Impact of Different H/D Ratio on Axial Gas Holdup Measured by Four-Tips Optical Fiber Probe in Slurry Bubble Column

Yasser Imad Abdulaziz
Instructor
Engineering College - Al-Nahrain University
email: dryasserimad@gamil.com

ABSTRACT

In wide range of chemical, petrochemical and energy processes, it is not possible to manage without slurry bubble column reactors. In this investigation, time average local gas holdup was recorded for three different height to diameter (H/D) ratios 3, 4 and 5 in 18" diameter slurry bubble column. Air-water-glass beads system was used with superficial velocity up to 0.24 m/s. the gas holdup was measured using 4-tips optical fiber probe technique. The results show that the axial gas holdup increases almost linearly with the superficial gas velocity in 0.08 m/s and levels off with a further increase of velocity. A comparison of the present data with those reported for other slurry bubble column having diameters larger than 18" and H/D higher than 5 indicated that there is little effect of diameter on gas holdup. Also, local section-average gas holdups increase with increasing superficial gas velocity, while the effect of solid loading are less significant than that of superficial gas velocity.

Key words: slurry bubble column, gas holdup, optical probe.

تأثير النسب المختلفة للارتفاع إلى القطر على المحتوى الغازي المحوري المقاس بواسطة المجس البصري ذو النهايات الأربعة في العمود الفقاعي الذي يحتوي على صلب

ياسر عماد عبدالعزيز
مدرس
كلية الهندسة – جامعة النهرين

الخلاصة

لمدى واسع من العمليات الكيمياوية و البتروكيمياوية و عمليات الطاقة ليس من الممكن الاستغناء عن مفاعلات الأعمدة الفقاعية ذات المحتوى الصلب. في هذا البحث, تمت دراسة معدل المحتوى الغازي ألموقعي لثلاث نسب مختلفة من الارتفاع إلى قطر المفاعل و هي 3 و 4 و5 لقطر مفاعل مقداره 18 انج. استخدم نظام هواء – ماء – حبيبات زجاجية و سرعة الغاز تصل إلى 0,25 م/ثا. تم قياس المحتوى الغازي باستخدام تقنية المجس البصري ذو النهايات الأربعة. بينت النتائج أن المحتوى الغازي المحوري يتزايد تقرباً بشكل مستقيم مع زيادة سرعة دخول الغاز عند 0,08 م/ثا و تستقر مع زيادة سرعة دخول الغاز. إن مقارنة النتائج مع باحثين آخرين عملوا على مفاعلات فقاعية بمحتويات صلبة ذات أقطار اكبر من 18 انج و نسبة ارتفاع إلى قطر أعلى من 5 بينت انه يوجد تأثير محدود لقطر المفاعل على المحتوى الغازي. أيضاً, و جد أن متوسط المحتوى الغازي للمقاطع يزداد مع زيادة سرعة الغاز السطحية في حين أن تأثير تركيز الصلب هي اقل أهمية من سرعة الغاز السطحية.

الكلمات الرئيسية: العمود الفقاعي ذو العالق الصلب, المحتوى الغازي, المجس البصري.

1. INTRODUCTION

slurry bubble column reactors have been considered as very important and promising technologies in multiphase operations such as biological waste water treatment, flue gases, desulphurization, Fischer–Tropsch synthesis, fermentation production of ethanol and mammalian cells and hydro–treating of heavy petroleum, **Larson,** and **Tingjin, 2003**, **Azzopardi, et al., 2011, Prakash, et al., 2001**. The hydrodynamics and reaction kinetics play a major role in the selection, design, size and performance of these reactors. Since, the reaction regimes are highly affected by phase holdup and mass transfer which are needed to maintain the gas concentration in the reaction regimes at certain level, that sustain the reaction progress. While, it should be interested to study low ratios of H/D as it is used in bulk industrial applications, most published data are obtained in small column diameters, with H/D ratio greater than ten times.

Some researchers reported that the overall gas holdup is not affected when the H/D ratio above 5, **Parasu,** and **Joshi, 2000**. Numerous authors reported that, in homogeneous regime, the overall gas holdup is independent on the column diameter when it is greater than 0.15m (except for highly viscous solution), **Joshi, et al., 1998,** and **Shah, et al., 1982**. In general, all papers dealing with column size reported that liquid recirculation and back-mixing increases strongly with column diameter, **Krishna, 2000, Baird,** and **Rice, 1975, Towell,** and **Ackerman, 1972**. However, the data reported in open literatures are disordered and have to be assessed and validated at different conditions and scaling up design parameters, **Forret, et al., 2006**.

Recently, the data which has been published in literatures of several investigators, **Vandu,** and **Krishna, 2004, Chilekar, 2007**, **Yu, et al., 2012**, is also in agreement with the proposed influence of the column diameter on the hydrodynamics of the slurry bubble column which is in same trend with the previously work of, **Shah, et al., 1982**. They revealed that the gas hold-up decreases with increase in the column diameter up to 15cm (5.9") due to increase in liquid re-circulations. Above 15cm diameter there is no influence of column diameter on the measured gas hold-up up to 5.5 m column diameter. On the other hand, they did not report how the variation are under different solid loading and low H/D ratios which are essential to achieve reliable figuring out for scaling up of industrial applications. The lack of complete understanding of the hydrodynamics of bubble columns under this range of H/D ratios makes it difficult to improve their performance by right selection and control of operation parameters.

The main objective of this research is to focus on the measurements of hydrodynamic parameters using four tips optical fiber probe and evaluate the impact of scale and solid loading on the hydrodynamics of slurry bubble column.

