SWIRL MOTION EFFECT ON THE AERATION EFFICIENCY IN SPRAY ABSORBERS

Lubomira Broniarz - Press, Marek Ochowiak and Agnieszka Kalek - Skraburska

Poznan University of Technology, Department of Chemical Engineering and Apparatus, PL 60-965 Poznan, pl. M. Sklodowskiej-Curie 2, Poland

Mass transfer operations involve two heterogeneous phases such as gas - liquid, liquid - liquid, gas - solid and liquid - solid phases. Because of ineffective mass transfer in a laminar flow, the turbulent conditions are desirable for enhancement of mass transfer. The traditional method of the intensification of absorption processes consists in obtaining of interfacial turbulence of flows near the interphase by changing the hydrodynamic conditions. The following methods are applied: increase of flow velocity; increase of turbulence of fluid boundary layer; enlargement of the transitional range of process; utilization of the effect of turbulent spraying; effects of free turbulence; ribbing and roughness of apparatus walls; mechanical failure of boundary layer as well as an interaction of the high frequency fields with the boundary layer[1].

The liquid may be sprayed into gas stream by means of a nozzle which disperses the liquid into a fine spray of drops. In classical solutions the flow may be countercurrent or co-current, as in vertical towers with the liquid sprayed downward, or parallel, as in horizontal spray chambers. The latter are frequently used for adiabatic humidification - cooling operations with recirculating liquid. In the spray tower the gas enters at the bottom and the liquid is introduced through a series of sprays at the top. The performance of these units is generally rather poor, because the droplets tend to coalescence after they have fallen through a few feet, and the interfacial surface is thereby seriously reduced. Although there is considerable turbulence in the gas phase, there is little circulation of the liquid within the drops, and the resistance of the equivalent liquid film tends to be high[2]. It is difficult to compare the performance of various spray towers since the type of spray distributor used will influence the results[2]. The studies of Pigford and Pyle[3] performed on stripping of oxygen from water showed that for short heights the efficiency of the spray chamber approximates closely to that of a packed tower, but for heights greater than 1.2 m efficiency of the spray tower drops off rather rapidly.

The further fundamental two-phase heat - mass transfer studies for classical and modified spray - cascade co-current columns have been carried out. The construction of the co-current spray column during the processing of polluted gases and liquids, an absorption with fast chemical reaction (e.g. absorption of fluoric gases) as well as in gas scrubbing, has been applied in practice. The modification of the spray elements was directed to reduction of flow friction factor at the same cross - section of a confusor. The co-current spray scrubber equipped with typical confusors is characterized by relatively high pressure drop in two-phase flow. The constructional modifications of confusors are intended to improve the conditions of atomization and the reduction of drag coefficient. The measurements of friction factors and heat - mass transfer coefficients performed for classical and modified spray - cascade co-current columns (Fig. 1) have been carried out. The main elements of the test installation were: two-stage absorber with two cone - shaped or modified confusors as liquid distributor; liquid separator; air - heater; cyclonic temperature stabilizer; measurement units of air flow, humidity, temperatures and pressure drop. The following confusors were chosen for the study with the shape showed in the Fig. 2: classical (K1); with swirl plate (K2) and with swirl plate and profiled inside surfaces (K3). The experiments on heat-mass transfer were performed for air - water system in two - stage tower with active volume of $V = 7.63\cdot 10^{-3}$ [m^3].

