GAS HOLDUP AND PRESSURE DROP IN A MULTISTAGE VIBRATING DISK COLUMN WITH COCURRENT GAS-LIQUID FLOW*

KAKUJI TOJO, KEI MIYANAMI AND TAKEO YANO
Department of Chemical Engineering, University of Osaka Prefecture, Sakai

The gas holdup and pressure drop of a multistage vibrating disk column with cocurrent gas-liquid flow are measured and the effects of column geometry and operating variables are determined for the evaluation of column performance.

Among the operating variables, the vibrating speed of the disks $A\nu$ (amplitude A multipled by vibrating frequency ν) has a definite effect on the gas holdup and pressure drop at speeds higher than a certain critical speed $A\nu_c$. At speeds lower than $A\nu_c$, disk vibration has little effect on gas holdup and pressure drop.

The gas holdup and pressure drop are correlated successfully by the addition of increased values due to disk vibration to those in the absence of vibration.

Introduction

The multistage vibrating-disk column (M.V.D.C.) has been used as a contactor for gas absorption, liquid-liquid extraction and gas-liquid reaction. In this column high contacting efficiency is promoted by the reciprocating motion of disks. This type of column is particularly suitable for contact of a gas-liquid mixture with a suspended solid catalyst and for emulsification of immiscible liquids. Though the M.V.D.C. is expected to be applied more widely to various mass transfer operations, only a few studies of this type of column have been published.

Novotny *et al.*[1] have measured longitudinal mixing coefficients in a column of this type with a single-phase liquid flow. Takeba *et al.*[2] have investigated the performance of a M.V.D.C. in terms of the stage efficiency and have discussed its application to gas-liquid reaction with a suspended solid-catalyst. In our previous paper[3], the liquid-phase mixing characteristics of the M.V.D.C. with cocurrent gas-liquid flow were studied.

In this work, the effects of the operating variables and the column dimensions on the average gas holdup and mean pressure drop in a column with cocurrent gas-liquid flow are investigated for the evaluation of column performance.

Experimental

The schematic flow diagram of the experimental apparatus is shown in **Fig. 1**. The multistage vibrating disk column (M.V.D.C.) is the same as the one described in the previous paper[3]. Air and water are used as the gas and liquid phases. These two phases flow cocurrently upward and leave the column.

The average gas holdup is statically measured after stopping both gas and liquid flows at the same time. The measurements of the mean pressure drops are made by open-ended water manometers through pressure taps provided along the column.

The experimental conditions and the column dimensions are listed in **Table 1**.

Results and Discussion

Gas holdup

Figure 2 shows the effect of the vibrating speed, $A\nu$,

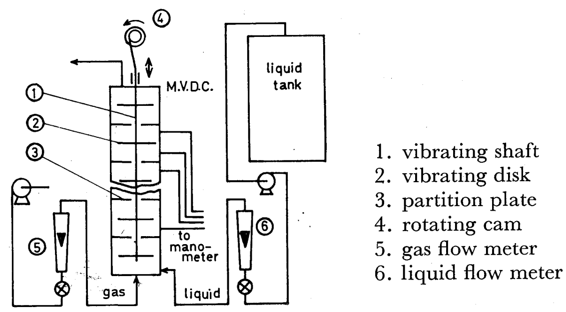

Fig. 1 Experimental apparatus

Table 1 Experimental conditions

Number of stages	N_s	$= 4, 7, 9$	[—]
Number of disks	n_d	$= 4, 7, 9$	[—]
Vib. disk diameter	d_d	$= 20, 30, 36, 40$	[mm]
Vib. shaft diameter	d_s	$= 3$	[mm]
Inside dia. of M.V.D.C.	d_i	$= 50$	[mm]
Hole dia. of partition plate,	d_h	$= 6, 12, 20, 30, 40$	[mm]
Height of one stage	h	$= 35, 70$	[mm]
Gas superficial velocity	u_g	$= 1.15$–7.72	[cm/s]
Liquid superficial velocity	u_l	$= 0.16$–1.12	[cm/s]
Vib. frequency	ν	$= 0$–7	[1/s]
Vib. amplitude	A	$= 0$–12	[mm]

