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DESIGN OF FEED DISTRIBUTION SYSTEM IN A FALLING FILM DISTILLATION USING CFD

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Abstract
This paper is about the analysis 0f the liquid discharge by falling film within a distillation tube. Specifically about some flow rates that can be used in this process, when we talk about film´s discharge and maintenance. This aim of this paper is to study through simulations in CFD (Computational Fluid Dynamics) what influence the feeding flow rate has on the film´s formation, its stability and thickness. This distillation process has low resistance to the liquid flow and high capability of separation, besides a simple construction unity. The commercial code used in order to solve the mathematical modeling was ANSYSY CFX 12.0. The results obtained show that the best results achieved were low feeding flow rates, which provided a rather stable and continuous film and lower values of vapor superficial velocity.

Keywords: distillation, falling film, CFD, feed distribution system, feed flow.

1. Introduction

Distillation by falling liquid film is a low residence time and simple structure process when compared to conventional distillation. It basically consists of a vertical unit, through which the liquid flows downwards, creating a film. Besides, when constructive details are taken into account, it is possible to obtain high heat and mass transference rates[2]. However, this is an inherently non-equilibrium process, where the effect of the vapor generated by the liquid has nearly no influence on the separation factor and rate. Due to the non-existence of the convention by the ebullition, the distillated flow is extremely contained, many times needing renovation. In short, the process presents a simple construction, low resistance to the liquid discharge and high separation ability. As a consequence of the constructive and phenomenological characteristics of this process, its effectiveness is intrinsically related to the feeding system.

The hydrodynamics of the contact liquid-vapor has an essential function on the falling liquid film distillation design, since it determines the column fluid dynamic limits and controls the mass transference rates. In the last few years, there has been a considerable raise on the academic or industrial interest in the use of computational fluid dynamics (CFD) in order to model the multiphase discharge inside many chemical engineering equipments[3, 4, 5]. As a consequence, it has become a powerful tool for chemical processes design and analysis.

Due to the characteristics of the distillation process, it is necessary to use feeding devices that allow a uniform distribution and adequate formation of a liquid film throughout the walls of the unit. In this paper we show the CFD computational studies used in order to help the design of a distribution system of the feeding of the process of distillation by falling liquid film, along with experimental tests of the equipment. By defining the appropriate geometry and operational conditions it is possible to obtain a distribution of the adequate liquid film, minimizing dry or stagnation points. After defining the feeding systems and the conception of the geometry representing mesh, simulations were carried out varying the feeding flow rate. This variable was chosen due to its great importance to the distillation process by film, for it controls the evaporation and mass transference rates.

The aim of this paper is to evaluate what influence the feeding flow rate has in the formation and quality of the film besides its influence on the superficial velocity of the gas, for a feeding system previously designed and studied for this separation unity. The CFD technique was used as an auxiliary design tool due to its great ability of representing discharges in ducts. The CFD tools are used in order t solve mathematical equation of the model and to present a graphic solution that enables to easily visualize the problem solved, as well as the interpretation of the results.

2. Materials and Methods

The comercial code used to solve the modeling done, was ANSYS CFX 12.0. This code is based on the resolution of the differential equations by the finite volume method. The software demands some steps to be taken for the process modeling: pre-processing; processing; post-processing.

2.1 System Geometric Characteristics

Based on the paper by Batistella (1999), in some simulations and experimental results in CFD, the feeding distribution system was designed. Figure 1 presents a picture of the part used for the feeding distribution, with designed features. With the features of this part the experiments and simulations in CFD were carried out by varying the feeding flow rate (50, 25 e 10 $kg.h^{-1}$). The basically consists of a drilled steel cone, where the liquid flows throughout the outer wall and the vapor is generated by the inner part. This part is attached to the 1 m high and 26 mm internal diameter distillation unit. We can observe in Figure 2 the hybrid mesh (are used prismatic and tetrahedral volumes for better representation of the field and optimization calculations) built for the simulation.

Figure 1. Distribution and feeding part.

