Journal of
Chemical Engineering & Process Technology

Gharib and Moraveji, J Chem Eng Process Technol 2012, S1
DOI: 10.4172/2157-7048.S1-003

Research Article Open Access

Determination the Factors Affecting the Vane-Plate Demisters Efficiency Using CFD Modeling

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Abstract

Vane-plate demisters (VPD) or wave-plate mist eliminators are a kind of liquid eliminator equipments used to remove the liquid with 10-100 μm droplet diameter from the gas. In this paper we determine the factors affecting the vane-plate mist eliminator efficiency using Computational Fluid Dynamics (CFD). The simulation results were compared with the experimental results of Jia et al. [1]. The work considers three factors

1. Flow speed

2. Plates distance

3. Hook existence

After comparing the parameters effects. It was proved that, the higher velocity the more efficiency but meanwhile more re-entrainment occurrence that is not desired and the closer the plates, the better. It was shown that the best way to gain 100% removing is hook existence.

Keywords: Mist eliminating; Wave-plate mist eliminator; Demister; Vane-plate demister; Vane plate; Drainage

Introduction

Small drops in gas cause some problems for downstream equipments such as turbine, compressor and etc. In some cases we are obliged to remove hazardous liquid mist from gas. In order to remove water or other liquids from the gas there are some equipments like mesh mist eliminator and vane-plate mist eliminator. Figure 1 shows a vertical vane plate demister.

In VPD the gas enters a narrow path (the distance is 10-20 mm in general).the flow has to pass a zig-zag way between the plates, where drops encounters a sudden change in inertia and collide onto the surfaces. Drops accumulate in the bends then liquid film is removed by gravity drainage. VPDs are made horizontal or vertical but the elements which control the removal are the same:

1- The inertia of the drops

2- Drag force.

In comparison to mesh mist eliminators VPDs have this advantage:

a) Less pressure drop (due to tiny passing section in mesh demisters pressure drop is higher than VPD).

b) VPD can collect about 100 % of the droplets greater than 40 μm Galletti et al. [2].

c) VPD is capable of removing liquids with high viscosity, salty liquids, liquids which make foam (using mesh demister for this kind of liquids plugs the mesh after a short time).

VPDs are useful for flows with approximately 10% liquid in industry for better performance mesh demisters and vane-plate demisters are coupled. Geometrical parameters such as bend angle, plate distance, length of the vane are investigated in experimental studies. Droplet size is another parameter (10-100 μm)

Wang and James deposition [3,4] employed fluid dynamics to calculate the drops deposition. Their work showed that increasing the inertia drop by higher velocity increases the efficiency. Azzopardi and Sanaullah [5] calculated the critical velocity which the re-entrainment occurs and lowers the efficiency. Houghton and Radford [6] showed that although higher velocity makes a better efficiency after a maximum velocity flooding (at vertical type) or re-entrainment of the trapped liquid lowers efficiency. Verlaan [7] proposed that in vertical VPDs flooding (upward gas stream prevents the down flow of liquid) is factor that should be considered. James et al. [8] and Galetti et al. [2] to solve the flooding and re-entrainment introduced vane-plate demisters with hook. Jame et al. [9] investigated the collection efficiency of wave-plate mist eliminator with hook. Zhao et al. [10] used CFD for droplet sizes

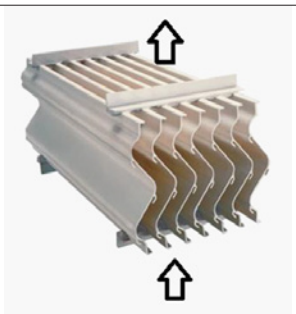

Figure 1: A Vertical Zig-Zag Vane-Plate Mist Eliminator with Hook.

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Received August 16, 2011; **Accepted** February 18, 2012; **Published** February 25, 2012

Citation: Gharib J, Moraveji MK (2012) Determination the Factors Affecting the Vane-Plate Demisters Efficiency Using CFD Modeling. J Chem Eng Process Technol S1:003. doi:10.4172/2157-7048.S1-003

10-40μm. the author calculated the efficiency for speeds 3-5 m/s. he neglected the turbulence dispersion model. He compared the data with an experimental investigation Lang et al. [11] It had 5% error Varlaan [7] used STD k- ε turbulence model for the gas phase. He neglected turbulence disperation effects and used Lagrangian frame work for droplet trajection. Wang and Davies [12] did the same Gillandt et al. [13] used low Re k- ε turbulence model and pointed out that low Re is closer to experimental data.