2. EXPERIMENTAL WORK

A large scale Plexiglas column of 18" (45cm) diameter and 115" (292 cm) length was used as a test contactor in this research, as shown in **Fig.1**. The column was supported by firm steel structure to keep it vertical and minimize the vibrations which might affect the measured gas holdup signals. All experiments were carried out using filtered tap water and oil free compressed air. A perforated plate was used as a distributor with 1.09% open area (area of open holes to total area of plate), 241 holes of 3mm diameter placed in a square pitch. The gas flow rate was regulated by two rotameters to cover the range of flow and the water was used in batch mode with varied hydrodynamic height above the distributor according to the H/D ratios used throughout the experiments in the range of 3 to 5. Glass beads particles of 150 μm and 2430 kg/m^3 density were used as suspended solids with loading of 0, 9 and 20%. The glass particles were mixed with tap water over night to ensure complete wetting and good liquid distribution throughout the experiments. Four – tips optical probe was used to obtain the hydrodynamic measurements. The technical and working details were described elsewhere, **Youssef, 2010**. Local probe measurements were taken at five different axial positions (14, 28, 42, 56 and 70") at the center of the column when the probe tips facing downward. It is well known that the gas holdup measured by the probe, which is time based, is little different from the overall volume based gas holdup, that is commonly used. The overall gas holdup based on volume ratio is defined as the fraction occupied by gas in multiphase system which is measured using the bed expansion method. The local gas holdup obtained by the probe is defined as:

$$\varepsilon_{g,t} = \frac{t_g}{t} \quad (1)$$

where, t_g is the time which the probe spends in the gas phase and t is the total measuring time, **Xue, 2004**.

3. RESULT AND DISCUSSION

The profiles of axial gas hold up were obtained from the measured signals of optical fiber probe at different slurry concentrations and several ratios of H/D. Three main regions can be distinguished to the axial gas holdup profile in slurry bubble column. These are mainly categorized as: the distributor region which is near the column bottom, the bulk region and the foam or disengagement region at the top of the column, **Gandhi, et al., 1999**. The relative size and magnitude of each region would vary depending on operating conditions. In general, gas holdups were low near the distributor region, relatively constant in bulk region and high in the top region. These observations are generally in agreement with literatures.

3.1 Effect of H/D ratio on gas holdup

The effect of H/D ratio and suspended solid concentration on axial gas holdup for three superficial gas velocities 0.08, 0.16 and 0.24 m/s. are properly illustrated in **Fig. 2** to **4**. It is worth mentioning, from visual observation that the glass beads blocked some of distributor holes leading to plume formation during the bubbling of gas in the column near the entrance zone. This phenomenon led to an earlier regime transition, and decreased the gas holdup. Thus, the low values of gas holdup that is observed near the distributor could be attributed to a fouled distributor plate and there will be a negligible effect of coalescence behavior of bubbles as supported by other researchers, **Chilekar**, **2007**. **Gandhi, et al., 1999** reported that the gas holdup in the distributor region is a net result of the bubble formation, bubble coalescence and bubble breakup hence, the probe response does not increase substantially throughout this zone.

In the next region i.e. the bulk zone, the behavior of bubbles became more uniform throughout the experiments due to the higher pressure drop across the distributor, hence the gas was bubbling uniformly though the holes over the distributor region. Moreover, gas holdups measured in the column with 0% and 9% solid loading are slightly different at H/D of 3 and 4, this result is in agreement with the conclusion revealed by, **Lau, et al., 2009**. The influence of the distributor is expected to extend up to an axial height of about 0.7m and beyond that, higher gas holdup was be achieved through the bulk region and the maximum values were recorded at the top of the column specially when the H/D ratio equals five. It was also noticed, the increase in superficial gas velocity enhanced the local gas holdup as shown in **Fig. 3** and **4**. The main presence of gas holdup in the distributor region comes from gas bubbles which were drifted by the high circulation of slurry resulting from the higher gas velocity. Also, it was clearly noticed from the above mentioned figures that the gas holdup in the above regions (bulk and the top) is much higher especially at gas velocity 0.24m/s comparing with lowest gas velocity i.e. 0.08m/s. This observation is agreed with other researches like, **Forret, et al., 2006**. They explained that the circulation bubbles may enter the bottom region from the minimum resistance path, and the presence of the gas distributor dispatch most gas bubbles to the upward direction which enhances the gas holdup in the above regions.

3.2 Effect of superficial gas velocity

The variation of local gas holdup with superficial gas velocity at different solid concentrations were illustrated in **Fig. 5**, **6** and **7**. From these figures, it is evidently shown that gas holdup is increasing continuously with increasing of superficial gas velocity at all slurry concentrations from 0 – 20%. These increments are very slow and slight in the distributor zone especially when the slurry concentration is elevated to 20%, but in general there is no significant change in gas holdup under these conditions as shown in **Fig. 5**.

On the other hand, an obvious increase in gas holdup at bulk and top regions for all solid concentrations was found but it was decreasing with increasing the loading concentration till it reached the lowest values at 20% concentration. This may be attributed to the reduction in bubble break-up due to increasing suspension viscosity and this is compensated by availability of larger bubbles which have higher breakage rate as agreed with, **Prince,** and **Blanch, 1990**. Such an increment in gas holdup was not recorded at low gas velocities for example in 0.08m/s, but it was a distinguishable increase in gas holdup at higher gas velocities from 0.16 to 0.24 m/s in bulk and progressively in the top regions due to the high gas holdup in the top region which extended further down the column at higher gas velocities. While the increment of slurry concentration has incompatible effect with gas holdup and superficial gas velocity has affirmative gradient effect with gas holdup.

