GAS HOLDUP IN A BUBBLE COLUMN

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ABSTRACT

An experimental data in a bubble column (BC) for a gas holdup as a function of superficial gas velocity, pressure, temperature, hole diameter of perforated plate distributor, and column diameter were obtained using commercial hexane (liquid phase) in a batch wise and air (gas phase) in a continuous wise.

Results shows there was a positive influence for the gas velocity, pressure, and temperature, and negative influence for the whole diameter, and no influence for the column diameter on the gas holdup.

The following simple dimensionless correlation for predicting gas holdup is suggested.

$$\varepsilon_g = 0.041\left(\mathrm{Re}\,\mathrm{Fr}^2\right)^{0.2}\left(A_f\right)^{-0.04}\exp\left[0.01\left(P+P_v\right)\right]$$

INTRODUCTION

Bubble columns (BCs) are widely used in chemical, petrochemical, and biochemical process industries as absorbers, fermenters and gas-liquid reactors due to their simple construction, and good interphase mixing characteristics. Gas holdup is the basic parameter indicating the hydrodynamic behavior of BCs. It characterizes the retention of bubbles in the column and is indicative of their residence times, bubble velocity, and effective interfacial area, thus affects the mass transfer rates. So it is one of the necessary and important parameters for the design of BCs. Gas holdup may be defined as the fractional gas volume in two or / and three phase gas dispersions. It is related with bubble diameter and interfacial area by:

$$a = \frac{6\varepsilon_g}{d_b} \qquad (1)$$

Many research works have been conducted on gas holdups in BCs. A good review of this subject has been given by Shah et al. [1], where, most of the works are devoted to the air-water systems under ambient conditions. Ozturk et al. [2] studied a comprehensive set of organic liquids in order to assess the influence of the liquid and gas properties on the gas holdup and to check on the applicability of the previously published correlation. They [2] found that the correlation of Akita and Yoshida [3], Eq. (2), and of Hikita et al. [4], Eq. (3) give the best fit.

$$\frac{\varepsilon_g}{\left(1-\varepsilon_g\right)^4} = 0.2\,\mathrm{Fr}\left(\mathrm{Bo}\right)^{1/8}\left(\mathrm{Ga}\right)^{1/12} \qquad (2)$$

$$\varepsilon_g = 0.672\left(\mathrm{Mo}\right)^{-0.131}\left(\frac{u_g\mu_l}{\sigma_l}\right)^{0.578}\left(\frac{\rho_g}{\rho_l}\right)^{0.062}\left(\frac{\mu_g}{\mu_l}\right)^{0.10} \qquad (3)$$

Zou et al. [5] studied gas holdup in a BC of 10 cm in diameter and 1.05 m in height operated at elevated temperatures (25 – 96.56 °C) for the systems air-water, air-alcohol, and air-5% NaCl solution. They [5] found that the operating temperature influence remarkably gas holdup in a BC. The reason is mainly that the sizes of the bubbles in the liquid are smaller at elevated temperature. A gas holdup correlation implicating the effect of the operating temperature was developed with an average deviation of 3.1% in the form:

$$\varepsilon_g = 0.172\left(\mathrm{Mo}\right)^{-0.1544}\left(\frac{\mathrm{Fr}^2\,\mathrm{Bo}}{\mathrm{Re}}\right)^{0.5897}\left(\frac{P+P_v}{P}\right)^{1.610} \qquad (4)$$

The relationship between the gas holdup and the temperature is basically similar to the change tendency of the vapor pressure of the liquid with temperature. Therefore, the vapor pressure of the liquid phase can be used to indicate the effect of temperature on the gas holdup [5].

Saxena[6] reported that the gas holdup exhibit a characteristic qualitative dependence on air velocity, where its value at a particular gas velocity decreases with an increase in temperature, the rate being faster at lower temperatures and the values almost identical at the two higher temperatures, particularly at higher air velocities.

Oyevaar et al.[7] found that the gas holdups as well as the interfacial areas in the BC increase with increasing operating pressure. The magnitude of the pressure influence depends on the superficial gas velocity. This positive influence of pressure on the gas holdups and the interfacial areas in the BC originates from the formation of smaller bubbles at the gas distributor.

