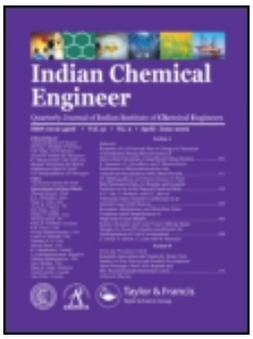

Indian Chemical Engineer

ISSN: 0019-4506 (Print) 0975-007X (Online) Journal homepage: www.tandfonline.com/journals/tice20

Studies on Gas Holdup in a Draft Tube Fluidised-bed Bioreactor

A. Venu Vinod, K. N. Ajeesh & G. Venkat Reddy

To cite this article: A. Venu Vinod, K. N. Ajeesh & G. Venkat Reddy (2010) Studies on Gas Holdup in a Draft Tube Fluidised-bed Bioreactor, Indian Chemical Engineer, 52:2, 128-137, DOI: 10.1080/00194506.2010.485860

To link to this article: https://doi.org/10.1080/00194506.2010.485860

Published online: 13 Aug 2010.

Submit your article to this journal

Article views: 74

View related articles

Citing articles: 1 View citing articles

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=tice20

INDIAN CHEMICAL ENGINEER Copyright © 2010 Indian Institute of Chemical Engineers
Vol. 52 No. 2 April-June 2010, pp. 128-137
Print ISSN: 0019-4506, Online ISSN: 0975-007X, DOI: 10.1080/00194506.2010.485860



Taylor & Francis
Taylor & Francis Group

Studies on Gas Holdup in a Draft Tube Fluidised-bed Bioreactor

A. Venu Vinod,* K.N. Ajeesh and G. Venkat Reddy
Department of Chemical Engineering, National Institute of Technology, Warangal - 506 004, India

Abstract: Studies on gas holdup have been carried out in a draft tube gas-liquid-solid fluidised-bed bioreactor treating phenolic wastewater at different feed concentrations of phenol, feed flowrates and air flowrates. From the data obtained through a set of experimental runs, an empirical correlation was developed for the overall gas holdup using dimensional analysis. It was found that the gas holdup increases with the flow rate of air and decreases with increase in the flow rate of water. In the concentration range considered in the study the variation of feed concentration of phenol did not affect the gas holdup.

Keywords: Gas holdup, Biodegradation, Wastewater, Phenol, Fluidised-bed bioreactor.

Introduction

Chemical and petroleum industries produce a wide variety of highly toxic organic wastes. The effluents of these industries often contain aromatic compounds that are resistant to natural degradation and, therefore, persist in the environment. One of the major organic pollutants found in these wastewaters is phenol. Process industries that are major sources of phenolic discharges include petroleum refineries, coal carbonisation units, gas and coke industries, fibreglass units etc. Biodegradation of phenol in fluidised-bed bioreactors (FBRs) has been reported because of their superior performance and some inherent advantages [1-7].

The present study addresses biodegradation of phenolic wastewater in a gas-liquid-solid FBR. In gas-liquid-solid fluidised-bed, a draft tube was coaxially placed inside the fluidisation column. The liquid was passed upward through a bed of solid particles at velocities sufficient to fluidise the bed. The draft tube served to provide bulk circulation of gas, liquid and solid between itself and the annulus; thereby, achieving intimate contact between the gas, liquid and solid phases in the bed.

For chemical and biochemical processes where mass transfer is the rate-limiting step, it is important to estimate the gas holdup as this relates directly to the mass transfer. A lot of work has been carried out on gas holdup in three phase fluidised-bed columns. Extensive studies have

*Author for Correspondence. E-mail: avv@nitw.ac.in; avv122@yahoo.com
Paper received: 26/06/2008; Revised paper accepted: 29/01/2010

been reported on the hydrodynamics in a three-phase fluidised column emphasising the importance of gas holdup [8-12] and the various factors affecting it [13, 14]. Studies on the hydrodynamic behaviour of a draft tube gas-liquid-solid fluidised-bed column by Fan et al. [15] have shown that the overall gas holdup is higher than that in a conventional three-phase fluidised-bed column. A model was proposed for the overall gas holdup. But this model predicts the overall gas holdup in terms of apparent circulation of liquid, which requires the knowledge of liquid velocities and liquid holdups in specific regions of the column.