Rafee et al. [14] used Reynolds Stress Transport Model (RSTM) with standard wall function. They used Reynolds- average Navier-Stokes (RANS) in conjunction with RSTM. They showed that RSTM cannot predict the removal efficiency especially for low gas velocities. Tian and Ahmadi [15], Li and Ahmadi [16] used k - ε turbulence model. James et al. [9] used the so called varied EIM. Galletti et al. [2] made the simulation using Shear Stress Transport (SST). Ghetti [17] did an experimental work, and Galletti [2] his data with Ghetti's experimental data.

Shahrokh and Elhame [18] introduced a critical Weber number for re-entrainment. $We_{critical}$ is the max stable droplet size in a turbulent stream. In this paper STD k- ε model is used

In this project, we have tried to study the effect of different flow speeds (3-7 m/s) and two different plate distance (10 and 20 mm) and a VPD with drainage (hook) on removing efficiency by using CFD simulation based on the Eulerian-Lagrangian solving method. Then the results were compared with experimental data.

Numerical Simulation Methodology

The plate's space is 10 mm (series 1) and 20 mm (series 2). The angel of bend is 120 degree. Flow speed is in the range of 3-7 m/s. in this condition we can get the flow, turbulent. k-ε turbulence model is employed. The distance between the plates is very small in comparison to the plate's width, so the variation in the third direction is neglected. Euler-Lagrange calculation method is employed to predict droplet transport and deposition. Firstly to simulate the multiphase model, the Mixture model is selected then Eulerian model was chosen. The effect of one droplet on other droplets is not considered.

The assumptions are:

1- Droplets are assumed as spheres.

2- There's no interaction between liquid-liquid

3- There's no re-entrainment of the trapped liquid.

4- The only acting force is drag.

The water volume fraction is 0.09, so it satisfies the fundamental assumption that mentions the dispersed second phase occupies a low volume fraction. In Eulerian-Lagrangian model the continuum phase is fluid phase and it is solved by Navier-Stokes equations, while the dispersed phase is solved by tracking the droplets through the flow field. The dispersed phase exchanges momentum and energy with the fluid phase.

Droplet motion equation

$$\frac{d\vec{u}_d}{dt} = \frac{\vec{u}_g - \vec{u}_d}{\tau_d}$$

U_g is the gas velocity; τ_d is the droplet relaxation time

U_d is the droplet velocity

τ_d is calculated as follows ;

$$\tau_d = \frac{4\rho_d d_p}{3\rho_g C_D \left|\vec{u}_g - \vec{u}_d\right|}$$

C_d is calculated according to Schiller-Naumann

$$C_D = \frac{24}{\mathrm{Re}_d}(1 + 0.15\,\mathrm{Re}_d^{0.687}).$$

Drag coefficient is a function of Re number of droplet.

Re number is defined as follows

$$\mathrm{Re} = \frac{\rho d_p \left|u_p - u\right|}{\mu}$$

The variables needed for the solver are: gas densities, droplet diameter, volume fraction of water, mean gas velocity, Reynolds number.

If we write the trajectory of discrete phase in Lagrangian form we get:

$$\frac{du_p}{dt} = F_D(u - u_p) + \frac{gx(\rho_p - \rho)}{\rho_p} + Fx$$

U_p: the particle velocity, U: the flow velocity, ρ: the fluid density

F_x: additional acceleration, F_d: drag force, ρ_p : the particle density

F_D is the drag force per unit particle mass and can be obtained from

$$F_D = \frac{18\mu}{\rho_p d^2{}_p}\frac{C_D \mathrm{Re}}{24}$$

Table 1 shows the operating conditions and properties.

Continuous phase model

Standard k-ε is reasonable accurate and it is a semi-empirical model, so that the equation derivation relies on phenomenological considerations and empiricism.

This model is applicable to wall-bounded flows.

The turbulence kinetic energy k, and its rate of dissipation ε, are obtained from the following k-ε Transport Equations:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho k u_j) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + \mu\frac{\partial u_i}{\partial x_j}\left[\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right] - \rho\varepsilon$$

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_k}(\rho\varepsilon u_k) = \frac{\partial}{\partial x_k}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_k}\right] + \frac{C_1\varepsilon}{k}\mu\frac{\partial u_i}{\partial x_j}\left[\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right] - C_{2\rho}\frac{\varepsilon^2}{k}$$

And the model constants are as below

$$C_\mu = 0.09, C_{\varepsilon 1} = 1.44, C_{\varepsilon 2} = 1.92, \sigma_k = 1, \sigma_\varepsilon = 1.3z$$

σ_k and σ_ε are the turbulent Prandtl numbers for k and ε, respectively. These default values have been determined from experiments with air and water.