Deckwer and Schumpe[8] reported that the experimental studies concerning the effect of operating pressure on gas holdups, the researchers conclude that the gas holdup increases with increase in operating pressure. Dewes [9] also noted the positive influence of pressure on gas holdup.

The BCs as industrial scale absorbers, strippers, scrubbers, fermenters, and gas-liquid reactors is considerably growing as various aspects of these columns. Most of the previous studies are, however, limited to air-water at ambient conditions despite the fact that most BCs in industry are operated under a wide range of temperature and pressure using various gas-liquid systems, the contradictory among the results of the available works concerning temperature effects, and the limitation of the work concerning the effect of temperature and pressure together, so this work aim to:

1. Predict gas holdups for a BC with commercial hexane as a liquid phase and air as a gas phase on a semi-batch basis under different conditions of temperature and pressure in connection with hole diameter of perforated plate distributor and column diameter.
2. Suggestion a relation gives gas holdups taking into account the various parameters concerned.

EXPERIMENTAL

The experimental apparatus is shown in Fig.1. Two BCs of stainless steel 1.5 m long each, one of 15 cm inside diameter (ID) with 7.5 mm wall thickness, and the other of 7.5 cm ID with 6 mm wall thickness, were separately used. Pressure drop along the column were measured via eight valves (equally spaced 20 cm between each two valves and 5 cm between the upper and lower valves with column ends). The upper cover was provided with safety valve, outlet (needle) valve, and filling valve. The lower cover was provided with one-way (check) valve for entering gas, and drain valve.

Three distributors of perforated plate type with each BC were separately used. The distributors differ in hole diameters (0.5, 1.0, and 1.5 mm). The distributors used with BC of 7.5 cm ID contains 21 holes, while those used with BC of 15 cm ID contains 84 holes, Fig.2. The number of holes on distributors for the two columns was designed to give same free area (A_f).

Air (gas phase) was supplied by means of U compressor (19), via the gas bottle (30). Two calibrated rotameters (26) of (0-4) m^3/hr provided with a valve were connected in parallel, used to measure the flow rate (of the air). Then air introduced to BC (1) through the distributor (2), where the contact with liquid phase attains. The air leaves the column (1) through outlet valve (31).

Commercial hexane (narrow boiling mixture of n-hexane and iso-hexanes) of 85% wt. n-hexane was selected as a test liquid (liquid phase). The test liquid was fed to the specified height, 85 cm, in the column (1), where it was used on a batch basis.

Pressure drop along the axial height of the column was measured via pressure taps (8) using differential gauge pressure (10). The column pressure was controlled by means of a pressure controller (27).

Tape heaters (12) of 400 watt, were used to achieve the desired bulk temperatures of the test liquid. The rate of heat input was controlled using temperature controller (14).

All experiments were carried out under same conditions of pressure 0, 2.5, 5, 7.5, and 10 atmosphere gauge and temperatures 25, 50, 75, 100, and 125 °C on a semi-batch basis in the two BCs mounted in a vertical position. Tables (1) and (2) shows the experimental results obtained.

RESULTS AND DISCUSSION

As shown in Figs. (3) and (4), the gas holdup is mainly dependent on the superficial gas velocity, it increases with increasing superficial gas velocity.

Figs. (3) and (4) also shows , that gas holdup increases with decreasing hole diameter (free area). This confirms that the smaller bubbles give higher gas holdups, consequently good mixing.

Figs. (5) and (6) shows that the operating pressure and temperature has a positive influence on the gas holdup. The positive influence is due to formation of smaller bubbles in the liquid at elevated pressures and temperatures.

CORRELATION DEVELOPMENT

Dimensional analysis was used to derive a correlation to predict the gas holdup. The suggested correlation is of the form:

$$\varepsilon_g = C_1 \left(Re\,Fr^2 \right)^{C_2} A_f^{C_3} \, Exp\left[C_4 \left(P + P_v \right) \right] \quad (5)$$

The group of ($ReFr^2$) give the effect of superficial gas velocity along with the important physical properties (density and viscosity) and to cancel the effect of column diameter. The term (A_f) was put to give the effect of distributor. And ($P + P_v$) term gather the effect of temperature and pressure on the gas holdup.