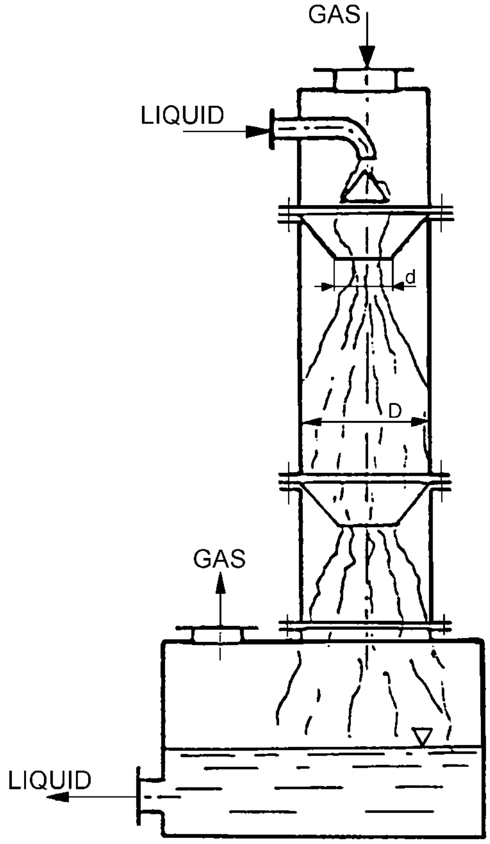

Fig. 1. Scheme of the spray - cascade co-current absorber.

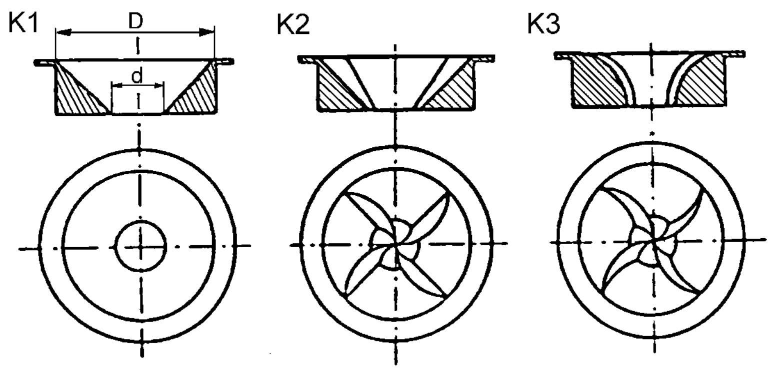

Fig. 2. Studied confusor constructions:
K1 - classical; K2 - with swirl plate; K3 - with swirl plate and profiled inside surfaces

The characteristics of the tested constructions were as follows: diameter of a confusor of d = 0.0333 m; orifice factor of $\varphi = d^2/D^2 = 0.137$ and an angle of confusor inclination α = 0.786 [rd].The experiments were carried out in following ranges of process parameters: inlet air temperature $T_{a,1} \in (326.0;359.1)K$; outlet air temperature $T_{a,2} \in (286.5;309.5)K$; inlet water temperature $T_{w,1} \in (284.9;290.1)K$; outlet water temperature $T_{w,2} \in (285.6;298.8)K$; equivalent air mass velocity referred to the minimal cross-section of single confusor $g_{G,o} \in (15.5;50.6)[kg/m^2 s]$; equivalent water mass velocity referred to minimal confusor cross-section $g_{L,o} \in (14.0;680)[kg/m^2 s]$; air inlet humidity $X_{a,1} \in (0.0054;0.0180)$; air outlet humidity $X_{a,2} \in (0.0098;0.0188)$. For determination of volume mass transfer coefficient the Lewis law for synchronous heat and mass transfer has been used. The generalized correlations were elaborated by means of multiply regression in the following form:

$$Sh_v = C \cdot \mathrm{Re}_G^A \cdot Sc^{0.4} \cdot \mathrm{Re}_L^B \cdot \left(\frac{\eta_L}{\eta_G}\right)^D \tag{1}$$

where the Reynolds number for gas phase

$$\mathrm{Re}_G = \frac{4 \cdot G_G}{\pi \cdot D \cdot \eta_G} \tag{2}$$

and for liquid phase

$$\mathrm{Re}_L = \frac{4 \cdot G_L}{\pi \cdot D \cdot \eta_L} \tag{3}$$

refer to the column inside diameter *D*. The modified Sherwood number is defined as follows:

$$Sh_v = \frac{k_{Av} \cdot D}{\delta_A \cdot a} \tag{4}$$

where $a = a_w$ is the column wall surface. Then, the enhancement factor for modified systems:

$$\phi_v = \frac{Sh_v}{Sh_{v,o}} = f(\mathrm{Re}_G; m) \tag{5}$$

where *m* is the two-phase flow number:

$$m = \frac{g_L}{g_G} = \frac{G_L}{G_G} \tag{6}$$

and $Sh_{v,o}$ refers to mass transfer for classical confusor K1, has been analyzed. The correlation equations for tested classical and modified confusors are listed in Table 1.