Fluid	Pattern	P (kPa)	ρ_g (kg/m³)	ρ_l (kg/m³)	μ_g (kg/m.s)	μ_l (kg/m.s)	σ
Air-water	Dispersed	101.3	1.225	998	0.0242	0.001	10

Table 1: Operating Conditions and Properties.

Navier stokes equations are as follow:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=F_x-\frac{\partial p}{\partial x}+\frac{1}{\mathrm{Re}}\left[\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right]$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=F_x-\frac{\partial p}{\partial y}+\frac{1}{\mathrm{Re}}\left[\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right]$$

Boundary condition

Velocity inlet is set for the inlet boundary condition .we assume that the velocity of the liquid and gas are equal. In this paper the velocity range is 3-7 m/s. volume fraction of water is 0.09 .at first VPD was simulated with 20 mm plate space for different speeds(3-7m/s) ,then simulation was repeated for 10 mm plate space .first simulation was compared with experimental data reported by Jia et al. [1]. To calculate the efficiency the volume fraction of liquid was calculated every 100iteration for outlet. The average values were then calculated.

The efficiency calculation is as:

$$\text{Efficiency} = \frac{\text{water volume fraction at outlet} - \text{water volume fraction at inlet}}{\text{water volume fraction at inlet}}$$

Results

Effect of velocity

Figure 2 shows a two- dimensional view of water fraction through vane plate demister that has accumulated in the angles (contours of 3 m/s). Figure 3 shows the comparison between simulation and experimental data. the parameters are: 20 mm plate space, 120 degree bend angle, 0.23 m vane length. This figure shows that the efficiency increases smoothly by increasing velocity in our simulation work, whereas in experimental work efficiency rising is considerable versus velocity increasing. According to velocity range (3-7 m/s) and the vane length flow passes the vane in short time and it does not differ between for instance 4 m/s and 5 m/s very much. e.g. for this length, speeds (3-7 m/s) have approximately the same effect on efficiency. Although the experimental cure slip is sharper than this paper simulation curve, the trend is the same, e.g. by increasing the velocity increases the efficiency and after a velocity, efficiency decrease because of re-entrainment.

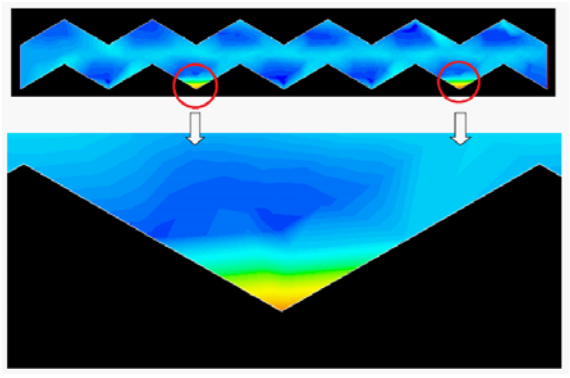

Figure 2: Volume Fraction of Water, Trapped Water through Vane Plate Mist Eliminator is accumulated in the Angles.

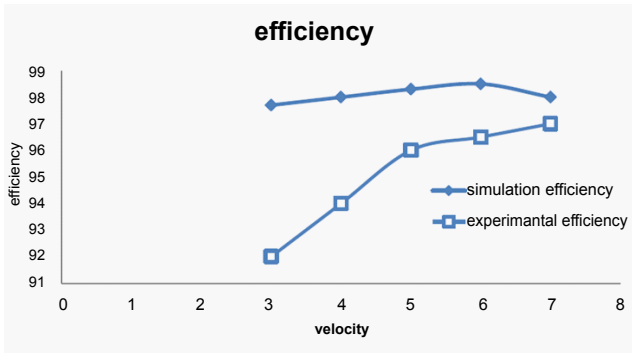

Figure 3: The efficiency comparison with experimental data.

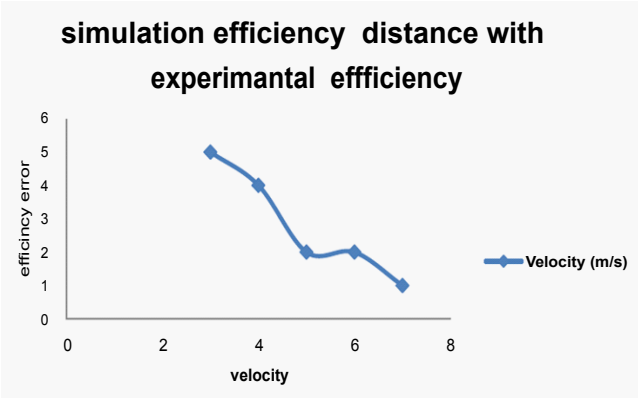

Figure 4: Efficiency error.