With the help of dimensional analysis program, the final form of the correlation is as follows:

$$\varepsilon_g = 0.041 \left(Re\,Fr^2 \right)^{0.2} \left(A_f \right)^{-0.04} Exp\left[0.01 \left(P + P_v \right) \right] \quad (6)$$

The absolute average relative deviation (AARD) = 9.357×10^{-2}, and the standard error of estimation (SEE) = 1.12×10^{-3} and with $\pm 93.9\%$ of the data was within ($\pm 20\%$) accuracy limits, Fig. (7).

CONCLUSIONS

1. the superficial gas velocity has the most significant positive effect on the gas holdup.
2. The operating pressure and temperature has positive influence on the gas holdup.
3. The hole diameter of the distributor used has a negative influence.
4. The distributor of 0.5 mm hole diameter exhibits higher values of gas holdup compared with the other hole diameters.
5. The column diameter has no effect on the gas holdup.
6. The present data indicate that the popular correlations of gas holdup which have been found to hold under ambient conditions might lead to grossly erroneous predictions if they are extrapolated to the conditions used in this work.
7. The simple correlation developed (Eq. 6) successfully explain the effects of various parameters concerned in this work.

Notation

A_f	Free area, equal to (total area of holes/area of distributor)	(-)
a	Specific gas-liquid interfacial area	(m^2/m^3)
C_1,..,C_4	Constants of correlation (4)	(-)
d	Diameter	(m)
g	Gravity acceleration	(m/s^2)
P	Pressure	(atm)
P_v	Vapor pressure	(atm)
u	Superficial velocity	(m/s)

Dimensionless Numbers

Bo	Bond number = $(d_c^2 \rho_l g / \sigma_l)$
Fr	Froude number = $(u_g / \sqrt{g d_c})$
Ga	Galilie number = $(d_c^3 \rho_l^2 g / \mu_l^2)$
Mo	Morton number = $(g \mu_l^4 / \rho_l \sigma^3)$
Re	Reynolds number = $(\rho_l u_g d_c / \mu_l)$

Greek Letters

ε	Holdup	(-)
μ	Viscosity	(kg/m . s)
ρ	Density	(kg/m^3)
σ	Surface tension	(N/m)