Generally, according to numerous researchers, **Koide, et al., 1984, De Swart,** and **Krishna, 1995**, **Krishna, et al., 1997**, the increase of gas holdups obtained at high gas velocities can be attributed to the higher rate of bubble break-up caused by interaction of turbulent eddies with bubbles. The presence of solid particles can cause a dampening effect on bubble break-up rate due to higher suspension viscosity where the probe response does not increase substantially above a particular velocity which is specified by, **Xue, 2004,** up to 0.35m/s. So, the optical probe response recorded in this study for different superficial gas velocities along with various solid concentration match with the behavior of gas holdup which was proved by the previously mentioned researches.

4. CONCLUSIONS

The effect of low H/D ratios on gas holdup measured by optical fiber probe in large scale slurry bubble column was studied by analyzing the experimental results under operating condition of solid loading and superficial gas velocity. It was found that operating under low H/D ratios gave reasonable values of gas holdup and there is significant variation along the axial direction. As well as, the four tips optical fiber probe which was used in this investigation was able to get reasonable data within good agreement with open literatures. where, the data which have been obtained for gas holdup led to the following finding:

1- At H/D ratio as 3 under different operating conditions, the local gas holdup increased with axial direction and superficial gas velocity become more identical. While, it decreased with elevation of slurry concentration. At the highest solid loading, almost about 20% the trend approached steady state along the height, but with less addition of solid the gas holdup it increased progressively throughout the axial distance.

2- At H/D ratio as 4 with same operating conditions as previous ratio, the gas holdups obtained significantly varied along the column at all solid loadings and there was no identical values along the height with an obvious increasing of gas holdup in comparison with the 3 H/D ratio.

3- At H/D ratio as 5 under the previously mentioned operating conditions, the gas holdup increased along with axial height and approached the value of 0.34 and 0.25 at 9% and 20% loading of solid respectively. This increment started with low value in the region near the distributor and proceed toward the highest value where it approached steady state at this point. The increase of gas flow rate enhanced the gas holdup as expected and had an advantage of approaching steady state early.

5. REFERENCES

- Azzopardi, B.J., Mudde, R.F., Lo, S., Morvan, H., Yan, Y. and Zhao, D., 2011, *Hydrodynamics of Gas-Liquid Reactor*, John Wiley & Sons, Ltd. 1st edition.

- Baird, M. H. and Rice, R.G., 1975, *Axial dispersion in large un-baffled column*, Chem. Eng. J., Vol. 9, PP. 171-174.

- Chilekar, V.P., 2007, *Hydrodynamics and mass transfer in slurry bubble columns: scale and pressure effects*, Ph.D. thesis, Eindhoven University of Technology, Netherlands.

- De Swart, J. W. A. and Krishna, R., 1995, *Effect of particles concentration on the hydrodynamics of bubble column slurry reactors*, Chem. Eng. Res. Design, Trans Ind. Chem. Eng., Vol. 73, PP. 308-313.

- Forret, A., Schweitzer, J.M., Gauthier, T., Krishna, R. and Schweich, D., 2006, *Scale up of slurry bubble reactors*, Oil and Gas Science and Technology – Rev. IFP, Vol. 61, No.3, PP. 443-458.

- Gandhi, B., Prakash, A. and Bergougnou, M. A., 1999, *Hydrodynamic behavior of slurry bubble column at high solid concentrations,* Powder Technology, Vol. 103, PP.80 – 94.

- Joshi, J.B., Parasu Veera, U., Phanikumar, Ch.V., Deshphande, N.S., Thakre, S.S. and Thorat, B.N., 1998, *Gas holdup structure in bubble column reactors,* PINSA Review article, Vol. 64 A, No. 4, PP. 441-567.

- Koide, K., Takazawa, A., Komura, M. and Motsunga, H**.,** 1984, *Gas hold-up of volumetric liquid phase mass transfer in solid suspended bubble columns*, J. Chem. Eng. Japan, Vol.17, No. 5, PP. 459- 466.

- Krishna, R., 2000, *A scale-up strategy for a commercial scale bubble column slurry reactors for Ficher-Tropsch synthesis,* Oil and Gas Science and Technology – Review. IFP, Vol. 55, PP. 359-393.

- Krishna, R., De Swart, J. W. A., Ellenberger, J., Martina, G. B. and Maretto, C., 1997, *Gas holdup in slurry bubble columns: Effect of column diameter and slurry concentrations*, AIChE Journal, Vol. 43, PP. 311 – 416.

- Larson, E. D. and Tingjin, R., 2003, *Synthetic fuel production by indirect coal liquefaction,* Energy for Sustainable Development, Vol. VII No.4, PP. 79–102.

- Lau, R., Sim, W. Sh. and Mo, R., 2009, *Effect of gas distributor on hydrodynamics in shallow bubble column reactors,* Can. J. Chem. Eng., Vol.87,No.6, PP. 847 – 854.

- Parasu Veera, U. and Joshi, J.B., 2000, *Measurement of gas holdup profiles in bubble column by gamma ray tomography, effect of liquid phase properties,* Trans. IChemE, Vol. 78, part A, PP. 425-434.

- Prakash A., Margaritis A. and Li H., 2001, *Hydrodynamics and local heat transfer measurements in a bubble column with suspension of yeast*, Biochem. Eng. J., Vol. 9, No.1, PP. 55–63.

- Prince, M. J. and Blanch, H.W., 1990, *Bubble coalescence and break-up in air-sparged bubble columns*, AIChE Journal, Vol. 36, No.10, PP. 1485–1499.