Figure 4 shows the efficiency error. (Compared with experimental data). According to the figure as velocity increases the error decrease.

Effect of plates space

Figure 5 shows a part of VPD with 20 mm space. The zones that the collision possibility is more are indicated by green triangles. The red rectangle shows free zones that flow without any collision passes the vane length. To lower the free zone in vane-plate demisters one alternative is to reduce the plate space that concludes eliminating the free space approximately.

Figure 6 shows a VPD velocity vectors with 10 mm plate space. It's clearly shown that almost all the droplet velocity vectors collide the walls, and there's no free zone. So the droplet collection efficiency is about 100 % (Efficiency=99.4%).But lower plate distance higher pressure drop.

The effect of hook

Figure 7 shows velocity contours of VPD with hooks. it's found out that the hooks make the a change in fluid direction and lead the fluid to the wall and simultaneously hooks make a place for droplets to steady stand and prevents them to re-introduce to the gas in addition upper hooks causes less possibility for the droplets to deposit. Hook existence helps the droplets relax on the surface and reduces re-entrainment Wang and James [3,4]. With using hook can achieve 100 % efficiency and it doesn't have the simple VPD problem (which after a max velocity, efficiency will decrease).

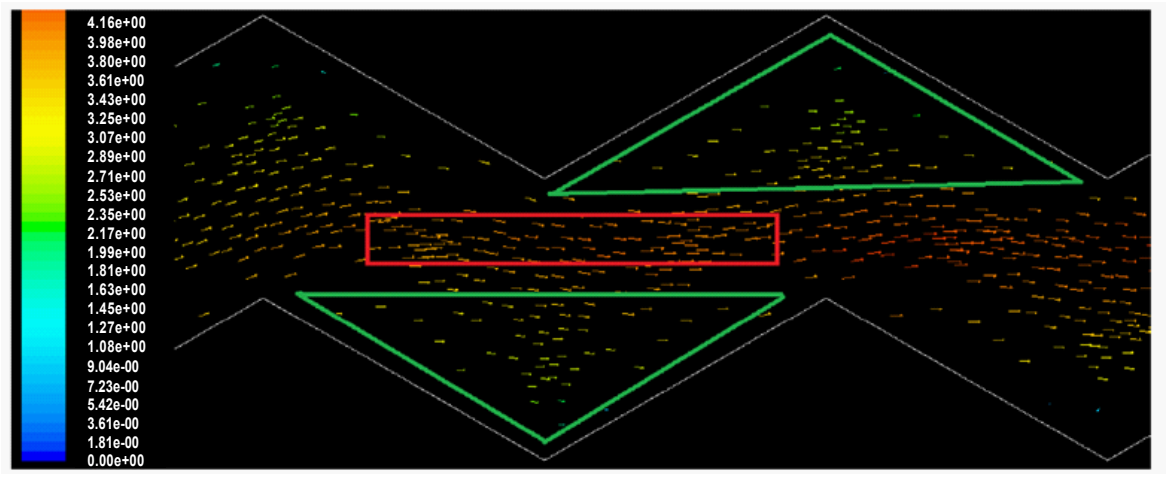

Figure 5: Collision space (Green Triangle) and Free (Rectangle) Zones.

