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Chemical Engineering Research and Design

journal homepage: www.elsevier.com/locate/cherd

Optimal design of drainage channel geometry parameters in vane demister liquid–gas separators

Fatemeh Kavousi[a], *Yaghoub Behjat*[b,*], *Shahrokh Shahhosseini*[a]

[a] *School of Chemical Engineering, Iran University of Science and Technology, Tehran, Iran*
[b] *Process Development and Equipment Technology Division, Research Institute of Petroleum Industry, Tehran, Iran*

ABSTRACT

Vane liquid–gas demisters are widely used as one of the most efficient separators. To achieve higher liquid disposal and to avoid flooding, vanes are enhanced with drainage channels. In this research, the effects of drainage channel geometry parameters on the droplet removal efficiency have been investigated applying CFD techniques. The observed parameters are channel angle, channel height and channel length. The gas phase flow field was determined by the Eulerian method and the droplet flow field and trajectories were computed applying the Lagrangian method. The turbulent dispersion of the droplets was modeled using the discrete random walk (DRW) approach. The CFD simulation results indicate that by applying DRW model, the droplet separation efficiency predictions for small droplets are closer to the corresponding experimental data. The CFD simulation results showed that in the vane, enhanced with drainage channels, fewer low velocity sectors were observed in the gas flow field due to more turbulence. Consequently, the droplets had a higher chance of hitting the vane walls leading to higher separation efficiency. On the other hand, the parameters affect the liquid droplet trajectory leading to the changes in separation efficiency and hydrodynamic characteristic of the vane. To attain the overall optimum geometry of the drainage channel, all three geometry parameters were simultaneously studied employing 27 CFD simulation cases. To interpolate the overall optimal geometry a surface methodology method was used to fit the achieved CFD simulation data and finally a polynomial equation was proposed.

Keywords: Vane; Drainage channels; Liquid–gas separator; Droplet removal efficiency

1. Introduction

Wave plate mist eliminators (vanes) are widely used in chemical, oil and gas industries to remove fine liquid droplets from gas flow. Fine liquid droplet separation is necessary for a number of reasons, such as reduction of pollutant emission into the environment, preventing damages to downstream equipments caused by corrosive or scaling liquid, recovering valuable products dispersed in a gas stream, increasing purity of gases for successive treatments and enhancement of the global operation economy.

Vane demisters can effectively remove entrained liquid droplets from a gas flow, usually by inertial impingement. The vane equipment basically consists of a number of narrowly spaced bended plates oriented in the direction of the gas flow as shown in Fig. 1. The droplet laden gas stream flows through the tortuous channels containing sharp bends and the flow direction changes repeatedly. The entrained droplets that are not able to follow these changes of direction, due to their inertia, deviate from the main gas flow and impact on the channel walls, where they coalesce and form liquid films that are continuously drained out from the separator by gravity.

The separation efficiency of a vane is affected by different factors, such as fluid inlet velocity, vane geometry and droplet mass fraction. Flooding due to separated liquid film accumulation on the walls and re-entrainment are also of concern. To overcome this issue and to increase droplet removal, the vanes are usually enhanced with drainage channels. The presence of drainage channels leads to an increase in separation efficiency and capacity of the system (Houghton and Radford, 1939; McNulty et al., 1987; James et al., 2003).

* *Corresponding author*. Tel.: +98 21 48253191; fax: +98 21 44739713.
E-mail address: Behjaty@ripi.ir (Y. Behjat).