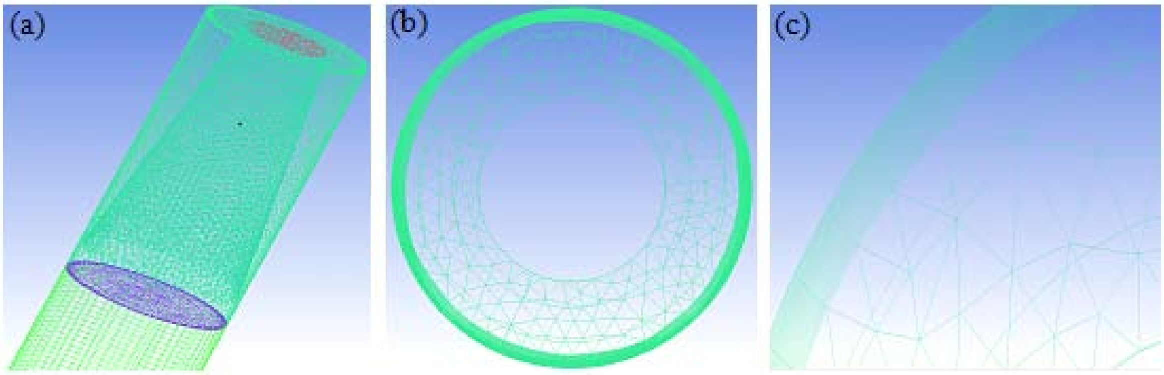

Figure 2. Hybrid mesh (a) cone (b) top view (c) mesh detail.

Table 1. Project Data

Data	Value	Unit
Cone Height	3.65	cm
Distillation Unit Height	100	cm
Distillation Unit Diameter	2.6	cm
Smallest Cone Radius	6.75	mm
Largest Cone Radius	10.5	mm

Table 1 presents the design data for the feeding distribution system study that were used in the simulations. With the geometry definition steps and the mesh generation finished, the processing step was taken next.

2.2 Mathematical Model

The focus for the liquid and gas flow was Eulerian-Eulerian. The conservation equations used for the solution of this problem were the continuity equation and the momentum equation. It is still necessary to add an equation for the momentum flow that relates the movement quantity between the phases. It is Equation (01) that relates the momentum transference in the interface ($M_{g,l}$).

$$M_{g,l} = \frac{3}{4}\frac{f_g \rho_l}{d_g} C_D \left|v_g - v_l\right| \left(v_g - v_l\right) \qquad (01)$$

Where f_g is the gas volumetric fraction, ρ_l liquid density (g.cm^{-3}), d_g is the bubble diameter (mm), C_D is the drag coefficient, v_g is the velocity of the gas phase (m.s^{-1}) and v_l velocity of the liquid phase (m.s^{-1}). The SST (Shear Stress Transport) model was taken as turbulence model for the multiphase discharge. Based on Assad and Lampinen (2002) works, the model considerations were:

1) Liquid and gas physical properties are constant,
2) The gas stream is uniquely composed by air,
3) Constant temperature on the distillation unit walls (25ºC),
4) The constants used for the turbulence model are the same as in the monophase model,
5) By analyzing the Weber number for this system the viscous forces can be despised.

The finite volume numeric method was used for the equations discretization, with a high order interpolation scheme (High Resolution) in order to avoid problems of oscillation and numeric diffusion. The time pace was 0.01s and the convergence criterion adopted was the average error 10^{-5}.

2.3 Outline Conditions

In those simulations type Dirichlet contour conditions were used, as follows:

1. Liquid inlet: Inlet conditions, with normal flow to the surface;
2. Liquid outlet: outlet condition, with normal flow to the surface;
3. Opening of the superior part of the cone: open condition, that is, it allows the air and/or liquid entry and exit of the top of the cone. What determines entry/exit is the pressure equalization,
4. The values of the interest variables, such as liquid volumetric fraction, air and water superficial velocity were investigated in three different heights of the distillation unit. Analysis horizontal lines were drawn with this aim.

Considering the feeding cone inferior base as zero (0) the lines were drawn at 10, 65 and 165 mm from the cone bottom. The studies were focused on the water volumetric fraction analysis, liquid film uniformity and thickness and formation of dry points throughout the distillation unit. In Table 2 the simulation conditions presented in this paper are listed.