- Shah, Y.T., Kelkar, B.G., Godbole, S.P. and Deckwer, W.D., 1982, *Design parameters estimations for bubble column reactors,* AIChE J., Vol.28, PP.353-379.

- Towell, G.D. and Ackerman, G.H., 1972, *Axial mixing of liquid and gas in large bubble reactors*, Proceeding of 2nd International Symposium of Chemical Reaction engineering, Amsterdam-Netherlands, B3.1 – B3.13.

- Vandu, C.O. and Krishna, R., 2004, *Influence of scale on the volumetric mass transfer coefficient in bubble columns*, Chem. Eng. and Proc., Vol. 43, PP. 575-579.

- Xue, J., 2004, *Bubble velocity, size and interfacial area measurements in bubble columns"* Ph.D. Dissertation Washington University, St. Louis, Missouri – USA.

- Youssef, A., 2010, *Fluid dynamics and scale-up of bubble columns with internals*, Ph.D. Dissertation Washington University, St. Louis, Missouri – USA.

- Yu, Z., Zhaoqi, L., Hongbo, L., Lijun, W. and Xi, L., 2012, *Studies on hydrodynamics of turbulent slurry bubble column with multilayer screens*, CIESC J., Vol. 63, No.2, PP. 392-392.

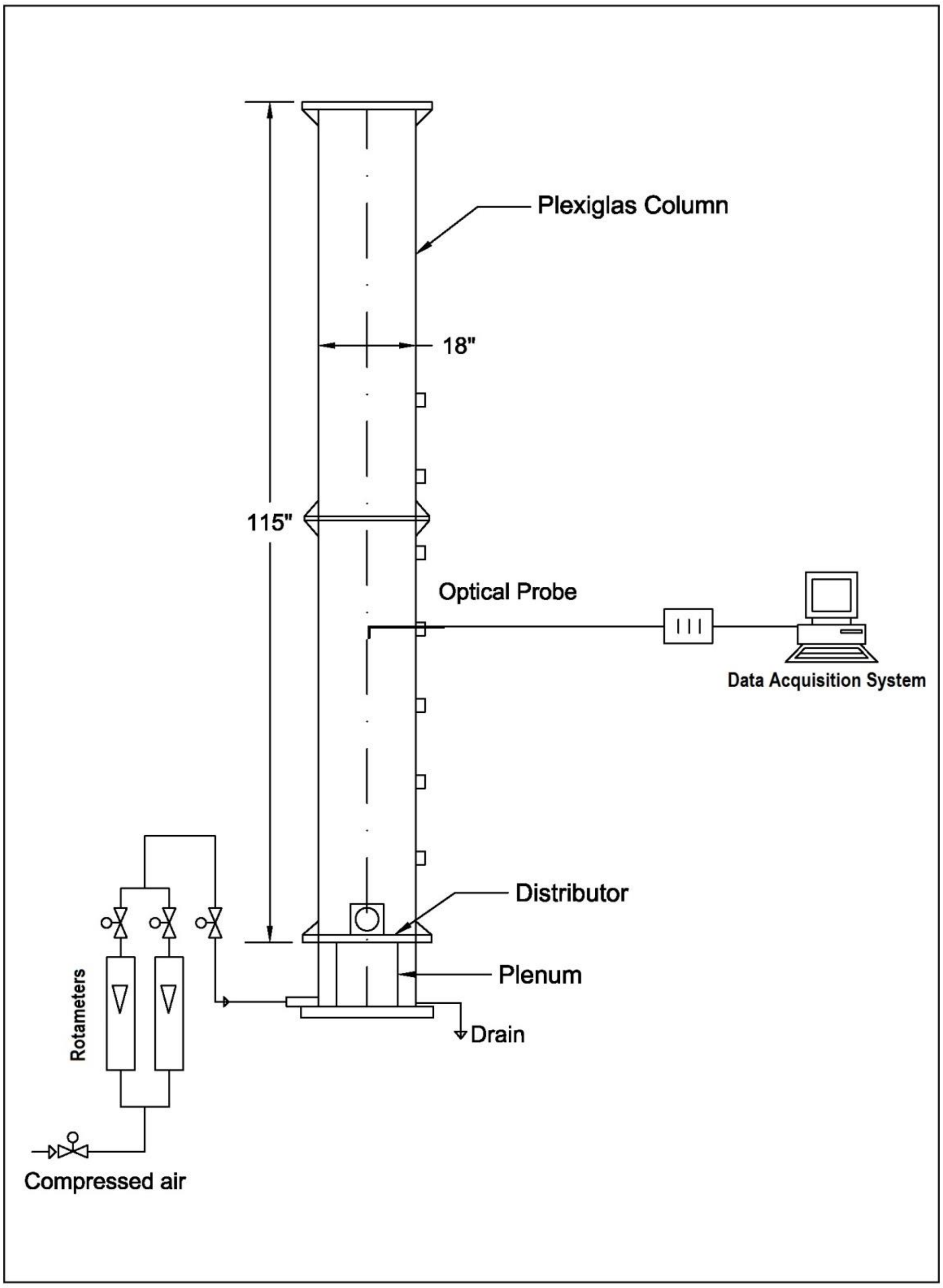
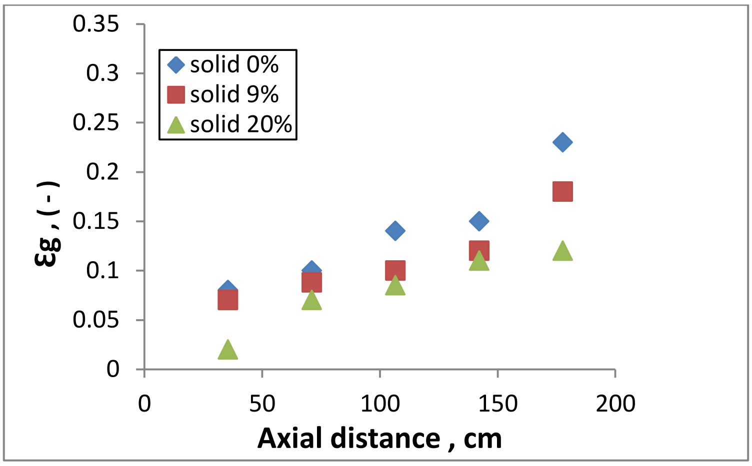
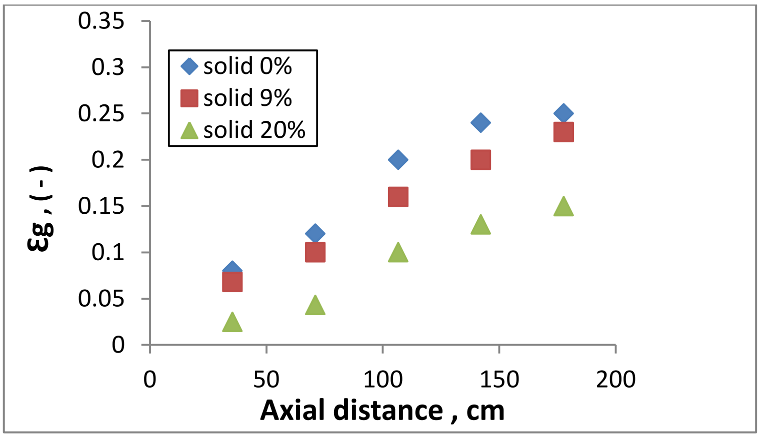