Subscripts

b	Bubble
c	Column
g	Gas phase
h	Hole
l	Liquid phase

REFERENCES

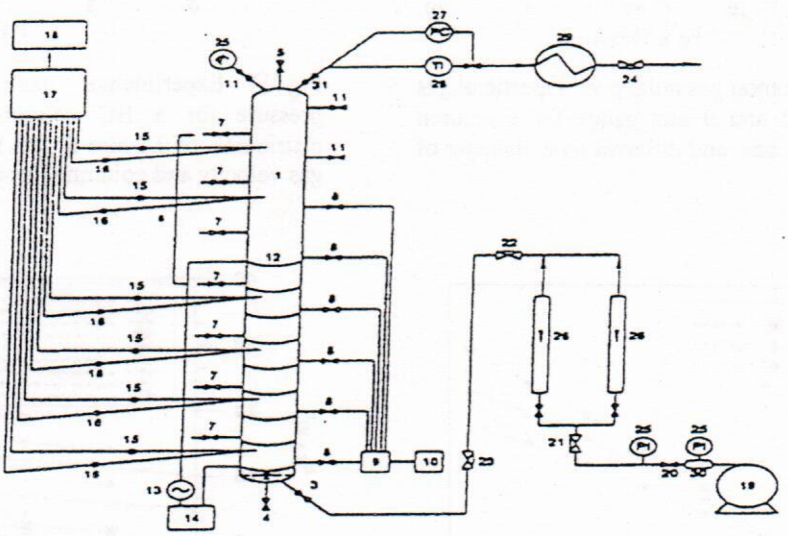
1. Shah, Y. T., Kelkar, B. G., and Godbole, S. P., "Design parameters estimations for bubble column reactors", AIChE J., Vol. 28, No. 3, P. 353, (1982).
2. Ozturk, S. S., Schumpe, A., and Deckwer, W. D., "Organic liquids in a bubble column: holdups and mass transfer coefficients", AIChE J., Vol. 33, No. 9, P. 1473, (1987).
3. Akita, K., and Yoshida, F., "Gas holdup and volumetric mass transfer coefficient in bubble columns", Ind. Eng. Chem. Process Des. Dev., Vol. 12, P. 76, (1973).
4. Hikita, H., Asai, S., Tanigawa, K., Segawa,K., and Kitao, M., "Gas holdup in bubble columns", Chem. Eng. J., Vol. 20, P. 59, (1980).
5. Zou Renjun, Xinzhen, J., Li Baozhang, Zu Young, and Laiqi, Z., "Studies on gas holdup in a bubble column operated at elevated temperatures", Ind. Eng. Chem. Res., Vol. 27, No.10, P. 1910, (1988).
6. Saxena, S. C., "Bubble column reactors and fischer-tropsch synthesis", Catal. Rev. Sci. Eng., Vol. 37, No.2, P. 227, (1995).
7. Oyevaar, M. H., De La Rie, T., Van Der Sluijs, C. L., and Westerterp, K. R., "Interfacial Areas and Gas Holdups in Bubble Columns and Packed Bubble Columns at Elevated Pressures", Chem. Eng. Process., Vol. 26, No.1, P. 1, (1989).
8. Deckwer, W. –D., Schumpe, A., "Improved Tools for Bubble Column Reactor design and scale-up", Chem. Eng. Sci., Vol. 48, No.5, P. 889, (1993).
9. Dewes, I., "Der EinfluB der Gasditchte auf Stoffübergang and Gasgehalt in Blasensäulen und Suspensions blasensäulen" Der Technitchen Fakultät der Universität Erlangen-Nürnberg zur Erlangung des Grades DOKTOR-INGENIEUR, Erlangen (1997).

Table (1): Gas Holdup (ε_g x 10^2) Data in a BC of 7.5 cm I. D.