* Received on July 13, 1973
Presented at the Okayama Meeting of The Soc. of Chem. Engrs., Japan, at Okayama, July 1972
〒591 堺市百舌鳥梅町4-804
大阪府立大学工学部化学工学科　東条角治

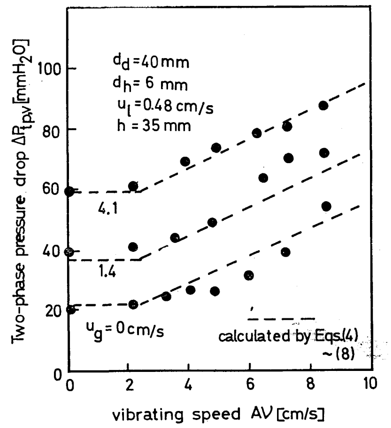

Fig. 2 Effect of vibrating speed on gas holdup

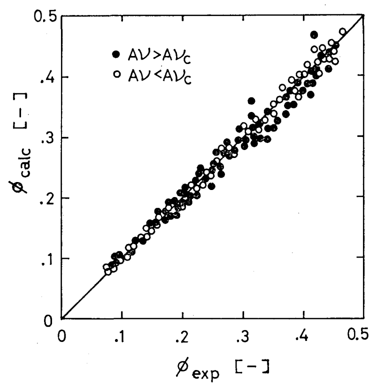

Fig. 3 Comparison of gas holdup data with Eq.(2)

of the disks on the gas holdup, $\phi_{g,v}$. The vibrating speed $A\nu$ is the product of the amplitude A and the frequency ν of the disk vibration. As is easily seen from this figure, the gas holdup is nearly constant until $A\nu$ exceeds a critical value, $A\nu_c$, and as $A\nu$ increases over this value, the gas holdup begins to increase almost proportionally to $(A\nu - A\nu_c)$. This fact has been observed in other types of column with vibrating, reciprocating or pulsating action[4,5]. The increase in the gas holdup is mainly due to the bubble-trapping action of the wakes in the vibrating liquid around the disks. This trapping action can be considered to arise when the linear velocity of the liquid pushed away by the vibrating disk through the free area between the disk and the column wall becomes of the same order as the free rising velocity of the bubbles. Hence the critical speed of the disk vibration $A\nu_c$, is not constant in general, and depends on factors such as the bubble rising velocity. However, so far as the air-water system is concerned, $A\nu_c$ is found to be nearly constant within a range of 2.4 ± 0.5 cm/sec.

In the lower range of vibrating speed $(A\nu < A\nu_c)$, the effect of vibration does not become noticeable and the gas holdup hardly increases even if the speed increases. The measured gas holdup can be correlated by Eq.(1) within an accuracy of $\pm 10\%$.

$$\phi_{g,0} = 0.074 u_g^{0.7} u_l^{-0.08} \left(\frac{d_d}{d_{i,eq}}\right)^{0.5} \left(\frac{d_{h,eq}}{d_{i,eq}}\right)^{-0.15} \left(\frac{h}{d_{i,eq}}\right)^{-0.3} \tag{1}$$