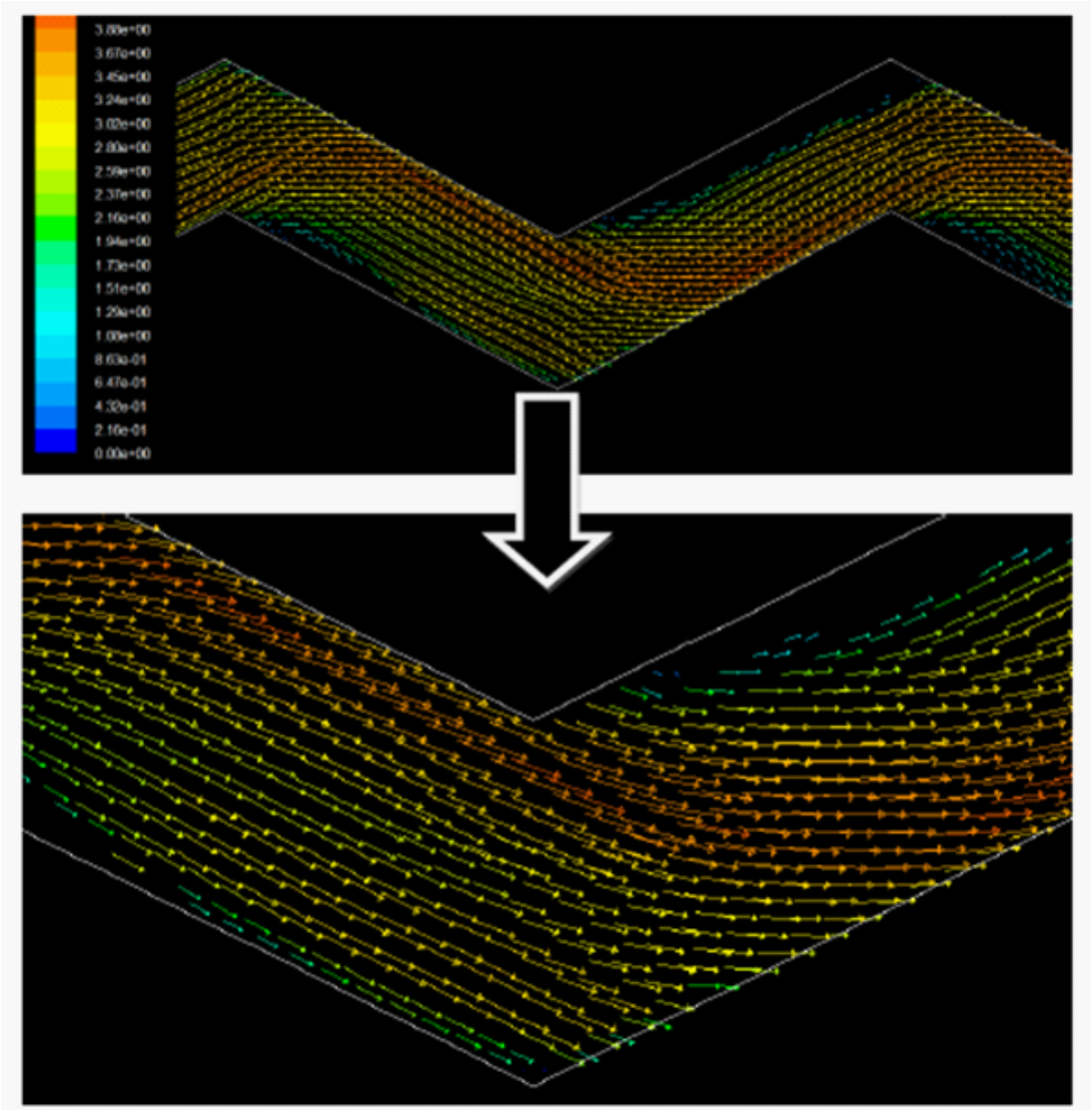

Figure 6: Collision possibility is almost 100%.

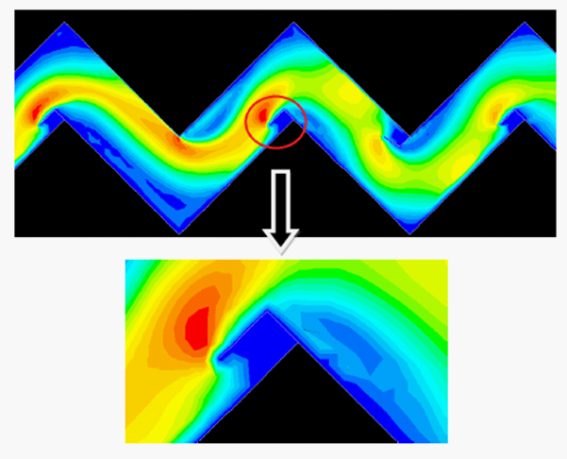

Figure 7: Vane-Mist Eliminator with Hook.

Conclusion

In vane plate demisters we can have upper efficiency with lower plates distance but pressure drop will increase simultaneously. An increase in velocity has an increase in efficiency but at after a velocity (6 m/s) re-entrainment phenomenon will lower it. But by using a VPD with hook we can have high efficiency at any fluid speed and re-entrainment is at least i.e. the shape is more effective than the speed.

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This article was originally published in a special issue, **Computational Fluid Dynamics** handled by Editor(s). Dr. Edo S. Boek, Imperial College, London, UK