Although gas holdup in three-phase fluidised-beds has received significant attention, there is relatively little work reported regarding gas holdup in FBRs. In this work an attempt has been made to investigate the overall gas holdup in an FBR with an internal draft tube and correlate it with the operating variables.

Experimental

Reactor Setup

The schematic diagram of the experimental set-up is shown in Fig. 1. The fluidised-bed column and the draft tube were made up of glass. A gas distributor made up of glass was provided at the bottom of the column through which air could be sparged into the column. The volume of the

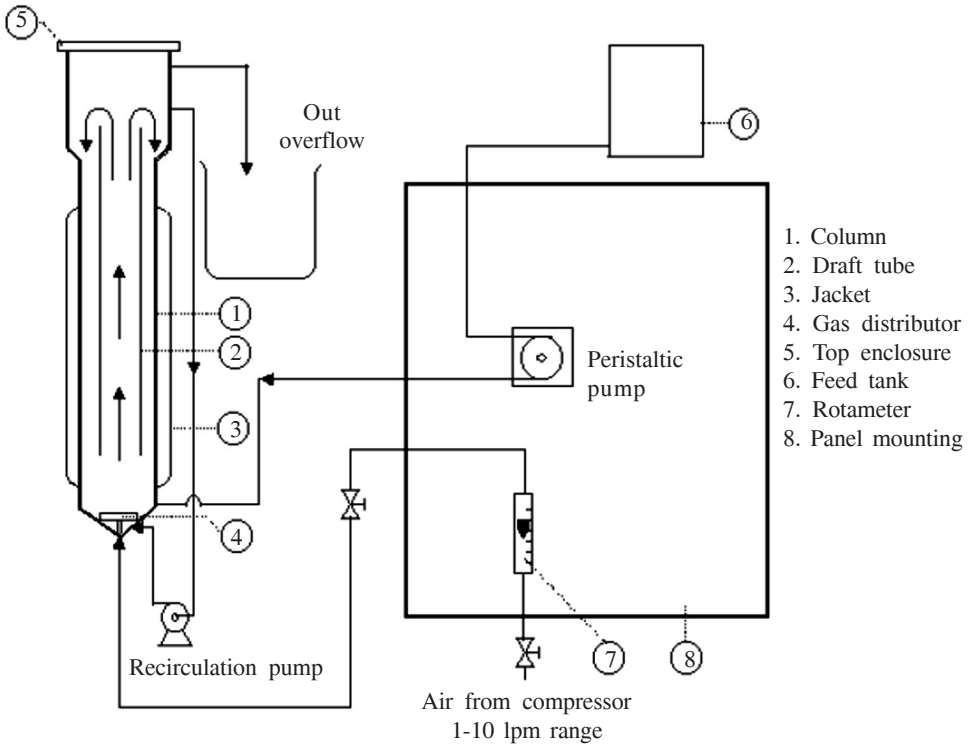

Fig. 1. Draft tube fluidised-bed column (experimental set-up).

column was 2.6 l. An overflow line was provided at the top for use in continuous operation. The column was provided with a glass jacket to control the column temperature using a cooling/heating medium.

The solid bed consisted of plastic beads having density 1.05 g/cm^3. Average diameter of the beads was 4.28 mm. Details of the reactor set-up are given in Table 1.

Table 1. Reactor dimensions

	Values	Unit
Column volume, V	2.6×10^{-3}	m^3
Column diameter, D_c	0.076	m
Draft tube diameter, D	0.046	m
Bead diameter, d_p	4.2816×10^{-3}	m

A peristaltic pump was used to put water into the column. The pump's flow rate could be set using a flow controller. The pump had a capacity range of 40-3500 ml/h. A centrifugal pump was provided at the bottom of the column to recirculate the liquid from the exit at a rate of 3.6 lpm. Air for fluidisation was supplied using a compressor. The flow rate of the air was measured using a rotameter with a range of 1-10 lpm.