Table 2. Simulation Conditions

	Mixture water/air		
Mass Flow (kg/h)	50	25	10
Wall Temperature (ºC)	25	25	25

3. Results and Discussions

In this item the main results obtained will be presented from the simulations carried out by using the CFX 12.0 software, in a multiphase system water-air. In figure 3 the development of liquid volumetric fraction profiles throughout the radius for the three height levels are presented for each of the feeding flows tested.

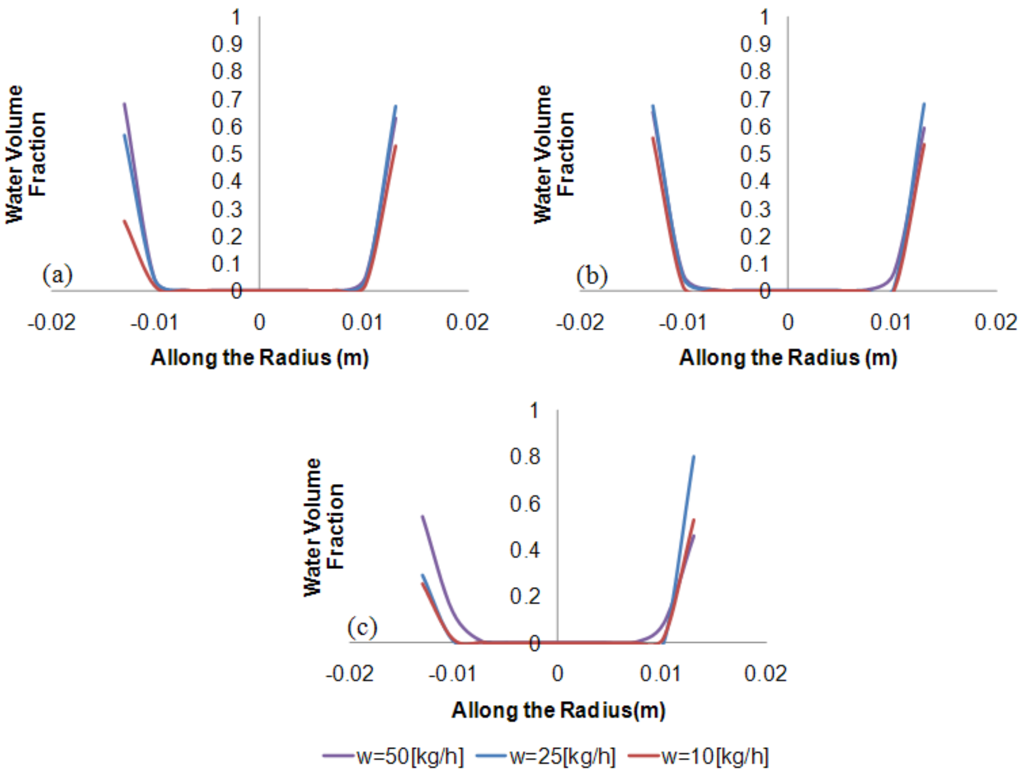

Figure 3. Profiles of Volumetric Fraction of Liquid (a) 10mm (b) 65mm and (c) 165mm below the feeding cone for the mass flows of 50, 25 and 10 (kg/h) with hybrid mesh.

When analyzing Figures 3 (a, b and c), we concluded that the profiles of the volumetric fraction of the liquid along the radius present similar characteristics for the three of the feeding flow rates, however for the 10 [kg/h] rate, the profile presented lower value comparing to the others. Such behavior was expected, since with a lower flow rate the formation of some preferential ways and dry points occurs on the walls of the distillation tube still by analyzing Figure 3 we can observe that the thickness of the film formed suffers variations as the discharge develops. Table 3 represents the values that quantify this film thickness.

Table 3. Film average thickness for case studies carried out until the present moment.