u_g x 10^2 (m/s)	H_s (m) / Press. atm.g \ T °C	0.5					1.0					1.5				
		25	50	75	100	125	25	50	75	100	125	25	50	75	100	125
3.1438	0	7.7	8.5	-	-	-	6.8	7.0	-	-	-	6.0	6.3	-	-	-
6.2876	0	12.1	13.9	-	-	-	10.6	11.3	-	-	-	9.0	9.5	-	-	-
9.4314	0	16.0	17.8	-	-	-	13.4	14.0	-	-	-	11.1	12.0	-	-	-
12.5752	0	19.0	20.8	-	-	-	15.8	16.3	-	-	-	13.8	14.2	-	-	-
15.719	0	21.6	23.5	-	-	-	17.9	18.3	-	-	-	15.4	16.1	-	-	-
18.863	0	24.2	26.0	-	-	-	20.0	20.8	-	-	-	17.0	18.0	-	-	-
3.1438	2.5	8.0	8.7	9.4	10.1	-	7.2	7.5	7.9	8.5	-	6.3	6.7	7.0	7.5	-
6.2876	2.5	12.8	14.0	15.0	16.0	-	11.1	11.8	12.4	13.2	-	9.5	10.1	10.6	11.2	-
9.4314	2.5	17.1	18.0	19.4	20.8	-	14.1	14.8	15.7	16.9	-	12.0	12.8	13.4	14.2	-
12.575	2.5	20.4	22.1	20.0	25.5	-	16.8	17.8	19.0	20.2	-	14.6	15.2	16.0	17.0	-
15.719	2.5	23.3	25.1	27.7	29.5	-	19.1	20.2	21.6	23.1	-	16.4	17.6	18.2	19.2	-
18.863	2.5	26.2	28.0	31.1	33.3	-	21.5	22.2	24.2	26.0	-	18.1	19.3	20.1	21.2	-
3.1438	5	8.4	9.4	10.0	10.7	11.5	7.5	8.0	8.3	8.9	9.5	6.7	7.3	7.7	8.2	8.8
6.2876	5	13.5	14.7	15.7	17.0	18.0	11.7	12.4	13.0	13.7	14.6	10.4	11.0	11.6	12.3	13.3
9.4314	5	18.1	19.0	20.4	22.0	23.1	14.8	15.4	16.6	17.6	18.5	13.0	13.7	14.5	15.6	16.2
12.575	5	21.8	23.0	24.7	26.2	28.0	19.7	18.8	20.2	21.0	22.5	15.4	16.2	17.2	18.3	19.5
15.719	5	24.9	26.8	28.5	31.0	33.0	20.3	21.9	23.0	24.1	25.7	17.3	18.5	19.6	20.7	22.5
18.863	5	28.2	30.0	32.0	34.2	35.1	23.0	24.7	25.6	27.2	28.5	19.2	20.4	21.6	23.0	24.5
3.1438	7.5	8.7	9.7	10.2	11.0	11.8	8.1	8.5	9.1	9.7	10.6	6.9	7.5	7.8	8.5	9.3
6.2876	7.5	14.3	15.3	16.4	17.0	18.5	12.3	13.0	14.0	15.0	16.0	10.5	11.3	12.3	13.2	14.3
9.4314	7.5	19.2	19.7	21.0	22.4	24.0	15.6	16.2	17.9	19.3	20.5	14.0	14.7	15.6	17.0	18.4
12.575	7.5	23.0	24.5	26.0	27.9	29.2	18.7	20.0	21.7	23.0	24.7	16.1	17.5	19.0	20.5	22.0
15.719	7.5	26.5	28.3	30.0	31.7	33.7	21.6	22.8	24.7	26.5	28.2	18.3	19.6	21.5	23.6	25.0
18.863	7.5	30.0	31.9	34.1	36.0	38.0	24.4	25.5	27.4	29.3	31.5	20.8	21.8	23.0	25.5	27.6
3.1438	10	9.2	10.2	10.8	11.7	12.2	8.5	9.0	9.6	10.4	11.0	7.3	7.8	8.4	9.0	9.8
6.2876	10	14.9	16.0	17.0	18.2	19.5	12.8	13.6	14.9	16.1	17.1	11.4	12.0	12.8	13.8	15.0
9.4314	10	20.0	21.5	22.5	23.2	25.4	16.3	17.9	19.4	21.0	22.2	14.6	15.0	16.0	17.7	19.1
12.575	10	24.0	26.0	27.9	29.0	31.1	19.7	21.2	23.0	25.2	27.0	16.8	17.9	19.5	21.2	22.8
15.719	10	28.2	30.0	32.0	33.1	35.9	22.8	25.0	27.0	29.0	31.0	19.2	20.3	22.3	24.0	26.0
18.863	10	31.5	33.8	36.3	37.5	40.0	25.8	27.8	30.0	32.2	34.3	21.4	22.8	24.8	27.0	29.0

Table (2): Gas Holdup ($\varepsilon_g \times 10^2$) Data in a BC of 15 cm I. D.