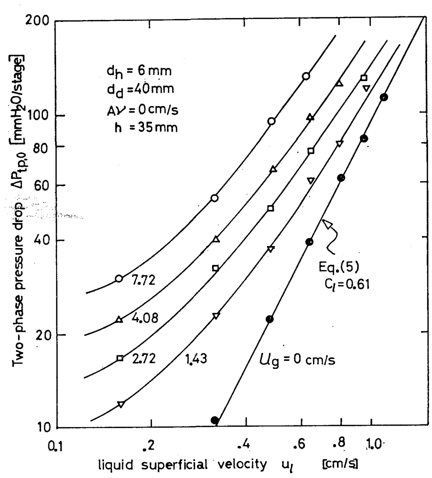

Fig. 4 Two-phase pressure drop in lower vibrating speed range

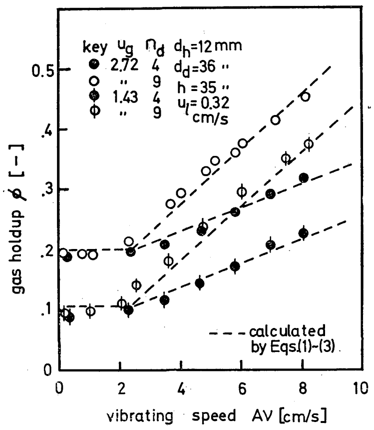

Fig. 5 Effect of vibrating speed on two-phase pressure drop $\Delta P_{tp,v}$

where $d_{i,eq}$ and $d_{h,eq}$ are the hydraulic diameter of the column and the partition plate hole. On the other hand, in the higher speed range $(A\nu < A\nu_c)$, the gas holdup is definitely increased by vibration. As can be seen from Fig. 2 the increase in the gas holdup is mainly affected by the number of disks and the vibrating speed. The gas and liquid velocities have little effect on the increase, so that the following relation holds approximately:

$$\phi_{g,v} = \phi_{g,0} + k n_d (A\nu - A\nu_c) \tag{2}$$

The coefficient k in Eq.(2) has been determined experimentally, as shown in Eq.(3).

$$k = 0.0034 \left(\frac{d_{h,eq}}{d_{i,eq}}\right)^{-0.56} \left(\frac{d_d}{d_{i,eq}}\right)^{2.0} \tag{3}$$

In **Fig. 3**, the observed gas holdups are compared with those calculated by Eqs.(1), (2) and (3). Agreement between them is obtained within an accuracy of $\pm 12\%$.

Pressure Drop

Single-phase flow

The pressure drop of the liquid or gas flow across the column may originate from expansion and/or contraction flow at the hole of the partition plates and at

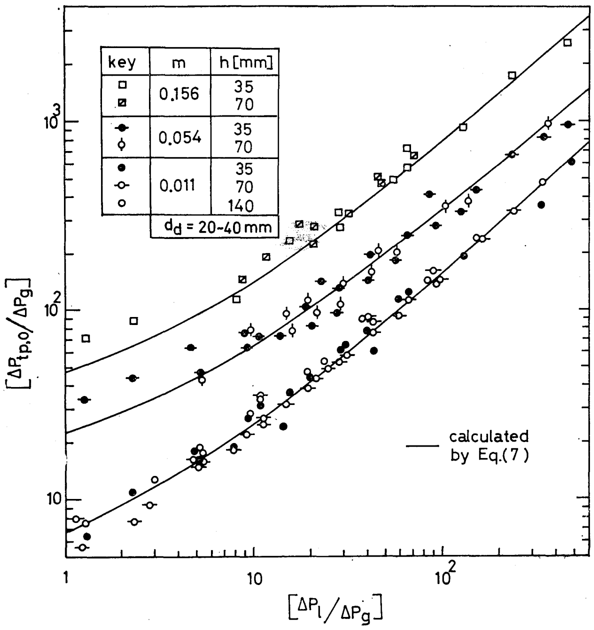

Fig. 6 Two-phase pressure drop correlation in lower vibrating speed range ($A\nu < A\nu_c$)

the free area between the disk and the column wall, and from the wall friction. But the results obtained show that the pressure drops across the partition plates are dominant, and are well explained by the orifice equations, Eqs. (4) and (5), for a hole in the partition plate.

$$\Delta P_g = \frac{1-m^2}{m^2} \frac{1}{C_g^2} \frac{\rho_g}{2_g} u_g^2 \tag{4}$$

$$\Delta P_l = \frac{1-m^2}{m^2} \frac{1}{C_l^2} \frac{\rho_l}{2_g} u_l^2 \tag{5}$$

where m is the fraction of free hole area of the partition plate, and C_g or C_l are the flow coefficients which depend on m and u_g or u_l.

Two-phase flow

The pressure drop ΔP indicated on the manometers for two-phase flow can be expressed as

$$\Delta P = \left(\frac{g}{g_c}\right) \rho_l l \phi_g - \Delta P_{tp} \tag{6}$$

where l is the level difference between the pressure taps and ΔP_{tp} the two-phase pressure drop across the partition plates.

Figure 4 shows the typical pressure drops of two-phase flow in the absence of disk vibration plotted against the liquid superficial velocity u_l.

