phase.

3.3. Boundary conditions and geometry

Taking into account two distinct drag coefficients for each section, the computational domain is divided into two parts. The upper section is initiated from the test tray deck to the outlet zone and the space under the test tray is the lower section where the liquid weeping appears under the special condition. The drag coefficient presented by Krishna et al. [18] independent of bubble diameter is used in the upper space because of its extensive use by several researchers [18, 19, 30, and 33]. Moreover, the heterogeneous and froth bubbly regimes are found in this domain for specific gas velocities. For the lower section, Grace's drag model is utilized, in which the liquid weeping is subjected to the upward gas stream [28].

$$C_D = \frac{4}{3} \frac{\rho_L - \rho_G}{\rho_L} g d_G \frac{1}{U_T{}^2}, \quad (12)$$

Fig. 2 represents the computational domain of the Nye tray. The Eulerian framework is utilized to investigate the weeping phenomena. Moreover, the utilized values of Fs for investigating the weeping phenomena are at the lower operation ranges. Based on the previous studies, a no-slip wall boundary condition is considered for the liquid phase, in addition, a free slip boundary condition is taken for the gas phase on the wall [15, 21, 28, 30, and 32]. The liquid and gas phases are water and air at the atmospheric pressure and 25. Initially, the volume fractions of water and air for the tray are identified. The water volume fractions of 0.8 and 0.01 are adjusted for the dispersion height and the region above this height, respectively. Moreover, it is presumed that the downcomer is occupied with water to the height of 0.275. The superficial gas velocity is utilized as an initial guess for the gas velocity's vertical component throughout the computational domain. A uniform horizontal velocity distribution equivalent to the liquid inlet velocity is considered for the froth region as the other initial guess [28]. Also, a parabolic profile is taken for the liquid inlet velocity and the outlet and inlet liquid volume fractions are both presumed to be unity. It is of note that only the liquid is introduced to the downcomer clearance. Similarly, the gas phase goes to the vapor inlet and leaves the vapor outlet with the volume fractions of 1 [28].

3.4. Mesh independency

In this section, the clear liquid height over the tray is determined for numerous meshes. The findings indicate that for the Nye tray, the optimal number of cells is 1,103,870. Table 2 illustrates the details of different meshes and Fig. 3 shows the meshing of the Nye tray.

4. Results and discussion

4.1. CFD and experimental results

Over the tests, various values of Fs within the range of 0.27-1.21 m/s (kg/m^3)$^{0.5}$ and 3 liquid rates of 0.0053, 0.0105, and 0.0158 m^3/s were used. These operating circumstances are in the weeping range allowing better investigation of this occurrence. The liquid rate values were in the industrial scale as well. Moreover, two different heights of the weir are utilized in the test.

4.1.1. CFD and experimental results at Q=0.0053 (m^3/s)

Figs. 4 and 5 show the liquid weeping rate for each tray half as a function of Fs respectively at$h_w = 5cm$ and $h_w = 7.5cm$ for Q=0.0053 (m^3/s) flow rate. As can be seen from these figures, weeping rates in the upstream are higher compared to the downstream for this flow rate. Figs. 6 and 7 confirm the results of Figs. 4 and 5. Based on these figures, higher heights of weir lead to the raising of liquid weeping from the tray deck.

4.1.2. CFD and experimental results at Q=0.0105 (m^3/s)

Figs. 8 and 9 illustrate the liquid weeping rate for each tray half as a function of Fs respectively at$h_w = 5cm$ and $h_w = 7.5cm$ for Q=0.0105 (m^3/s) flow rate. Raising the liquid flow rate results in an increase in the weeping rate for outlet and inlet halves of the tray. For a low gas velocity range, the flow regime has a tendency toward the dumping or channeling weeping for both parts of the tray. Also, it is obvious that weeping rates in the downstream are more than those of the upstream for this flow rate and weir height is effective in the amount of tray weeping. Overall, increasing the weir height results in a subsequent increase in the clear-liquid height and an increase in the weeping rate (Figs. 8 and 9). Figs. 10 and 11 and 12 confirm these issues.