To maintain pH of the system a pH meter and a controller were provided. The pH was maintained by the addition of acid or base from the tanks provided at the top. Oxygen is consumed in degradation of phenol by microorganisms. The oxygen required for the process was supplied in the form of air from a compressor and its content in the reaction medium was measured using a dissolved oxygen (DO) meter. The flow rate of air can be measured using rotameter, with a range of 0.167×10^{-4} to 1.67×10^{-4} m^3/s (1-10 lpm) [7].

Microbial Culture

A strain of microorganism *Pseudomonas putida* (NCIM – 2176) reported to be capable of utilising phenol as the sole carbon and energy source was obtained from National Collection of Industrial Microorganisms (NCIM), National Chemical Laboratory, Pune, India [7].

Culture Preparation

The culture was maintained by periodic subculture on nutrient agar and stored in a refrigerator. The reaction medium was prepared from this strain by growing the bacteria in 2.6×10^{-3} m^3 (2.6 l) of 0.05 kg/m^3 (50 ppm) of phenol solution containing growth medium [2, 6]. Before inoculation of the organism, sterilisation of the phenol solution was done in an autoclave at a gage pressure of 1.034×10^5 N/m^2 (15 psi) for 20 min to selectively grow the *Pseudomonas* species [7].

Growth Medium

The growth medium was prepared using tap water. Sterile conditions were not maintained during the continuous operation of the reactor, to simulate treatment of actual plant wastewater as the latter would contain different contaminants [7].

The reaction medium (2.6 l), after 24 h of incubation, was added to the FBR. The reactor was run in batch mode for further 36 h, for immobilisation of biomass onto the beads. Prior to starting the reactor, phenol concentration in the reactor was brought to feed concentration level by adding additional phenol to the reactor. The reactor was started with feed flow rate of 390 ml/h. The experimental conditions maintained were: pH 7.0 and temperature 30°C. The same conditions were maintained at other flow rates of wastewater. Phenol concentration in the outlet was monitored at regular intervals using the standard method of analysis [16].

Determination of Gas Holdup by the Simultaneous Closure of the Gas and Liquid Inlets

All measurements were made at 30°C and atmospheric pressure and after steady state was reached within the FBR. At this stage, oxygen consumption by the microorganisms in the reactor was constant. For feed rates of 390, 510 and 600 ml/h, at various concentrations of phenol and airflow rates, measurements were taken by the following procedure:

Degradation of the phenolic effluent was carried out at a particular feed rate, feed concentration and airflow rate. After the steady state was reached, the feed and air inlet valves were closed simultaneously and quickly. The volume of liquid displaced by air was measured by refilling the reactor with water up to the exit level using a measuring cylinder. Gas holdup is calculated as

$$\varepsilon_g = \frac{\text{Volume of liquid used to refill the reactor (ml)}}{\text{Total volume of the reactor (ml)}}$$

The same procedure was repeated with the recirculation pump switched on for the above-mentioned feed and airflow rates. The density of the reaction medium was determined using the specific gravity bottle and viscosity was found using Redwood viscometer.

Results and Discussion

For different feed rates (390, 510 and 600 ml/h), the variation of overall gas holdup at different airflow rates (2, 3 and 4 lpm) and feed concentrations (50, 100, 150, 200, 250 ppm) was measured. A centrifugal pump of capacity 3.6 lpm was used to recirculate the reactor contents and, thus, to find the variation of gas holdup upon recirculation. Tables 2 and 3 give the dimensionless overall gas holdup tabulated against superficial gas velocities without recirculating the liquid and with

Table 2. ε_g vs U_g (without recirculation)