The effect of the disk vibration on the pressure drop is shown in **Fig. 5**. As is similar to the case of the gas holdup, the vibration has little influence on the pressure drop until the vibrating speed $A\nu$ exceeds $A\nu_c$. As $A\nu$ increases beyond $A\nu_c$, the pressure drop increases proportionally to $(A\nu - A\nu_c)$.

In the lower vibrating speed range ($A\nu < A\nu_c$), Eq. (7) proposed by Murdock[6] for two-phase pressure drop through an orifice can be used to correlate our experimental data:

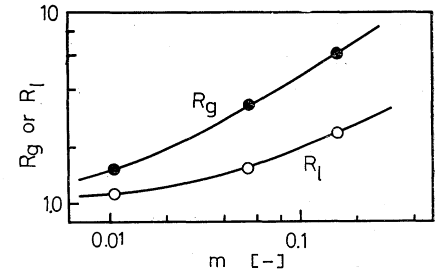

Fig. 7 Effect of m on R_g or R_l

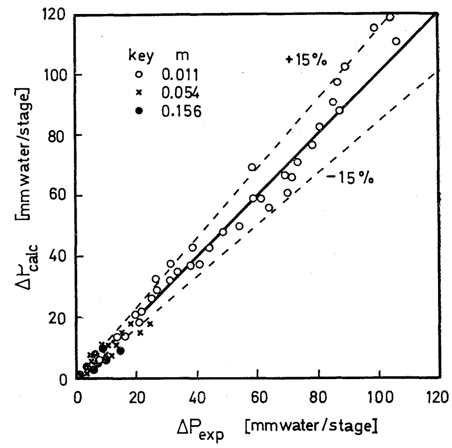

Fig. 8 Comparison of two-phase pressure drop data with Eq.(8)

$$\sqrt{\frac{\Delta P_{tp,0}}{\Delta P_g}} = R_l \sqrt{\frac{\Delta P_l}{\Delta P_g}} + R_g \tag{7}$$

where R_l and R_g are the ratios of the flow coefficients for respective single-phase flow to that for two-phase flow. Although the values of the two-phase flow coefficients cannot be known in advance, the values of R_l and R_g can be determined experimentally by plotting $\Delta P_{tp,0}/\Delta P_g$ against $\Delta P_l/\Delta P_g$ as shown in **Fig. 6**. The results are shown in **Fig. 7**.

At higher vibrating speed ($A\nu > A\nu_c$), the two-phase pressure drops are correlated in a manner similar to that for the gas holdup and Eq. (8) is obtained.

$$\Delta P_{tp,v} = \Delta P_{tp,0} + 0.41 \left(\frac{d_{h,eq}}{d_{i,eq}}\right)^{-0.99} \left(\frac{d_d}{d_{i,eq}}\right)^{2.0} (A\nu - A\nu_c) \tag{8}$$

where $\Delta P_{tp,0}$ can be calculated by Eq. (7) by using R_g and R_l shown in Fig. 7. The measured pressure drops agree well with those estimated by Eqs. (4), (5), (7) and (8), as shown in **Fig. 8**, and the accuracy of this correlation is about $\pm 15\%$.

Conclusion

The average gas holdup and the mean pressure drop have been measured in a multistage vibrating disk column with cocurrent gas-liquid flow.

At lower vibrating speed of the disks (less than a certain critical speed $A\nu_c$), the effect of the speed on the gas holdup and pressure drop is negligible, but for higher speeds, the gas holdup and pressure drop increase almost linearly as the speed increases.

The pressure drop across the holes of the partition plates is most of the total pressure drop in the column and can be interpreted by the orifice equations.

Both the gas holdup and pressure drop with disk vibration can be estimated as an amount proportional to $(A\nu - A\nu_c)$ added to the respective values without vibration.