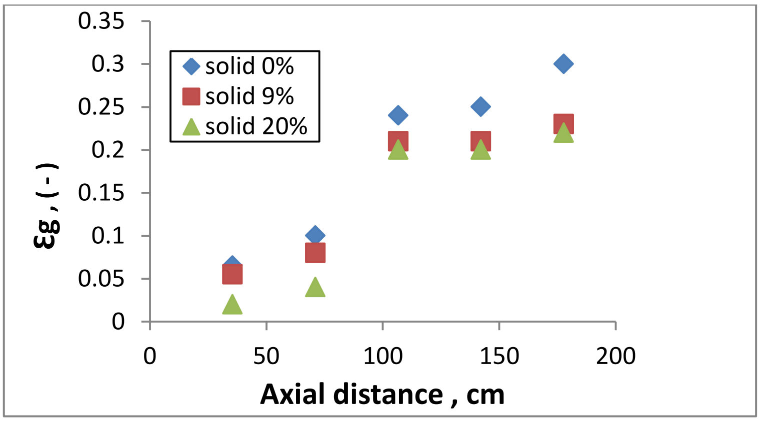
Figure 1. Schematic diagram of the experimental setup.



(a) H/D = 3

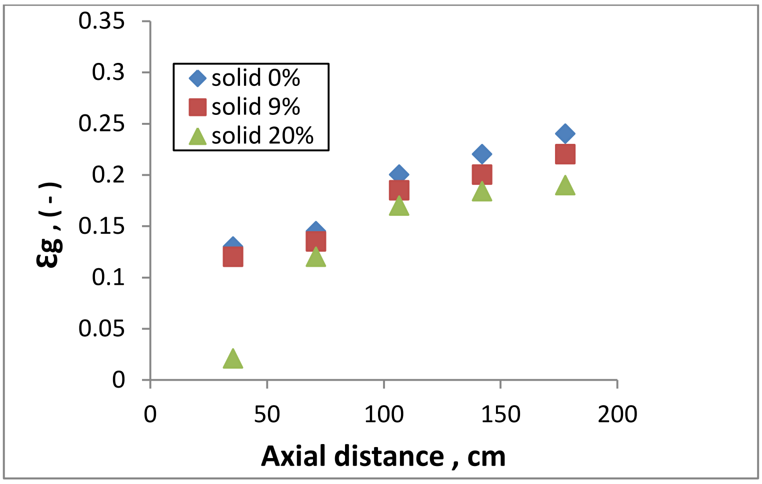


(b) H/D = 4

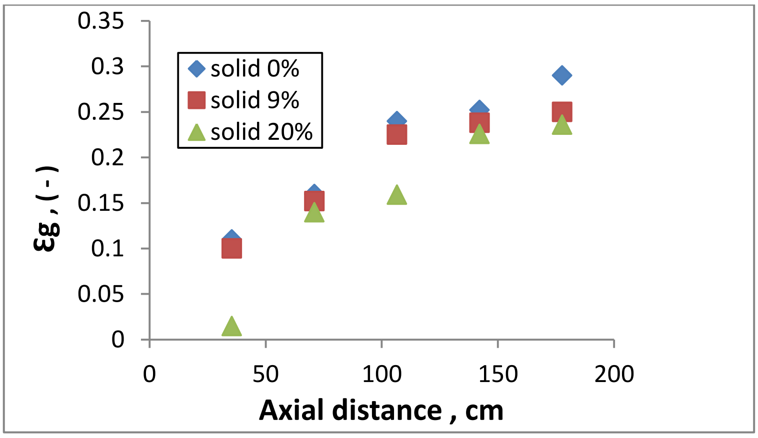


(c) H/D = 5

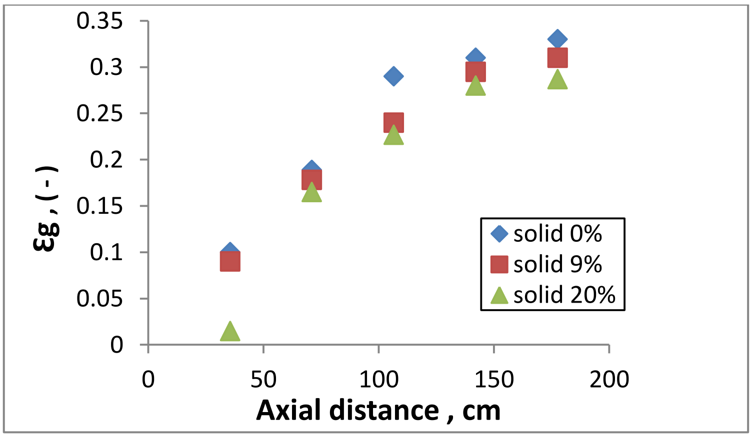
Figure 2. Variation of local gas holdup with axial distance for different solid concentrations and H/D ratios (a) H/D=3, (b) H/D=4, (c) H/D=5; at Ug=0.08 m/s.