	Film thickness [mm]					
	50 (kg/h)		25 (kg/h)		10 (kg/h)	
	right	left	right	left	right	left
10 [mm]	2	1.5	1	3	1	0.5
65 [mm]	2	1.5	0.5	3	1	0.5
165 [mm]	1.5	1	0.5	3	1	0.3

Based on the data observed in Table 3, it is possible to state that in relation to the film thickness, with a 50 (kg/h) flow rate, a thicker and more homogeneous film was obtained, opposite to the obtained with a 10 (kg/h) feeding flow rate. Another important variable is the air superficial velocity, which in this case is representing the gaseous phase of a distillation, inside of the tube. In Figure 4, we can observe the development of three profiles of air superficial velocities (on the three levels of 10, 65 and 165 mm of height below the feeding cone) obtained from three feeding flow rates.

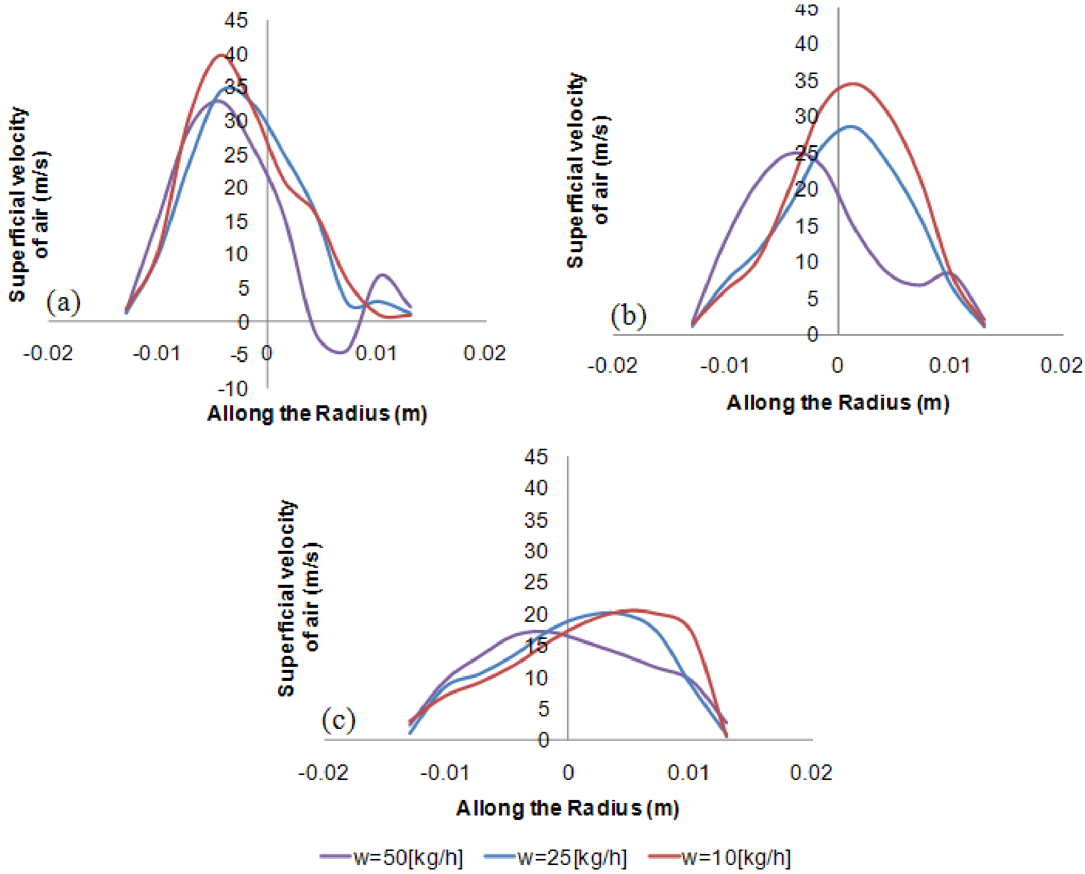

Figure 4. Profiles of Air Superficial Velocity (a) 10 mm (b) 65 mm and (c) 165 mm below the feeding cone for the mass flows of 50, 25 and 10 (kg/h) with hybrid mesh.