4.1.3. CFD and experimental results at Q=0.0158 (m^3/s)

Figs. 13 and 14 present the liquid weeping rate for each tray half as a function of Fs respectively at$h_w = 5cm$ and $h_w = 7.5cm$ for Q=0.0158 (m^3/s) flow rate. However, at high liquid rates, it is observed that changing the weir height from 5 to 7.5 cm has only a slight effect (Figs. 13 and 14). Evidently, weeping rates in the downstream are higher compared to the upstream for this flow rate. It is observed that different weeping rates in downstream and upstream of the tray decline with an increase in the gas flow rate. Figs. 15 and 16 verify the results of Figs. 13 and 14.

4.1.4. A limited CFD comparison between the Nye tray and the same sieve tray

Figs. 17 and 18 give the liquid velocity vectors and weep rates, respectively, for the Nye tray and the same sieve tray in Q=0.0105 (m^3/s), F_S=0.392 m/s $(kg/m^3)^{0.5}$, and $h_w = 5cm$. As can be noticed, there is a negligible difference between the weeping rate downstream and upstream of the sieve tray but concerning the Nye tray, the difference between the weeping rate downstream and upstream of the Nye tray is massive. Furthermore, the total weeping rate for the Nye tray is close to the total weeping rate of the sieve tray but slightly higher. Fig. 17 shows that the velocity of water drops is almost uniform along with the Nye tray, where this parameter is ununiformed along with the sieve tray.

5. Conclusion

The liquid weeping as a key element in performance of trays was investigated by the experiments and CFD model. A bunch of tests were carried out by the experimental tower in industrial scale where the experimental tower had two Nye trays and two chimney trays. The area of holes was 5% (based on total area).

The weeping in outlet and inlet sections of the tray and the total weeping rate were experimentally determined. It was found that the weeping rates in the inlet section of the Nye tray are higher compared to the outlet half of the Nye tray for low liquid flow rates where weeping rates were greater in outlet half of the Nye tray for middle and high liquid flow rates. Moreover, the difference between the weeping rate from downstream and upstream of the Nye tray reduces by increasing the gas flow rate. Moreover, higher gas rates provide low weeping rates along with the tray, which may result in increased tray efficiency. Besides, it was observed that taller weir height increased weeping rate unless at high liquid rate. Through a limited comparison between Nye tray and the same sieve tray, it was revealed that weeping rates in the inlet of the sieve tray were higher compared to the outlet of the sieve tray. But concerning the Nye tray, weeping rates in the downstream were very larger rather than those in the upstream. It is noteworthy that some weep can be endured without noticeably affecting the tray efficiency. Some mass transfer from and to the weeping liquid happens to reduce the effect of bypassing on efficiency. Weeping from the exit section of the tray is not detrimental to tray efficiency to some extent compared to weeping from the inlet of the tray and is endured to a much higher level [3]. Regarding this issue, it is demonstrated that the Nye tray is suitable for operating in high liquid rates where weeping rates tend toward the outlet half of the Nye tray. Overall, it seems that the inlet panel of the Nye tray makes a higher capacity for tray where it leads to very low weeping rates from the inlet of the Nye tray. This specification is a positive point of Nye tray and may provide high efficiency compared to a sieve tray.