(a) H/D = 3

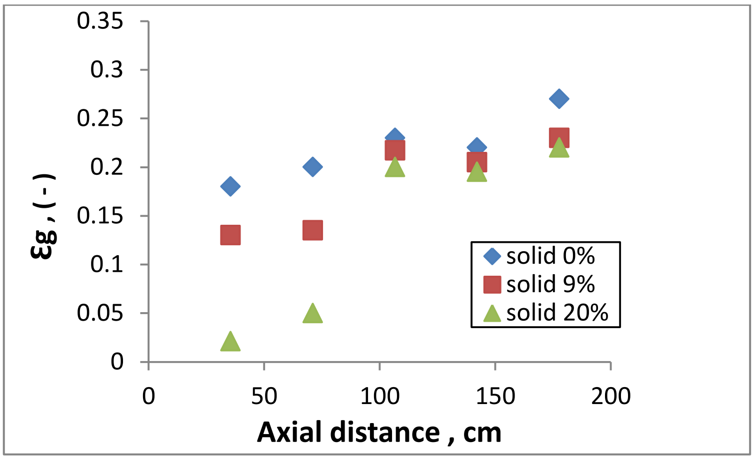


(b) H/D = 4

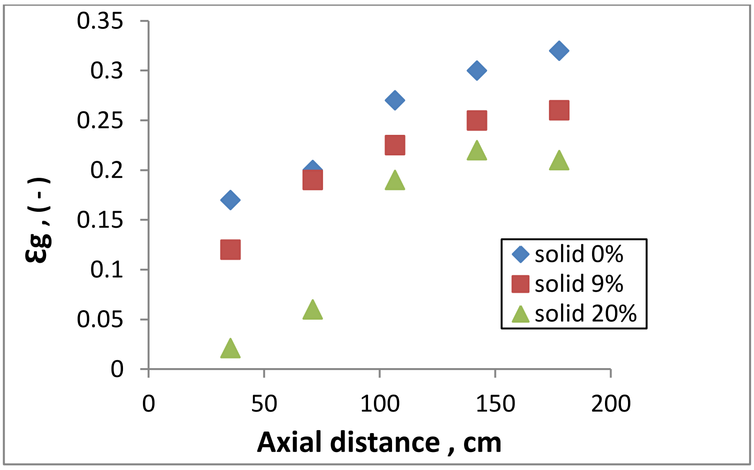


(c) H/D = 5

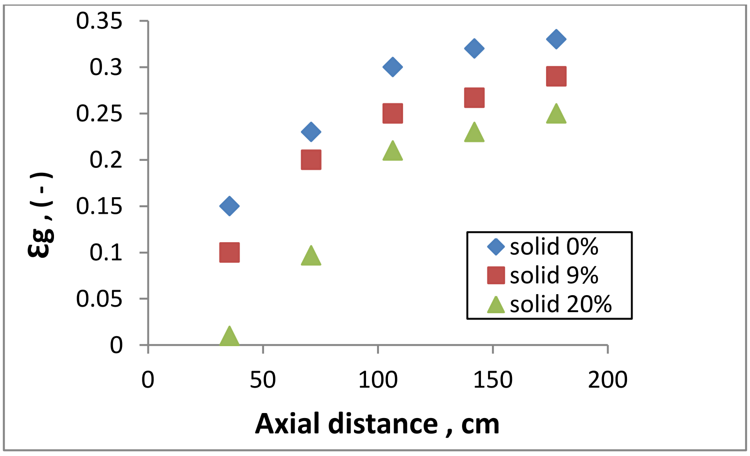
Figure 3. Variation of local gas holdup with axial distance for different solid concentrations and H/D ratios (a) H/D=3, (b) H/D=4, (c) H/D=5; at Ug=0.16 m/s.