$u_g \times 10^2$ (m/s)	Pressure	h_L (m) 0.5					1.0					1.5				
	T (°C)	25	50	75	100	125	25	50	75	100	125	25	50	75	100	125
1.5719	0	4.5	5.0	-	-	-	4.2	4.6	-	-	-	3.9	4.2	-	-	-
3.1438	0	7.6	8.4	-	-	-	6.8	7.0	-	-	-	6.0	6.3	-	-	-
4.7157	0	10.0	11.1	-	-	-	8.9	9.4	-	-	-	7.6	8.0	-	-	-
6.2876	0	12.0	13.8	-	-	-	10.5	11.3	-	-	-	9.0	9.5	-	-	-
7.8595	0	13.9	15.1	-	-	-	11.9	12.5	-	-	-	10.3	10.7	-	-	-
9.4314	0	16.0	17.6	-	-	-	13.4	14.0	-	-	-	11.0	12.0	-	-	-
1.5719	2.5	5.1	5.5	5.9	6.4	-	4.6	4.9	5.2	5.6	-	4.2	4.4	4.7	5.0	-
3.1438	2.5	8.0	8.7	9.4	10.0	-	7.0	7.5	7.9	8.4	-	6.3	6.7	7.0	7.4	-
4.7157	2.5	10.5	11.5	12.5	13.4	-	9.2	9.7	10.5	11.1	-	8.0	8.5	9.0	9.5	-
6.2876	2.5	12.7	13.9	15.0	16.0	-	11.1	11.8	12.3	13.1	-	9.5	10.0	10.5	11.1	-
7.8595	2.5	15.0	16.0	17.3	18.7	-	12.3	13.3	14.1	15.2	-	10.9	11.5	12.1	12.9	-
9.4314	2.5	17.0	18.0	19.2	20.7	-	14.0	14.7	15.6	16.9	-	11.9	12.8	13.1	14.1	-
1.5719	5	5.5	6.0	6.5	7.0	7.6	4.7	5.1	5.4	5.8	6.2	4.4	4.7	5.2	5.5	5.8
3.1438	5	8.4	9.3	9.9	10.7	11.5	7.5	8.0	8.3	8.8	9.4	6.7	7.2	7.7	8.2	8.8
4.7157	5	11.2	12.2	13.0	14.2	15.2	9.6	10.4	10.9	11.5	12.3	8.4	9.2	9.7	10.6	11.4
6.2876	5	13.5	14.6	15.6	16.9	17.9	11.7	12.3	13.0	13.7	14.5	10.2	10.9	11.6	12.3	13.2
7.8595	5	15.8	17.0	18.0	19.5	20.7	13.3	14.3	15.0	15.9	16.9	11.6	12.5	13.2	14.0	15.1
9.4314	5	18.0	19.0	20.1	21.8	23.0	14.7	15.6	16.5	17.5	18.4	12.9	13.7	14.5	15.5	16.7
1.5719	7.5	5.5	6.0	6.4	6.8	7.5	5.0	5.4	5.9	6.4	6.9	4.6	4.9	5.3	5.6	5.9
3.1438	7.5	8.7	9.6	10.3	11.0	11.8	7.9	8.5	9.0	9.7	10.5	6.9	7.4	7.8	8.5	9.3
4.7157	7.5	11.7	12.6	13.5	14.5	15.5	10.1	11.0	11.7	12.7	13.8	8.6	9.4	10.2	11.0	11.9
6.2876	7.5	14.2	15.3	16.3	17.0	18.4	12.3	13.1	14.0	15.0	16.0	10.4	11.3	12.2	13.2	14.3
7.8595	7.5	16.5	17.7	19.0	20.0	21.5	13.9	15.0	16.1	17.3	18.5	12.0	13.0	14.0	15.1	16.3
9.4314	7.5	19.1	19.6	20.9	22.3	23.9	15.5	16.1	17.8	19.2	20.5	13.5	14.4	15.3	16.8	18.2
1.5719	10	5.8	6.3	6.7	7.2	7.8	5.2	5.7	6.1	6.6	7.0	4.8	5.1	5.5	6.0	6.6
3.1438	10	9.1	10.2	10.7	11.7	12.2	8.2	8.9	9.6	10.4	11.0	7.1	7.7	8.3	8.9	9.8
4.7157	10	12.2	13.2	14.1	15.0	16.3	10.7	11.5	12.3	13.3	14.3	9.4	10.0	10.9	11.6	12.6
6.2876	10	14.7	15.9	16.9	18.0	19.4	12.7	13.6	14.9	16.0	17.0	11.4	12.0	12.7	13.7	14.9
7.8595	10	17.3	18.7	19.9	21.0	22.9	14.8	15.8	17.0	18.6	20.1	12.6	13.5	14.6	16.0	17.0
9.4314	10	20.0	21.5	22.5	23.2	25.3	16.3	17.9	19.4	21.0	22.1	14.5	15.0	15.9	17.6	19.0



1. Bubble column 2. Distributor 3. Check valve 4. Discharge valve
5. Inlet valve 6. Level indicator 7. Sample valve 8. Pressure tap
9. Selection box 10. Differential gauge pressure 11. Accessory valve
12. Heating tape 13. Power supply source 14. Temperature controller
15. Bulk temperature thermocouple 16. Surface temperature thermocouple
17. Selector switch 18. Temperature reader 19. Air compressor
20. Needle valve 21, 22, 23, 24. Three-way valve 25. Pressure gauge
26 Rotameter with valve 27. Pressure controller 28. Temperature indicator
29. Condenser 30. Surge tank 31. Outlet valve