Nomenclature

A	= amplitude of vibration	[mm]
C_g	= flow coefficient for gas phase	[—]
C_l	= flow coefficient for liquid phase	[—]
d_d	= diameter of vibrating disk	[mm]
d_i	= inner diameter of column (50 mm)	[mm]
$d_{i,eq}$	= hydraulic diameter of column	[mm]
d_h	= hole diameter of partition plate	[mm]
$d_{h,eq}$	= hydraulic diameter of partition plate hole	[mm]
g	= gravitational constant	[cm/s^2]
g_c	= conversion factor	[g·cm/G·sec]
h_l	= column height of one stage	[mm]
l	= level difference between taps	[mm]
m	= fraction of free hole area of partition plate	[—]
n_d	= disk number	[—]
N_s	= stage number	[—]
ΔP	= pressure difference defined by Eq.(6)	[mmH_2O/stage]
ΔP_g	= gas-phase pressure drop defined by Eq.(4)	[mmH_2O/stage]
ΔP_l	= liquid-phase pressure drop defined by Eq.(5)	[mmH_2O/stage]
ΔP_{tp}	= two-phase pressure drop defined by Eq.(6)	[mmH_2O/stage]
$\Delta P_{tp,0}$	= two-phase pressure drop defined by Eq.(7)	[mmH_2O/stage]
$\Delta P_{tp,v}$	= two-phase pressure drop defined by Eq.(8)	[mmH_2O/stage]
R_g	= coefficient defined by Eq.(7)	[—]
R_l	= coefficient defined by Eq.(7)	[—]
u_g	= gas superficial velocity	[cm/sec]
u_l	= liquid superficial velocity	[cm/sec]
ν	= vibrating frequency	[l/sec]
ρ_g	= density of gas phase	[gr/cm^3]
ρ_l	= density of liquid phase	[gr/cm^3]
ϕ_g	= gas holdup defined by Eq.(6)	[—]
$\phi_{g,0}$	= gas holdup defined by Eq.(1)	[—]
$\phi_{g,v}$	= gas holdup defined by Eq.(2)	[—]

Literature Cited

1) Novotny, P., J. Prochazka and J. Landau: *Can. J. Chem. Eng.*, **48**, 405 (1970)
2) Takeba, K., Y. Shirai and R. Kimoto: "Preprint of the 10th General Symp. of the Soc. of Chem. Engrs., Japan", p. 124 (1971)
3) Miyanami, K., K. Tojo and T. Yano: *J. Chem. Eng. Japan*, **6**, 518 (1973)
4) Baird, M. H. and S. H. Garstang: *Chem. Eng. Sci.*, **27**, 828 (1972)
5) Baird, M. H. and S. H. Garstang: *ibid*, 28, 947 (1973)
6) Murdock, J. W.: *J. Basic Eng., Trans. ASME*, **84**, 410 (1962)

MASS TRANSFER IN A MULTISTAGE VIBRATING DISK COLUMN WITH COCURRENT GAS-LIQUID FLOW*

KAKUJI TOJO, KEI MIYANAMI AND TAKEO YANO

Department of Chemical Engineering, University of Osaka Prefecture, Sakai

Mass transfer characteristics of a cocurrent multistage vibrating disk column are studied by the absorption of pure carbon dioxide into water. Axial mixing in the liquid phase is taken into account by using a back-flow model.

Disk vibration definitely enhances the mass transfer rate at low gas velocity and high liquid velocity. On the other hand, at high gas velocity and low liquid velocity, disk vibration does not noticeably improve the mass transfer characteristics, and even worsens them in some cases.

The increase in absorption rate by disk vibration can be well estimated by information on the gas holdup characteristics, the mass transfer characteristics without vibration, the gas bubble size data and the axial mixing characteristics in the liquid phase.

Introduction

Various types of mechanical agitation have been used to improve the mass transfer characteristics in liquid-liquid and gas-liquid contacting operations. Not a few workers have dealt with rotating disk liquid-liquid extractors[5,10,12], pulsed extraction columns[1,2] and gas-liquid or liquid-liquid contactors with rotating impellers[4,6].

On the other hand, only a few studies[3,9,11] have been published about the vibrating disk or perforated plates types of contactor, although this type of agitation is found to be particularly suitable for gas-liquid reaction with suspended solid catalysts, and is expected to be more widely applied to various mass transfer operations.

Prochazka *et al.*[9] have investigated the performance

* Received on July 13, 1973
Presented at the 37th Annual Meeting of The Soc. of Chem. Engrs., Japan, April, 1972

〒591 堺市百舌鳥梅町4-804
大阪府立大学工学部化学工学科　東条角治