(a) H/D = 3

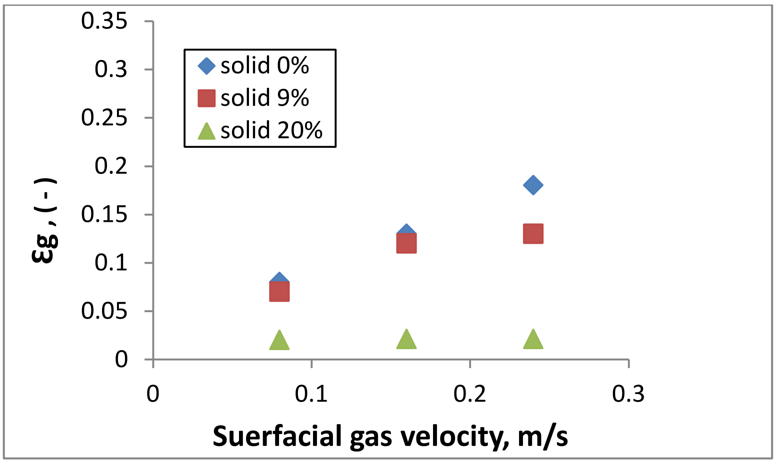


(b) H/D = 4

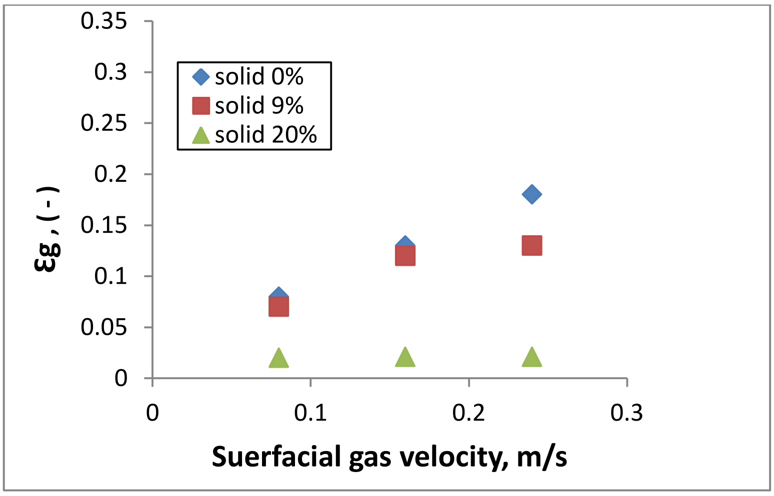


(c) H/D = 5

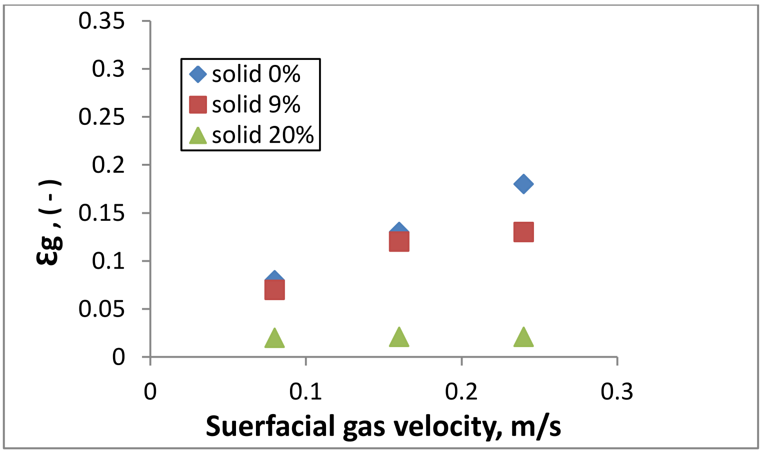
Figure 4. Variation of local gas holdup with axial distance for different solid concentrations and H/D ratios (a) H/D=3, (b) H/D=4, (c) H/D=5; at Ug=0.24 m/s.