Air rate (lpm) →		2	3	4
U_g (m/s) →		0.02007	0.03010	0.04014
$Fr_g = U_g^2/(d_{Pg})$ →		0.00960	0.02159	0.03839
Feed rate (mlph)	Feed conc. (ppm)		ε_g	
390	50	0.0426	0.0545	0.078
	100	0.0421	0.0537	0.0774
	150	0.0436	0.0531	0.0787
	200	0.0425	0.0558	0.0796
	250	0.0434	0.0546	0.08
510	50	0.0383	0.0489	0.0596
	100	0.0374	0.0502	0.0587
	150	0.0357	0.0502	0.0617
	200	0.0366	0.0481	0.0596
	250	0.0349	0.0494	0.0596
600	50	0.0332	0.0441	0.0491
	100	0.0348	0.0432	0.0512
	150	0.0336	0.0438	0.0506
	200	0.0356	0.0433	0.0505
	250	0.0344	0.0439	0.051

Table 3. ε_g vs U_g (with recirculation rate = 3.6 lpm)

Air rate (lpm) →		2	3	4
U_g (m/s) →		0.02007	0.03010	0.04014
$Fr_g = U_g^2/(d_{Pg})$ →		0.00960	0.02159	0.03839
Feed rate (mlph)	Feed conc. (ppm)		ε_g	
390	50	0.05106	0.06468	0.08298
	100	0.05106	0.06383	0.08213
	150	0.05106	0.06255	0.08085
	200	0.05021	0.06298	0.08043
	250	0.04894	0.06298	0.08085
510	50	0.04681	0.06298	0.072
	100	0.04681	0.06170	0.0732
	150	0.04894	0.06170	0.0722
	200	0.04170	0.05957	0.0711
	250	0.04255	0.05957	0.0715
600	50	0.044	0.0581	0.064
	100	0.0435	0.0582	0.065
	150	0.0438	0.0583	0.063
	200	0.0421	0.0576	0.0625
	250	0.0445	0.057	0.0626

recirculating the liquid, respectively. The variation of overall gas holdup with superficial gas and liquid velocities at different feed concentrations is shown in Figs. 2 to 7. The liquid and gas superficial velocities were calculated based on the draft tube diameter *D*.

Figures 2 and 3 show the gas holdup plotted as a function of superficial gas velocity at feed flow rates of 390 and 510 ml/h, respectively, at various concentrations of phenol in the feed when no recirculation was used. It can be seen that gas holdup increases with increase in gas velocity. The graphs can be extrapolated to origin, since the gas holdup is zero when there is no flow of

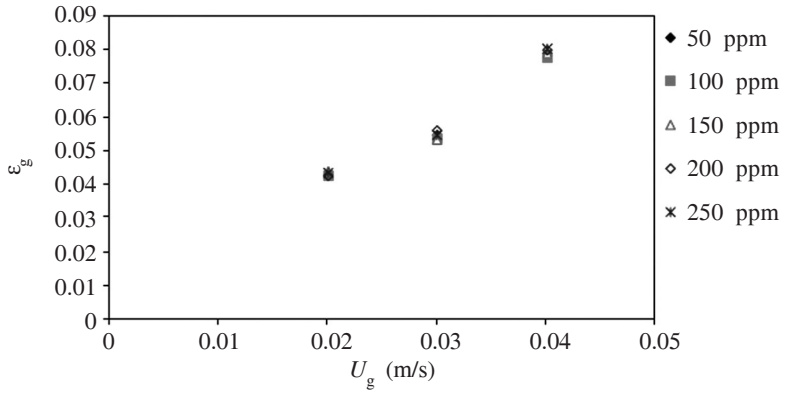

Fig. 2. ε_g vs U_g (at 390 ml/h, without recirculation).