Table 1. Correlation relations for studied confusors.

Confusor	Correlation equations	
K1	$Sh_{v,o} = 3.01 \cdot 10^{-4} \cdot \mathrm{Re}_G^{1.03} \cdot Sc^{0.4} \cdot \mathrm{Re}_L^{0.24} \cdot \left(\frac{\eta_L}{\eta_G}\right)^{0.24}$	$\phi_v = 1$
K2	$Sh_v = 1.94 \cdot 10^{-5} \cdot \mathrm{Re}_G^{1.28} \cdot Sc^{0.4} \cdot \mathrm{Re}_L^{0.28} \cdot \left(\frac{\eta_L}{\eta_G}\right)^{0.28}$	$\phi_v = 0.0645 \cdot \mathrm{Re}_G^{0.29} \cdot m^{0.04}$
K3	$Sh_v = 5.25 \cdot 10^{-5} \cdot \mathrm{Re}_G^{1.16} \cdot Sc^{0.4} \cdot \mathrm{Re}_L^{0.29} \cdot \left(\frac{\eta_L}{\eta_G}\right)^{0.29}$	$\phi_v = 0.174 \cdot \mathrm{Re}_G^{0.18} \cdot m^{0.05}$

The effect of mass transfer enhancement (Figures 3 and 4) for the both types of modified confusors: with swirl plate as well as with swirl plate and profiling of inside surface has been observed. The better effect of mass transfer for confusor K2 with swirl plate and without the special profiling of inside surface has been obtained.

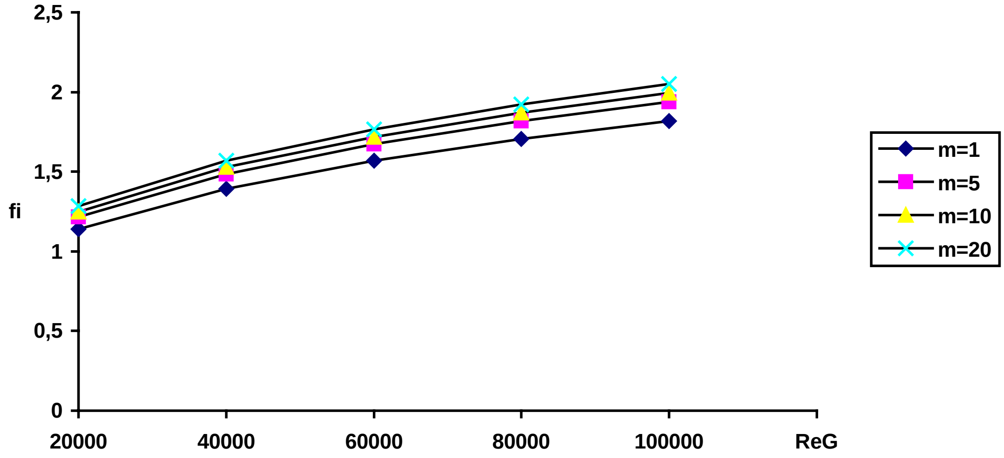

Fig. 3. Effect of gas Reynolds number and two-phase flow number on enhancement factor ϕ_V for confusor K2 with swirl plate.

Table 2. The correlation relationships for two-phase air-water flow and efficiency factor in studied spray columns.