(a) H/D = 3

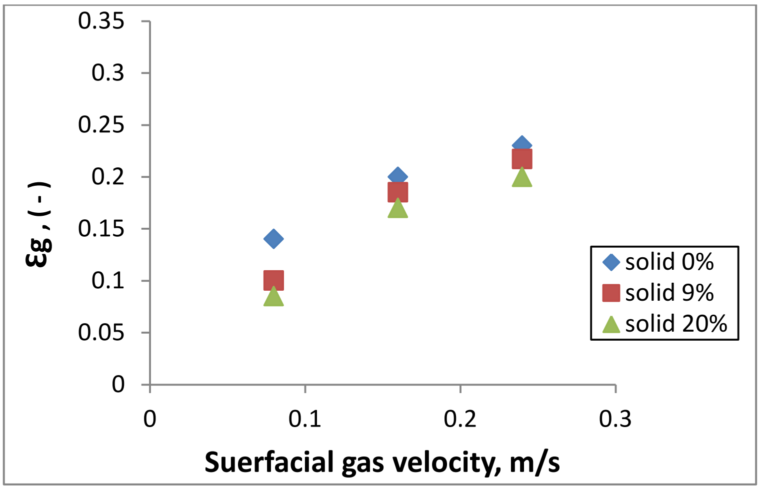


(b) H/D = 4

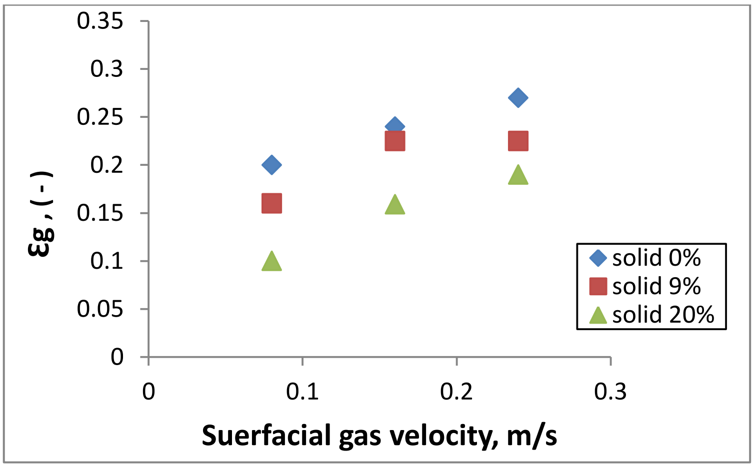


(c) H/D = 5

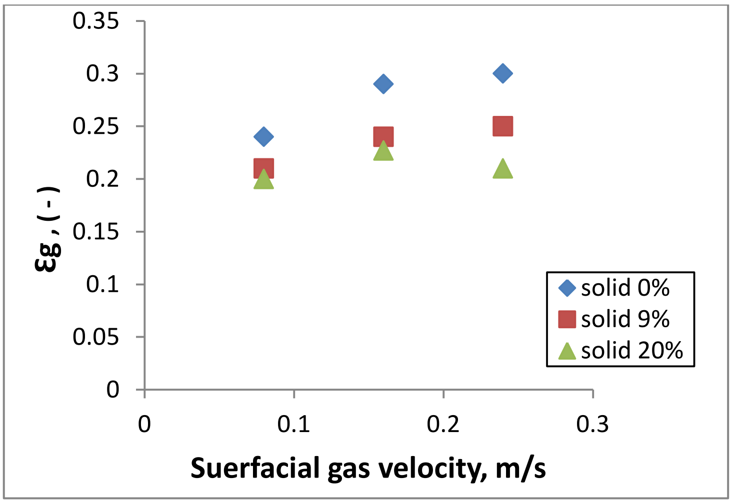
Figure 5. Variation of axial gas holdup with superficial gas velocity for different solid concentrations and H/D ratios (a) H/D=3, (b) H/D=4, (c) H/D=5; near the distributor.



(a) H/D = 3

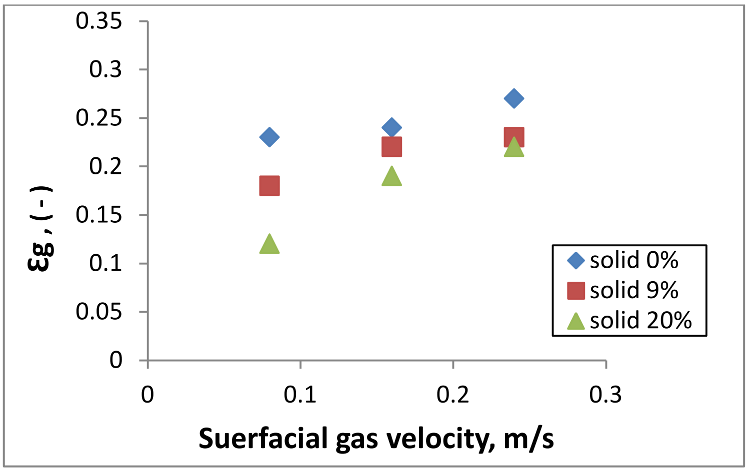


(b) H/D = 4

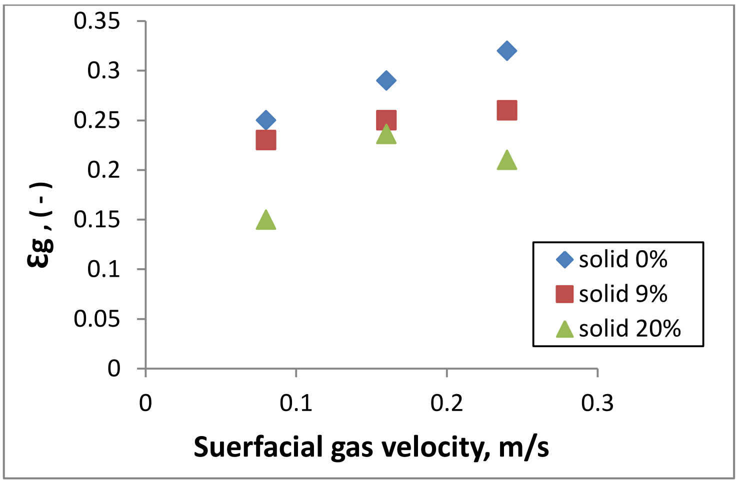


(c) H/D = 5

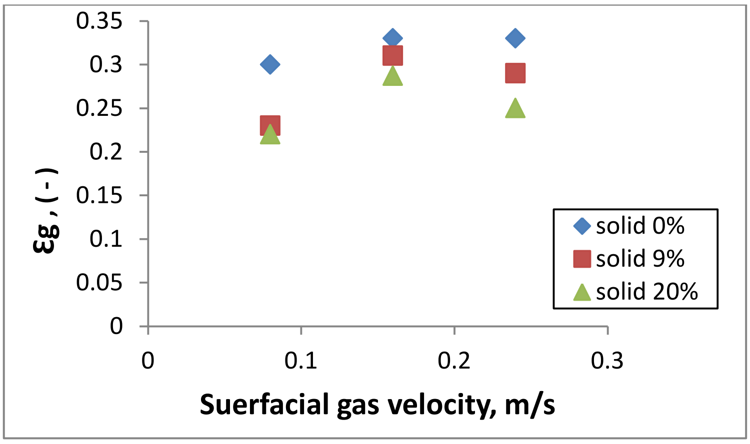
Figure 6. Variation of axial gas holdup with superficial gas velocity for different solid concentrations and H/D ratios (a) H/D=3, (b) H/D=4, (c) H/D=5; bulk region.



(a) H/D = 3



(b) H/D = 4



(c) H/D = 5

Figure 7. Variation of axial gas holdup with superficial gas velocity for different solid concentrations and H/D ratios (a) H/D=3, (b) H/D=4, (c) H/D=5; top region.