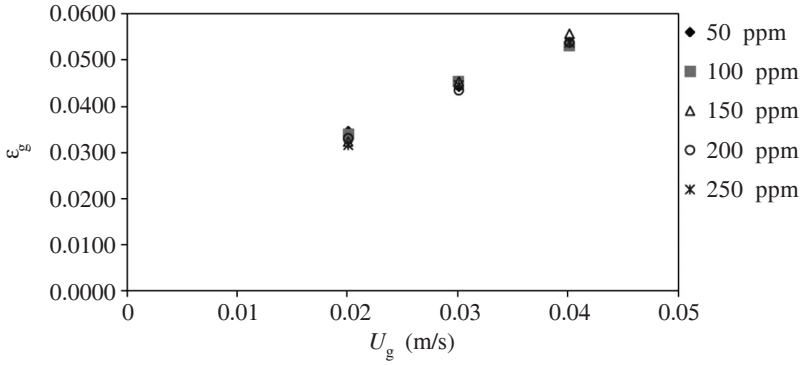

Fig. 3. ε_g vs U_g (at 510 ml/h, without recirculation).

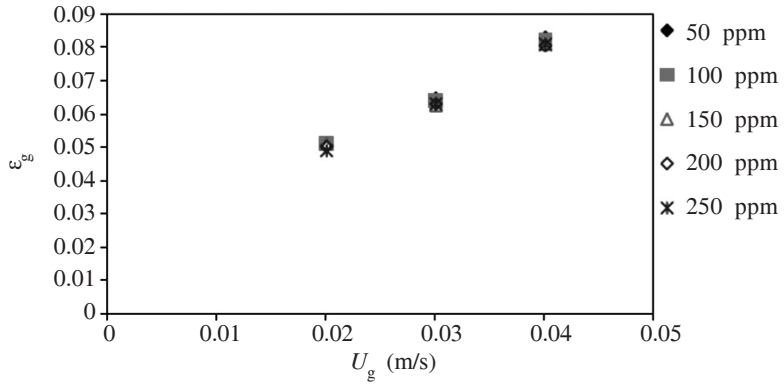

Fig. 4. ε_g vs U_g (at 390 ml/h, with recirculation).

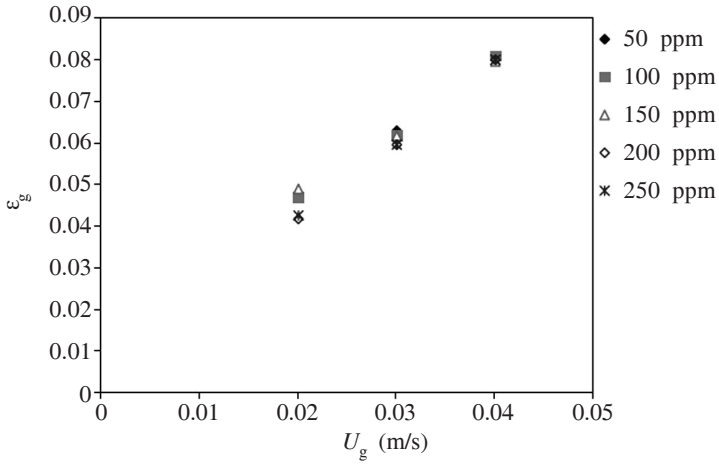

Fig. 5. ε_g vs U_g (at 510 ml/h, with recirculation).

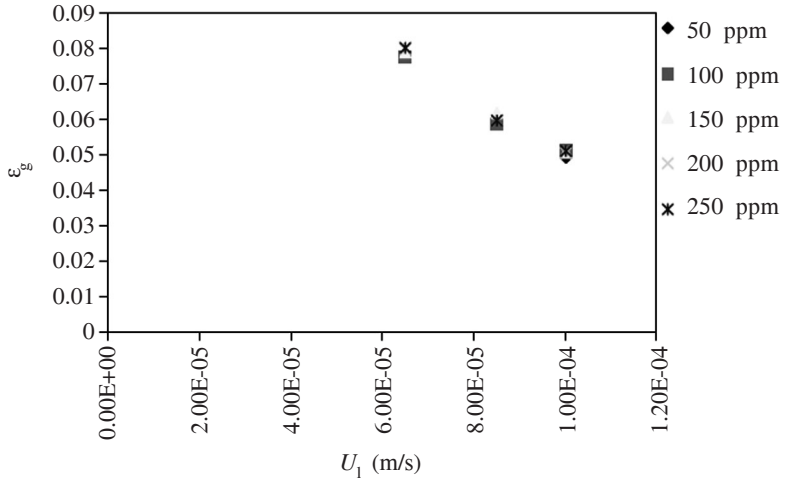

Fig. 6. ε_g vs U_l (at 4 lpm, without recirculation).