Received 7 August 2012; Received in revised form 16 January 2013; Accepted 23 January 2013
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http://dx.doi.org/10.1016/j.cherd.2013.01.012

Nomenclature

A	channel height
B	channel length
C_D	drag coefficient
C_L	time-scale constant
C_P	specific heat
D_d	diameter of droplet
S	distance between vane plates
g	gravity
H	heat transfer rate
x	length
m	droplet mass
P	pressure
Re	Reynolds number
t	time
T	temperature
v	velocity
y_i	mass fraction in gas phase
x_i	mass fraction in liquid phase
u', v', w'	velocity fluctuation
k	turbulent kinetic energy
T_L	time scale
r	random number between 0 and 1
E	overall separation efficiency
ΔP	pressure drop
Obj	distance between efficiency and pressure drop

Greek symbols

α	vane angle
μ	viscosity
τ	stress tensor term
τ_e	eddy life time
η	separation efficiency
β	unknown parameters
μ_t	turbulent viscosity
θ	channel angle
ρ	density
G	production of turbulent kinetic energy
ξ	distributed random number
ε	turbulent dissipation rate

Subscripts

g	index for gas phase
p	particle
d	droplet
l	liquid

The increasing need for cost and pollution control has generated great interest in vane demister performance studies. Early experimental and theoretical studies including those of Burkholz and Muschelknautz (1972) form the basis of the efficiency model for vane demisters currently used in the industry. In addition, Worrlein (1975) investigated separation calculations leading to the proposal that the optimal distance between the bends of a mist eliminator should be equal to the channel width. Ushiki et al. (1982) examined the performance of a separator with multistage rows of flat blades as described by Phillips and Deakin (1990), who have reported their experimental results on two vane demisters.

Wang and James (1998) simulated a wave-plate mist eliminator (without drainage channel), through the software CFX.

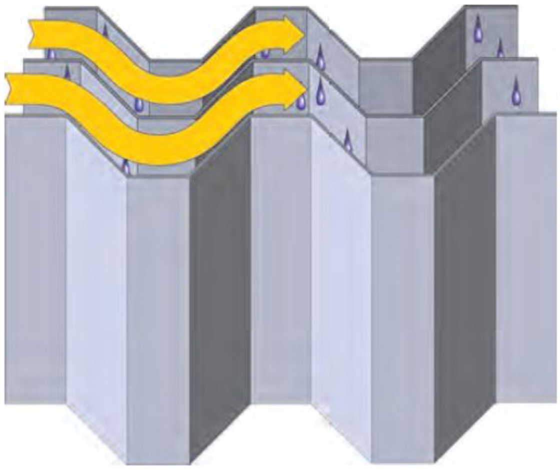

Fig. 1 – A horizontal vane demister.

The performance of low Re and STD k–ε models were studied and it was observed that the predictions were better applying the low Re turbulence model. In this survey, the comparisons between numerical predictions and experimental data showed a considerable difference due to neglected turbulent dispersion effects. In a later study (Wang and James, 1999) the effect of turbulent dispersion on droplet deposition was accounted for, using eddy interaction models (EIM). Modifications were made to the original model and it was proved that besides small droplets, the modified EIM resulted in more agreeable predictions when compared with the available experimental data.

Josang (2002) used various turbulence models when simulating the separating ability of the vane of their study. Having stated the importance of a co-ordinance between near wall treatment and the grids in their previous study, they compared predictions between structured and unstructured grid simulations. They have not reported any comparison with experimental data.

In the study of Jia et al. (2007) separation efficiency of a simple vane was compared with that of a vane with drainage channels. Among several re-entrainment mechanisms discussed, secondary droplet formation due to wall impingement of the droplets was taken into account. It was proven that drainage channels improve separation efficiency due to more turbulence and lower particle response time. Having studied a range of droplet diameters, it was concluded that generally for bigger droplets better separation was achieved, until re-entrainment was considerably increased.

The relation between separation efficiency and structural parameters of a demister vane was studied by Zhoa et al. (2007) using the response surface method. The authors investigated the separation of droplets in the size range of 10–40 μm, considering only the drag force in the equation of motion, the effect of turbulent dispersion was neglected.

Galletti et al. (2008) studied the importance of eddy interaction models by simulating two vane demisters. The results of their study indicated that the EIM model was unable to predict realistic results for a range of droplet sizes. Comparisons of the results with some experimental data are reported in their paper. They suggested a modified EIM model as well as a model for turbulent flow in low velocities.

Recently, Narimani and Shahhosseini (2011) stated the importance of vane geometry on removal efficiency and pressure drop using CFD. In their study the effect of increasing gas