Fig. (1) Experimental apparatus

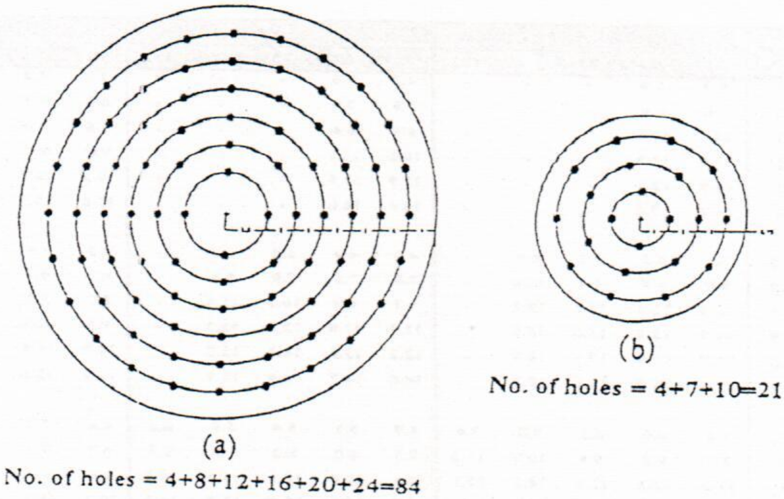


Fig. (2) Distribution of BCs used

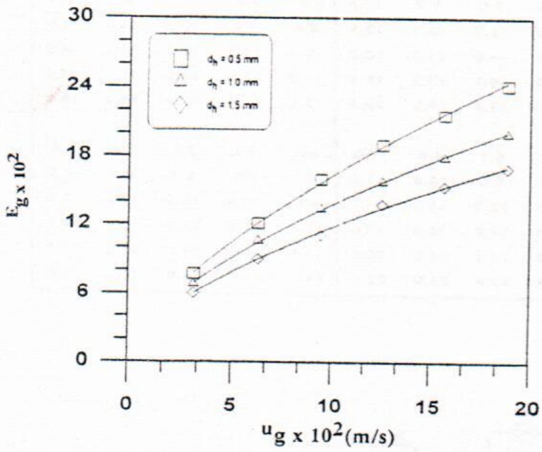


Fig.(3) Experimental gas holdup vs. superficial gas velocity at 25°C and 0 atm gauge for a column diameter of 7.5 cm and different hole diameter of distributor.

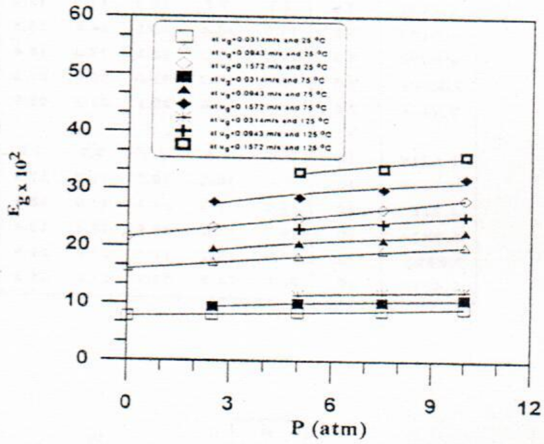


Fig.(5) Experimental gas holdup vs. column pressure for a BC column of 7.5 cm ID and distributor of 0.5 mm d_h as a function of superficial gas velocity and column temperature.

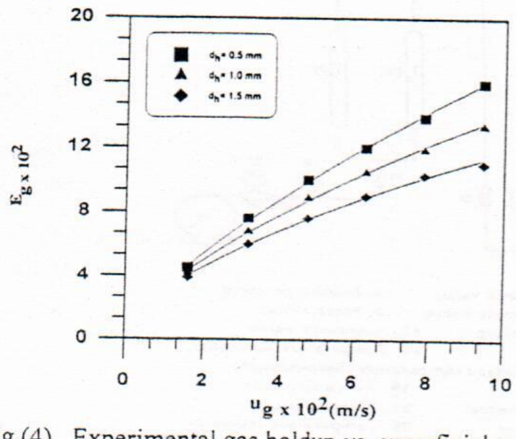


Fig.(4) Experimental gas holdup vs. superficial gas velocity at 25°C and 0 atm gauge for a column diameter of 15 cm and different hole diameter of distributor.