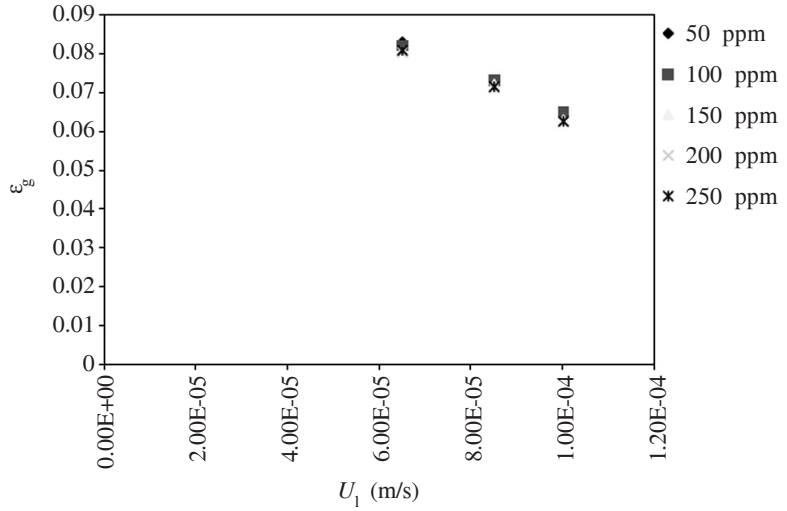

Fig. 7. ε_g vs U_l (at 4 lpm, with recirculation).

gas. The variation in feed concentration has little effect on the gas holdup. But experiments carried out in the reactor using tap water showed that gas holdup in the reactor media was more than that in the water [17]. This was due to the increase in bubble coalescence by the bioflocs present in the reactor media and the increase in the density and viscosity of the reactor broth.

The variation of gas holdup with U_g in the presence of recirculation (Figs. 4 and 5) shows a similar behaviour as that seen in Figs. 2 and 3 when no recirculation was used. However, when recirculation was used, the gas holdup was higher than when no recirculation was present. Figures 6 and 7 show the variation of gas holdup, ε_g against liquid velocity, U_l at a constant gas flow rate

of 4 lpm without and with recirculation, respectively. The liquid velocities used in this study were low, in the range of 0.006 to 0.01 cm/s, since the biodegradation reaction requires high detention time as compared to ordinary chemical reactions. The graphs indicate that the gas holdup decreases as liquid velocity increases.

Empirical Correlation for Gas Holdup in the FBR

From the experiments it was found that overall gas holdup increased with increase in gas velocity and decreased with increase in liquid velocity. So the gas holdup is strongly dependent on the gas and liquid velocities. Apart from these two variables, the physical properties of the liquid such as viscosity, density, surface tension and concentration of suspended fine particles also affect gas holdup. This is evident from the experiments conducted using tap water and reactor broth separately [17]. Upon comparing the results obtained from these experiments it was found that the overall gas holdup can be written as a function of these variables as

$$\varepsilon_g = f\,(U_g,\ U_l,\ \rho_l,\ \mu_l,\ \sigma_l,\ d_p,\ D,\ g) \tag{1}$$

Using dimensional analysis ε_g is related to the three dimensionless parameters as

$$\varepsilon_g = f\,(\mathrm{Fr}_g,\ \mathrm{Re}_l,\ \mathrm{Wb}) \tag{2}$$

where

Re_l = Reynolds number for liquid = $\dfrac{D\rho_l U_l}{\mu_l}$

Fr_g = Froude number for gas = $\dfrac{U_g^2}{d_p g}$

Wb = Weber number = $\dfrac{D\rho_l U_g^2}{\sigma_l}$

Let the function take the form

$$\varepsilon_g = \alpha \mathrm{Fr}_g^a\ \mathrm{Re}_l^b\ \mathrm{Wb}^c \tag{3}$$

where α, a, b and c are the constants to be determined. The dimensionless correlation has been obtained by regression on gas holdup, Fr_g, Re_g and Wb as

$$\varepsilon_g = 0.0715\ \mathrm{Fr}_g^{0.0016}\ \mathrm{Re}_l^{-0.673}\ \mathrm{Wb}^{0.3154} \tag{4}$$