	Pulsation range $m\langle m_k$	Steady flow range $m\rangle m_k$	m_k
Experimental correlations[4-5]			
K1	$Eu_{e,o} = 0.843 \cdot m^{0.20}$	$Eu_{e,o} = 9.6 \cdot 10^{-2} \cdot \mathrm{Re}_G^{0.12} \cdot m^{0.58}$	$m_{k,o} = 303 \cdot \mathrm{Re}_G^{-0.42}$
K2	$Eu_e = 0.848 \cdot m^{0.27}$	$Eu_e = 3.06 \cdot 10^{-2} \cdot \mathrm{Re}_G^{0.26} \cdot m^{0.71}$	$m_k = 1900 \cdot \mathrm{Re}_G^{-0.59}$
K3	$Eu_e = 0.693 \cdot m^{0.26}$	$Eu_e = 1.67 \cdot 10^{-2} \cdot \mathrm{Re}_G^{0.28} \cdot m^{0.76}$	$m_k = 1720 \cdot \mathrm{Re}_G^{-0.56}$
Efficiency factor relationships			
	Pulsation range $m\langle m_k$	Steady flow range $m\rangle m_k$	
K1	$E = 1$	$E = 1$	
K2	$E = 0.0641 \cdot \mathrm{Re}_G^{0.29} \cdot m^{-0.03}$	$E = 0.202 \cdot \mathrm{Re}_G^{0.19} \cdot m^{-0.19}$	
K3	$E = 0.212 \cdot \mathrm{Re}_G^{0.18} \cdot m^{-0.01}$	$E = 1.000 \cdot \mathrm{Re}_G^{0.06} \cdot m^{-0.13}$	

In order to determine the efficiency of studied modified constructions, the values of a factor

$$E = \frac{\phi_v}{\phi_{\Delta P}} \tag{7}$$

where:

$$\phi_{\Delta P} = \frac{Eu_e}{Eu_{e,o}} \tag{8}$$

and $Eu_{e,o}$ refers to data for classical confusor, have been calculated additionally. The hydrodynamical data (Table 2) from experiments[4] have been used. The two-phase pressure drop was measured for air-water co-current flow. The course of pressure drop in a function of two-phase flow number *m* (3) showed that in this case two characteristic ranges: stationary and pulsatory flow, exist.

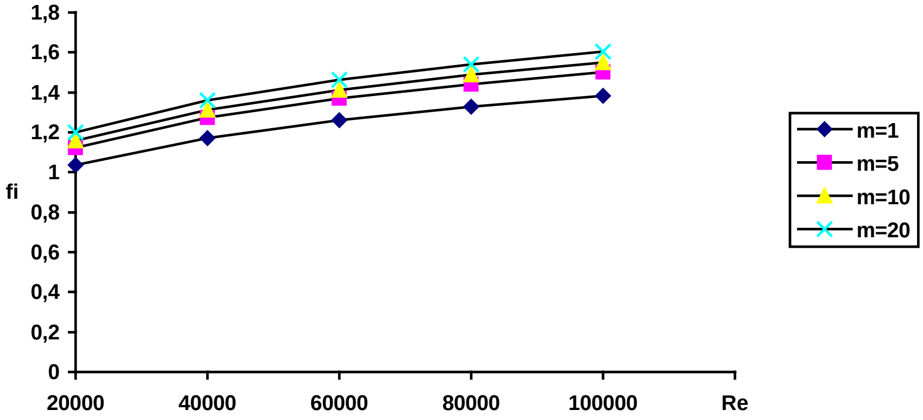

Fig. 4. Effect of gas Reynolds number and two-phase flow number on enhancement factor ϕ_V for confusor K3 with swirl plate and profiled inside surface.

The experiments [4] on two-phase flow for classical and new spray elements with characteristics of $\varphi = 0.137$ and $\alpha = 0.786$ [rd] were performed for 8 various values of gas velocity and the change of liquid mass rate in the wide range. The change of relation of $\Delta P = f(m)$ for critical values of m_k for modified solutions was similar to this one observed in classical column but the function $m_k = f(\mathrm{Re}_G)$ was characteristic for a given construction. In Table 2 the efficiency factor correlation relationships for studied confusors are presented. The efficiency of the both proposed modified constructions of confusor increases with the increase of gas volume rate and with the decrease of two-phase flow number values. It results from two parallel phenomena: additional swirl motion of the streams and the increase of gas - liquid interface. The best result of mass transfer enhancement has been obtained for the confusor with swirl plate K2.

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