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Experimental study of two phase flow characteristics on the dual-flow tray

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ABSTRACT

This paper addresses an experimental investigation in the hydrodynamic behavior of a new type of dual-flow fixed valve tray. Water/air system was used at atmospheric pressure and ambient temperature. The dry pressure drop, total pressure drop and clear liquid height were measured and the comparisons between different tray geometry were made. The results show that the total pressure drop and clear liquid height have the same trend, which is increased with the decreased center distance of holes, increased holes diameter and decreased open area. Correlation for clear liquid height is proposed, and the agreement of the experimental and calculated data is demonstrated in the paper.

The results show that gas and liquid flow counter-currently through the tray hole area and four main hydrodynamic regimes are distinguished at different gas/liquid load. A characteristic parameter named the fraction of holes passing gas is defined and deduced. The calculated results show that the fraction of holes passing gas is reduced by the decreased center distance of holes and holes diameter, while the increased open area leads to the less fraction.

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1. Introduction

In recent years, many efforts have been made to improve trays of columns to obtain better plate efficiency, capacity and lower pressure drop that encountered in commercial operation (Luo et al., 2012). A better understanding of the mechanisms that occur in large-scale industrial processes is important in order to improve equipment, design, and process development. However, despite the useful results obtained with these models, they assume a perfect mixture of the phases on the plates and it has been recognized that the flow pattern on a tray greatly affects the mass and energy transfer mechanisms, and this influence can only be analyzed through a fluid dynamics study.

Dual-flow trays possess greater capacity and lower pressure drop than trays with down-comers because the fluid can flow through the entire cross-section of the column (Xu et al., 1994). They are often used in distillation because of their high capacity and resistance to fouling. In its range of application, the tray provides good mass transfer efficiency with low capital investment. Importantly, the application of such devices to fouling systems has been eminently successful, the alternating vapor–liquid passage through the holes providing a self-cleaning action. As mentioned in Gaicia and Fair (2000), more and more cross-flow trays are being replaced by dual-flow trays to prevent problems of severe fouling.

The dual-flow trays have their own unique geometry while retaining the counter-current flow profile, wherein the liquid and gas flow through the same tray opening. While some designs promote a horizontal direction of liquid flow on the tray deck, there are still no components specifically allocated for the passage of one phase over the other. Also, the liquid

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Nomenclature

d_h	hole diameter (mm)
t_h	center distance of holes (mm)
t_t	tray thickness (mm)
A_h	free area on the dual-flow tray (m^2)
A_a	cross sectional area of tray (m^2)
A_{FG}	free area available for gas flow (m^2)
A_{FL}	free area available for liquid flow (m^2)
n	number of holes
OA%	fractional orifice area
L	liquid flow rate (m^3/s)
Q	vapor flow rate (m^3/s)
U_s	superficial velocity (m/s)
U_x	velocity through x fraction of total number of holes (m/s)
F_s	vapor F factor based on superficial area, $U_s \rho_G{}^{0.5}$ ($Pa^{0.5}$)
h_t	total pressure drop across the tray, height of clear liquid (m)
h_L	residual pressure loss for vapor flowing through the froth (m)
h'_L	liquid head to force liquid through $1-x$ fraction of holes (m)
h_{dG}	pressure drop for vapor passing through x fraction of holes (m)
h_{Ld}	pressure loss for liquid flowing through $1-x$ fraction of holes (m)
$h_{t,meas}$	measured total pressure drop for a dual-flow tray (m)
M_L	molecular weights of liquid
ρ_L	liquid density (kg/m^3)
ρ_G	vapor density (kg/m^3)
g	gravitational constant (m/s^2)
C_v	orifice coefficient
t_s	sufficient time (s)
x	fraction of total holes passing vapor at any instant
z_i	measured value of the parameter z in ith experimental run
z_i^c	correlated value of the parameter z in ith experimental run
Δ_{av}	standard deviation
Δ_{av}	$= \sqrt{\frac{\sum_{i=1}^{n}\left(z_i - z_i^c/z_i\right)^2}{n}}$

on tray occurred random flow at horizontal direction, especially in froth and fluctuating regimes. This is different from the trays with down-comers, on which cross flow of liquid occurs. There less general use appears to have derived from an expected narrow operating range of high efficiency, as well as a general unavailability of design models that can enable reliable prediction of their performance.