Effect of Recirculation on Gas Holdup

Considering the effect of recirculation on gas holdup as a linear function of the recirculation ratio, Eq. (4) can be written as

$$\varepsilon_g = (\alpha + \beta R)\ \mathrm{Fr}_g^{0.0016}\ \mathrm{Re}_l^{-0.673}\ \mathrm{Wb}^{0.3154} \tag{5}$$

where $\alpha = 0.0715$, β is the parametric coefficient, and R the ratio of recirculation rate to feed rate. It may be noted that when there is no recirculation, the above equation reduces to Eq. (4). Here R is taken as a ratio for keeping the dimensional consistency of the equation.

To find the value of β, a graph of ε_g vs. $Fr_g^{-0.0016}\ Re_l^{-0.673}\ Wb^{0.3154}$ was plotted using the data obtained from the gas holdup values measured with the recirculation pump switched on. For calculating the liquid Reynolds number Re_l, superficial liquid velocity was determined by taking into account the recirculation rate along with feed flow rate. The slope of the graph gives the value of $(\alpha + \beta R)$. Thus, the value of β can be determined since R is known. Upon solving, one gets $\beta = 2.52 \times 10^{-5}$.

Hence, Eq. (5) becomes

$$\varepsilon_g = (0.0715 + 2.52 \times 10^{-5} R)\ Fr_g^{0.0016}\ Re_l^{-0.673}\ Wb^{0.3154}$$

Conclusion

Gas holdup is an important parameter in the biodegradation process for the treatment of phenolic effluent. Since the rate of oxidation is determined by the intake of oxygen by the microorganisms, a higher holdup is necessary for the efficient operation of a bioreactor.

The draft tube fluidised-bed bioreactor offers great advantage as compared to other existing technologies in the field of biological treatment of industrial effluents, because it has a higher gas holding capacity and efficient mixing characteristics, as is evident from the experimental results. A dimensionless correlation for the overall gas holdup in the FBR based on the experimental data was developed using dimensional analysis. It was found that the gas holdup increases almost linearly with the increase in superficial gas velocity. The smaller the feed rate higher is the gas holdup. Other conditions being the same recirculation was found to increase the holdup.

Nomenclature

D Draft tube diameter, m
D_c Fluidising column diameter, m
d_p Particle diameter, m
Fr_g Froude number for gas = $\dfrac{U_g^2}{d_P g}$, dimensionless
g Acceleration due to gravity, ms^{-2}
R Recirculation ratio = Rate of recirculation, m^3h^{-1}/Feed rate, m^3h^{-1}
Re_l Liquid Reynolds number = $\dfrac{D\rho_l U_l}{\mu_l}$, dimensionless
U_g Superficial gas velocity based on draft tube diameter, ms^{-1}
U_l Superficial liquid velocity based on draft tube diameter, ms^{-1}
V Volume of the column, m^{-3}
Wb Weber number = $\dfrac{D\rho_l U_g^2}{\sigma_l}$, dimensionless

Greek Symbols

α Parameter in the empirical correlation for overall gas holdup, dimensionless
β Parameter in the empirical correlation for overall gas holdup, dimensionless
ε_g Gas holdup, dimensionless
μ_l Viscosity of liquid, $kgm^{-1}s^{-1}$
ρ_l Density of liquid, kgm^{-3}
σ_l Surface tension of liquid, Nm^{-1}