Nomenclature

F_S F-factor [m/s $(kg/m^3)^{0.5}$]

L_w Weir length [m]

P Pressure [Pa]

$U_{G,in}$ Hole gas velocity [m/s]

U_G Gas phase superficial velocity based on the bubbling area [m/s]

U_T Droplet terminal velocity (m/s)

g Gravitational acceleration [˜ 9.8 m/s^2]

$M_{G,\ L}$ Interphase momentum transfer [kg/m^2s^2]

$Q_{\ \mathrm{L}}$ Liquid volumetric flowrate [$1/m^3s$]

$C_{\ \mathrm{D}}$ Drag coefficient [-]

V_{Slip} Slip velocity [m/s]

h_c Effective clear liquid height [m]

V_L , u_L Liquid velocity [m/s]

V_G , u_G Gas velocity [m/s]

h_w Height of weir [m]

A_B Bubble area of tray [m^2]

A_H Total area of holes [m^2]

R Radius of the tray (m)

S_{GL} Rate of mass transfer from gas phase to liquid phase [kg/m^{3}s]

S_{LG} Rate of mass transfer from liquid phase to gas phase [kg/m^{3}s]

z Coordinate position in the transverse direction to liquid flow across tray [m]

x Coordinate position in the direction of liquid flow along tray [m]

$x\ /L$ Dimensionless coordinate position along tray [–]

y Coordinate position in the direction of vapor flow across tray [m]

$z\ /R$ Dimensionless coordinate position across tray [–]

Greek letters

ρ Density [kg/m^3]

?? Velocity [m/s]

μ Dynamic viscosity [Pa s]

ε Volume fraction [-]

ε^B Average volume fraction [-]

Subscript

eff Effective

Lam Laminar

Tur Turbulent

G Gas phase

g Gas phase

l Liquid phase

L Liquid phase

n $n = 1, 2, 3, 4, \ldots$

i part i

References

1. Biddulph, M.W., *Oscillating behavior on distillation trays-II.* AIChE Journal, 1975. 21(1): p. 41-49.

2. Summers, D.R. *Performance Diagrams–All Your Tray Hydraulics in One Place* . in *AIChE Annual Meeting, Austin, TX, Distillation Symposium–Paper 228f* . 2004.

3. Kister, H., *Tray design and operation.* Distillation Design, 1992: p. 319.

4. Kister, H.Z., *What caused tower malfunctions in the last 50 years?* Chemical Engineering Research and Design, 2003. 81(1): p. 5-26.

5 Lockett, M., M. Rahman, and H. Dhulesia, *Prediction of the effect of weeping on distillation tray efficiency.* AIChE journal, 1984. 30(3): p. 423-431.

6. Kageyama, O., *Tray efficiency of distillation tower with weeping.* Kagaku Kogaku, 1966. 30: p. 629.

7. O'Brien, N.G., *Calculation of effect of liquid leakage on tray efficiency and tray requirements.*Industrial & Engineering Chemistry Process Design and Development, 1966. 5(4): p. 382-387.

8. Kageyama, O. *Plate efficiency in distillation towers with weeping and entrainment* . in *Chem. E. Symposium Series* . 1969.

9. Fasesan, S.O., *Weeping from distillation/absorption trays.* Industrial & Engineering Chemistry Process Design and Development, 1985. 24(4): p. 1073-1080.

10. Zhang, W. and R. Tan, *A model for bubble formation and weeping at a submerged orifice.* Chemical engineering science, 2000. 55(24): p. 6243-6250.

11. Zhang, W. and R. Tan, *A model for bubble formation and weeping at a submerged orifice with liquid cross-flow.* Chemical engineering science, 2003. 58(2): p. 287-295.

12. Zhang, W. and R. Tan, *The influence of liquid head and liquid circulation on weeping rates at a submerged orifice.* Chemical Engineering & Technology: Industrial Chemistry-Plant Equipment-Process Engineering-Biotechnology, 2003. 26(11): p. 1169-1175.

13. Wijn, E., *On the lower operating range of sieve and valve trays.* Chemical Engineering Journal, 1998. 70(2): p. 143-155.

14. Mehta, B., K. Chuang, and K. Nandakumar, *Model for liquid phase flow on sieve trays.* Chemical Engineering Research and Design, 1998. 76(7): p. 843-848.

15. Yu, K.T., et al.,*Computational fluid-dynamics and experimental verification of two-phase two-dimensional flow on a sieve column tray.* Chemical Engineering Research and Design, 1999. 77(6): p. 554-560.