In the early investigation, most attentions were paid on understanding of the mass transfer efficiency of the dual-flow trays. Very little has been done to model the hydrodynamics. Xu et al. (1994) experimentally investigated dual-flow tray efficiency in a distillation column using methanol–water and methanol–isopropanol systems. Hutchinson and Baddour (1956) evaluated effects of different loadings and reflux ratios with ethanol–water system in a column containing three copper ripple trays. Furzer and Duffy (1977) studied mass transfer

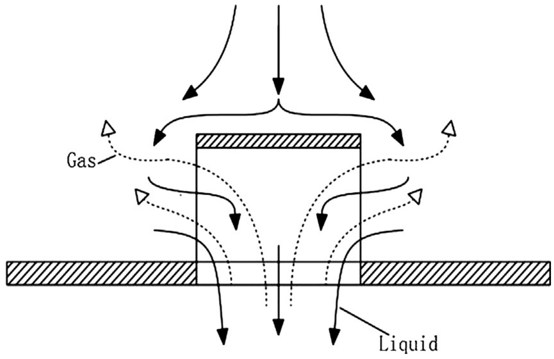

Fig. 1 – Characteristics of gas–liquid flow on dual-flow tray.

Table 1 – Dual-flow trays specifications.

	Tray 1#	Tray 2#	Tray 3#	Tray 4#
d_h	20	20	30	20
t_h	30	40	40	30
n	111	111	51	211
OA%	19.6	19.6	20.3	37.3

with different number of plates on sieve plates without downcomers. Miyahara et al. (1990) investigated the mass transfer coefficients in liquid phase side and gas–liquid interfacial area in both froth regime and transition regime. Gaicia and Fair (2002) proposed a rational method for the analysis and design of dual-flow tray distillation columns. The model presumed that majority of the mass transfer occurred in the froth zone and the spray zone was available for additional mass transfer. Domingues et al. (2010) proposed a new method inserted in the Aspen Plus 12.1 simulator to predict the overall efficiency of columns with valve and dual-flow trays. Kister (1992) discusses the dual-flow tray by a comparison with sieve, valve and bubble cap trays. Dual-flow trays have the highest capacity, but a low turndown ratio and reduced tray efficiency. Other experimental results (Billet, 2001; Shoukry et al., 1974; Shoukry and Kolar, 1974; Furzer, 2000) have been obtained for a comparison between turbogrid trays and a wide range of tray types. In addition, most experimental studies were done on sieve trays and few data was available on fixed valve tray. For these reasons, extrapolation to industrial scale is not yet optimal.

This work aims at providing more experimental data on dual-flow fixed valve tray and better understanding flow characteristics of such devices. A part is dedicated to present results of tray pressure drop and clear liquid height. Correlations are proposed for these different hydrodynamic parameters. Second, comparisons to the different tray geometries are made and changes in hydrodynamic behavior are highlighted. Last, a new parameter is proposed to describe the characteristics of gas and liquid alternatively passing through the same open area on the dual-flow tray.

2. Experimental studies

Hydraulic characteristics of dual-flow fixed valve tray were evaluated in a 500 mm diameter cold model column made of Plexiglas. Flow pattern of the trays can be seen in Fig. 1 with tray specifications given in Table 1. Experimental setup is shown in Fig. 2 and tray geometries are shown in Fig. 3. Air and water at normal temperature and pressure are used as test fluids. The air was provided using a positive displacement blower. The liquid was circulated using a centrifugal pump from the holding tank. The cold model experiment is conducted as

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