References

1. Tang, W.T. and Fan, L.S., "Steady State Phenol Degradation in a Draft-tube Fluidized Bed Bioreactor", *AIChE J.*, **33,** pp. 239-249 (1987).
2. Livingston, A.G. and Chase, H.A., "Modeling Phenol Degradation in a Fluidized-bed Bioreactor", *AIChE J.*, **35,** pp. 1980-1992 (1989).
3. Fan, L.S., Levya-Ramos, R., Wiesecarver, K.D. and Zehner, B.J., "Diffusion of Phenol Through a Biofilm Grown on Activated Carbon Particles in a Draft-tube Three Phase Fluidized Bed Bioreactor", *Biotechnol. Bioeng.*, **35,** pp. 279-286 (1990).
4. Livingston, A.G., "Biodegradation of 3,4-Dichloroaniline in a Fluidized Bed Bioreactor and a Steady State Biofilm Kinetic Model", *Biotechnol. Bioeng.*, **38,** pp. 260-272 (1991).
5. Beyenal, H. and Tanyolac, A., "The Effect of Biofilm Characteristics on the External Mass Transfer Coefficient in a Differential Fluidized Bed Biofilm Reactor", *Biochem. Eng. J.*, **1**, pp. 53-61 (1998).
6. Venu Vinod, A. and Venkat Reddy, G., "Simulation of Biodegradation Process of Phenolic Wastewater at Higher Concentrations in a Fluidized-bed Bioreactor", *Biochem. Eng. J.*, **24,** pp 1-10 (2005).
7. Venu Vinod, A. and Venkat Reddy, G., "Mass Transfer Correlation for Phenol Biodegradation in a Fluidized Bed Bioreactor", *Journal of Hazardous Materials*, **B136**, pp. 727-734 (2006).
8. Song, G.-H., Bavarian, F., Fan, L.-S., Buttke, R.D. and Peck, L.B., "Hydrodynamics of Three-phase Fluidized-bed Containing Cylindrical Hydrotreating Catalysts", *Can. J. Chem. Engg.*, **67**, pp. 265-275 (1989).
9. Koide, K., Kimura, M., Nitta, H. and Kawabata, H., "Liquid Circulation in Bubble Column with Draught Tube", *J. Chem. Engg. Japan*, **21(4)**, pp. 393-399 (1988).
10. Weiland, P. and Onken, U., "Fluid Dynamics and Mass Transfer in an Air Lift Fermenter with External Loop", *Ger. Chem. Eng.*, **4**, pp. 42-50 (1981).
11. Chern, S.-H., Fan, L.-S. and Muroyama, K., "Hydrodynamic Behavior of a Cocurrent Gas-liquid-solid Semi-fluidized-bed", *AIChE J.*, **30(2)**, pp. 288-294 (1984).
12. Sun, Y., Nozawa, T. and Furusaki, S., "Gas Holdup and Volumetric Oxygen Transfer Coefficient in a Three-Phase Fluidized-bed Bioreactor", *J. Chem. Engg. Japan*, **21**, pp. 15-20 (1988).
13. Kelkar, B.G. and Shah, Y.T., "The Effect of Slurry Properties on the Hydrodynamics and Axial Mixing in a Three-phase Fluidized Column", *Ind. Engg. Chem. Proc. Des. and Dev.*, **23**, pp. 308-313 (1984).
14. Sada, E., Kumasawa, H. and Lee, C.H., "Influence of Suspended Fine Particles on Gas Holdup and Mass Transfer Characteristics in a Slurry Bubble Column", *AIChE J.*, **32**, pp. 853-856 (1986).
15. Fan, L.-S., Hwang, S.-J. and Matsura, A., "The Hydrodynamic Properties of a Gas-liquid-solid Spouted Bed with a Draft Tube", *Chem. Engg. Sci.*, **39(12)** (1984).
16. Clesceri, L.S., Greenberg, A.E. and Trussell, R.R., *Standard Methods for the Examination of Water and Wastewater*, 17th Edn., American Public Health Association, Washington, D.C. (1989).
17. Venu Vinod, A., Ajeesh, K.N. and Venkat Reddy, G., "Studies on Gas Hold-up in a Draft Tube Fluidized-Bed Column", *Indian Chemical Engineer*, **46**, pp. 229-233 (2004).