By analyzing Figure 4 (a), we can notice that the development of the profiles of air superficial velocity obtained for three different feeding flow rates with a hybrid mesh, are similar and high when observed 10mm below the feeding cone. It is worth to remember that this region next to the feeding cone is quite turbulent due to the high velocity of the liquid, for there is a small area for it to pass between the feeding cone and the wall of the distillation tube, hence this high air velocity. The behavior observed on Figures 4 (b and c) for the development of the profiles of air superficial velocity, 65 and 65 mm below the feeding cone, present a higher distance along the radius and with lower magnitude, compared to the profiles presented on the 10mm height. This behavior is expected, for the further it is from the region of hanging of the liquid feeding, the lower the liquid velocity and then lower the air superficial velocity. Due to the discharge features some dry points are generated along the distillation tube as can be observed in Figure 3. Those points appear due to the discharge features inside the tubes, where the discharge takes some preferential ways but later it takes back its way forming again a uniform film on the walls of the tube. This phenomenon was observed with the system operating with the feeding distribution system for the three of the feeding flow rates studied.

Figure 5 presents the volumetric fraction of the liquid on the wall along the whole length of the distillation tube (divided into three equal parts) for a feeding flow rate of 50 (kg/h). Observing Figure 5 the volumetric fraction of the liquid on the walls of the distillation tubes, we can notice the formation of some preferential ways and also some dry points, as had already been observed in experimental studies. The formation of those dry points is not desirable from the point of view of distillation, for where there is no film, there can no liquid evaporating and in contact with the vapor that ascends inside the tube, however it is worth to emphasize that those dry points were minimized with this feeding system and for lower rates (25, e 20 (kg/h)).

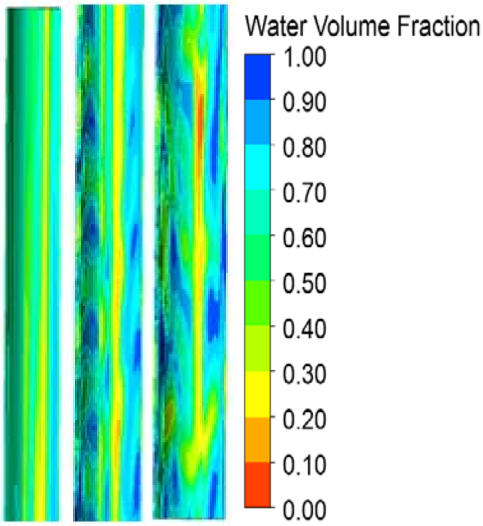

Figure 5. Profile of the volumetric fraction of liquid on the walls of the distillation tube with 50 (kg/h).

4. Conclusions

According to the results obtained through simulations in CFD, for a 50 (kg/h) flow rate the formation of the film is more uniform along the distillation tube, but it presented lower air superficial velocities, which is not desirable for the process. However, the formation of dry points occurs in a similar way to the other feeding flow rates, which presented a lower air superficial velocity. In this manner, we can conclude that the 50 (kg/h) flow rate has an impact on the renewal of the film, however, for a system with the characteristics of the mixture air/water the feeding with flow rates between 25 and 10 (kg/h) show appear to be more adequate, with the formation of the film along the distillation tube and in relation to the air superficial velocities, because they are lower.

Studies are being carried out in order to evaluate this feeding distribution system for a highly viscous mixture. Along with this the processes of mass and heat transference by distillation by falling liquid film are under analysis.

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References

1. M.E.H., Assad, M.J., LAMPINEN*, Int. J. Refrig*. 25(2002), 985-991.
2. C.B, Batistella, *"Tecnologia da destilação molecular: da modelagem matemática à obtenção de dados experimentais aplicada a produtos de química fina".* 1999. 216 f. (Tese de Doutorado) – Faculdade de Engenharia Química, Universidade Estadual de Campinas, Campinas, 1999, in Portuguese.
1. 3.X.G. Li, D. X. Liu, S. M.; Xu, H. Li, *Chem. Eng. Process.: Process Int*., 48(2009) 145-151.
3. M. R. K. Nikou, M. R. Ehsani*, Int. Comm. Heat Mass Transfer*, 35(2008) 1211-1219.
4. D. Noriler et.al,, *Chem. Eng. J*. doi:10.1016/j.cej. 2007.03.023 (2007).