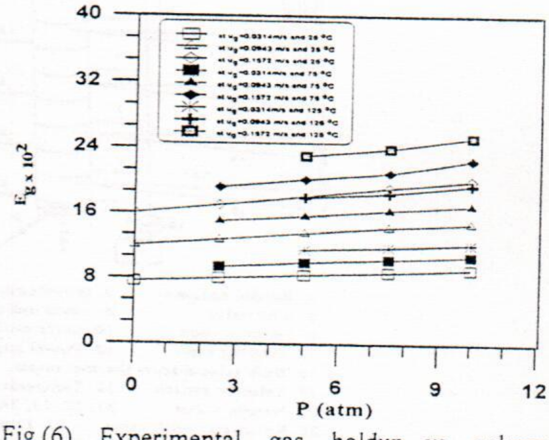


Fig.(6) Experimental gas holdup vs. column pressure for a BC column of 15 cm ID and distributor of 0.5 mm d_h as a function of superficial gas velocity and column temperature.

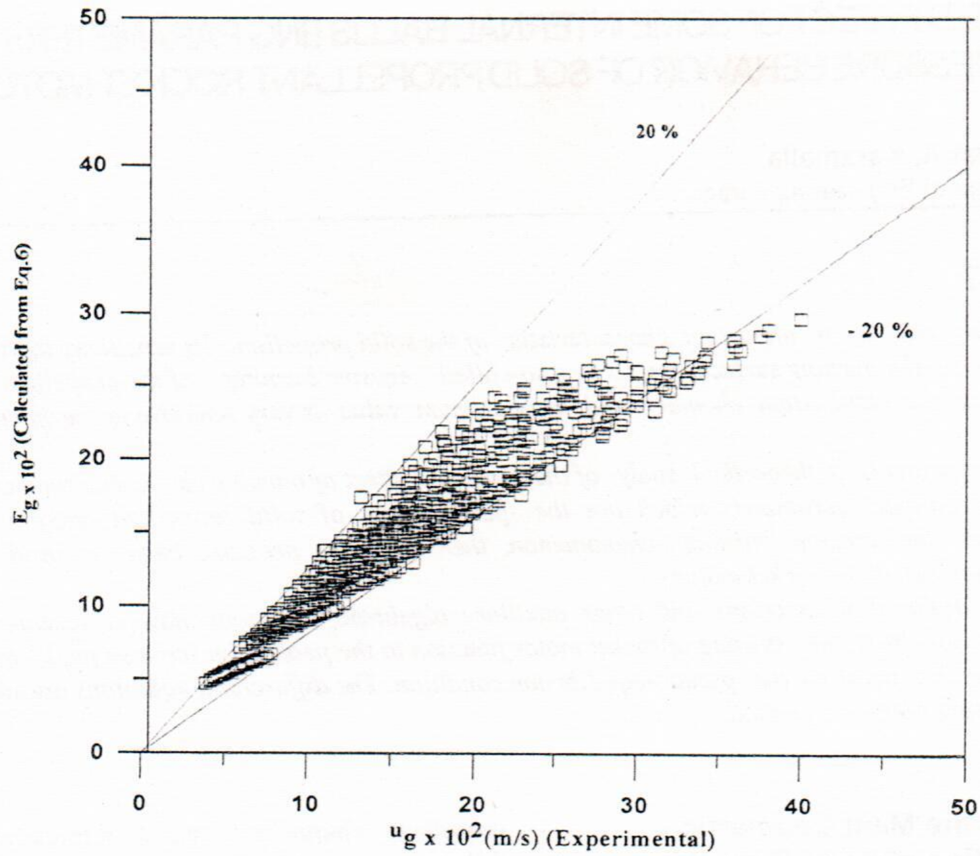


Fig. (7) Comparison between calculated and experimental gas holdup