16. Liu, C., et al., *A fluid–dynamic model for flow pattern on a distillation tray.* Chemical Engineering Science, 2000. 55(12): p. 2287-2294.

17. Fischer, C. and G. Quarini.*Three-dimensional heterogeneous modeling of distillation tray hydraulics* . in *AIChE annual meeting* . 1998.

18. Krishna, R., et al., *CFD simulations of sieve tray hydrodynamics.* Chemical Engineering Research and Design, 1999. 77(7): p. 639-646.

19. Van Baten, J. and R. Krishna,*Modelling sieve tray hydraulics using computational fluid dynamics.* Chemical Engineering Journal, 2000. 77(3): p. 143-151.

20. Bennett, D., R. Agrawal, and P. Cook, *New pressure drop correlation for sieve tray distillation columns.* AIChE Journal, 1983. 29(3): p. 434-442.

21. Gesit, G., K. Nandakumar, and K.T. Chuang, *CFD modeling of flow patterns and hydraulics of commercial-scale sieve trays.* AIChE journal, 2003. 49(4): p. 910-924.

22. Colwell, C.J., *Clear liquid height and froth density on sieve trays.* Industrial & Engineering Chemistry Process Design and Development, 1981. 20(2): p. 298-307.

23. Teleken, J., et al., *CFD simulation of multiphase flow in a sieve tray of a distillation column.*Brazilian journal of petroleum and gas, 2009. 3(3).

24. Teleken, J.G., et al.,*Computational fluid dynamics simulation of the feed distribution system of a falling film distillation device* , in *Computer Aided Chemical Engineering* . 2012, Elsevier. p. 845-849.

25. Teleken, J.G., et al.,*Fluid-dynamics study of multiphase flow in a sieve tray of a distillation column* , in *Computer Aided Chemical Engineering* . 2010, Elsevier. p. 73-78.

26. Yadav, R.L. and A.W. Patwardhan,*CFD modeling of sieve and pulsed-sieve plate extraction columns.*Chemical Engineering Research and Design, 2009. 87(1): p. 25-35.

27. Din, G.U., et al., *Modeling of a two-phase countercurrent pulsed sieve plate extraction column—a hybrid CFD and radiotracer RTD analysis approach.* Separation and Purification Technology, 2010. 73(2): p. 302-309.

28. Zarei, A., S.H. Hosseini, and R. Rahimi, *CFD and experimental studies of liquid weeping in the circular sieve tray columns.* Chemical Engineering Research and Design, 2013. 91(12): p. 2333-2345.

29. Yang, N., et al.,*Computational fluid dynamics and experimental validation of hydrodynamics of ripple tray.* Journal of the Taiwan Institute of Chemical Engineers, 2015. 53: p. 6-14.

30. Zarei, T., M. Farsiani, and J. Khorshidi, *Hydrodynamic characteristics of valve tray: Computational fluid dynamic simulation and experimental studies.* Korean Journal of Chemical Engineering, 2017. 34(1): p. 150-159.

31. Shenastaghi, F.K., et al.,*CFD simulation and experimental validation of bubble cap tray hydrodynamics.* Separation and Purification Technology, 2018. 192: p. 110-122.

32. Abbasnia, S., Z. Nasri, and M. Najafi, *Comparison of the mass transfer and efficiency of Nye tray and sieve tray by Computational fluid dynamics.* Separation and Purification Technology, 2019.

33. Krishna, R., Van Baten, J.M., 2003. *Modelling sieve tray hydraulicsusing computational fluid dynamics.* Chem. Eng. Res. Des. 81, 27–38.

34. Lockett, M. and S. Banik,*Weeping from sieve trays.* Industrial & Engineering Chemistry Process Design and Development, 1986. 25(2): p. 561-569.

Hosted file

`Figures.docx` available at https://authorea.com/users/319825/articles/449520-cfd-versus-experiment-an-investigation-on-liquid-weeping-of-nye-tray