Mass transfer coefficient and gas hold-up in rectangular air-lift columns
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Mass transfer coefficient and gas hold-up in rectangular air-lift columns

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Abstract

A system of columns was constructed and the effect of the column geometry, gas flow rate as well as viscosity and surface tension of liquid on gas hold-up and oxygen transfer coefficient in the air-lift column of rectangular cross section on technical scale with working height 4.2 m and volume exceeding 1.4 m^3 was investigated. Correlations equations of a broad range of experimental data describing these values have been proposed.

A pilot-plant simulation of the pretreatment of effluents from dyestuff production achieving as a result about 90% pollutant reduction in the mixture, measured by the COD index and 72% colour reduction measured by the ABS value.
Key words: air-lift columns, gas hold-up, mass transfer, preteatment wastewater.

1. Introduction

Pretreatment of industrial wastewater is one of to basic problems in many branches of industry. Majority of industrial plants have a limited space and therefore they search for relevant facilities which require little space to be installed. Such a requirement is satisfied best by module systems of rectangular cross section, called sets of columns. Such columns have numerous advantages. The most important being a simple construction, low energy consumption, intensive mixing and aeration of the liquid phase. The sets can be constructed or assembled according to individual requirements of plants regarding the size and current needs for sewage pre-treatment. Additionally, in the set of air-lift columns the residence time can be increased significantly and at the same time many stages of sewage treatment can be completed: averaging of the content, neutralization, oxidation, decoloration, coagulation, detergent defoaming and final biological treatment.

Only few studies concerning air-lift columns of rectangular cross section have been published in the literature (Couvert et al. 2004, Christi and Moo-Young 1988, Cristi 1989, Dziubinski et al. 2000). They refer mainly to small laboratory columns. Thus, the published results of investigations are of little practical importance in designing of industrial air-lift column sets. The aim of the present study was to investigate gas hold-up and oxygen transfer coefficient in a pilot-plant rectangular air-lift columns and to correlate the experimental data. Additionally, a simulation of the preatment of effluents from dyestuff production in a such columns were carried out.

2. Methods and materials

Experimental investigations were carried out in a pilot-plant scale rectangular air-lift column presented in Fig.1. The cross section of column was 0.31625m^2 (0.575*0.550m), while its total heights were 2.96 and 4.44m. Such height is analogous to the height of sludge layer used in aeration chamber in sewage treatment plant. Experimental column could be divided into two or three section by means of movable baffles (Fig.2). Experiments were carried out for four geometries of the columns for which A_r/A_d=0,5 ; 1 and 2 and for a column without baffles (a bubble column). For each geometrical variant three liquid overflows were used: h_{ov}=0,1; 0,2 and 0,4m. Construction of the air-lift reactor was discussed in detail elsewhere (Dziubinski et al. 2000).

Gas used was air supplied by a central compressed-air plant through a filter and the system of reducers, manometers and rotameters. As a sparger industrial fine-bubble sparger Schumaflex of diameter ϕ=70 mm and length L=500 mm was used. The sparger was mounted in mounted wells of the air-lift column set – see Fig.2.

The gas hold-up in the riser ε_{Gt} and downcomer ε_{Gd} was measured by a manometer method. The measurement included the recording of pressure difference shown by the manometers, whose ends were connected to measuring probes placed on the riser and downcomer. Experiments were carried out when probe ends were placed along the flow axis. Bottom probes were 0.7m above the sparger, while the upper one 0.5m below upper level of water in air-lift column. The probes in both the riser and downcomer zones were placed at the same height.

The measurement of the volumetric oxygen transfer coefficient k_La was made by the classical dynamic method using an external measuring system described by (Dziubinski et al. 2000). Prior to the measurement oxygen in the liquid was replaced by nitrogen supplied by the sparger. Then, a three-way valve was switched and air was supplied to the column at the same flow rate at which the liquid was saturated with nitrogen.

During saturation and aeration the mixture was taken by a peristaltic pump from the chamber through a probe to a measuring vessel. The vessel had the form of a vertical cylinder with axial oxygen electrode. As an oxygen electrode OXI 323 made by WTW (Germany) was used. The measurement consisted in recording the readouts of oxygen electrodes which showed changes in the level of O_2 dissolved in the liquid during aeration at a constant air flow rate. Results were recorded automatically by means of a computer system of data acquisition. On the basis of the dependence of dissolved oxygen concentration on the aeration time the value of volumetric oxygen transfer coefficient k_La was calculated in the same way as in the study by (Dziubinski et al. 2000, Kawalec-Pietrenko 1992).

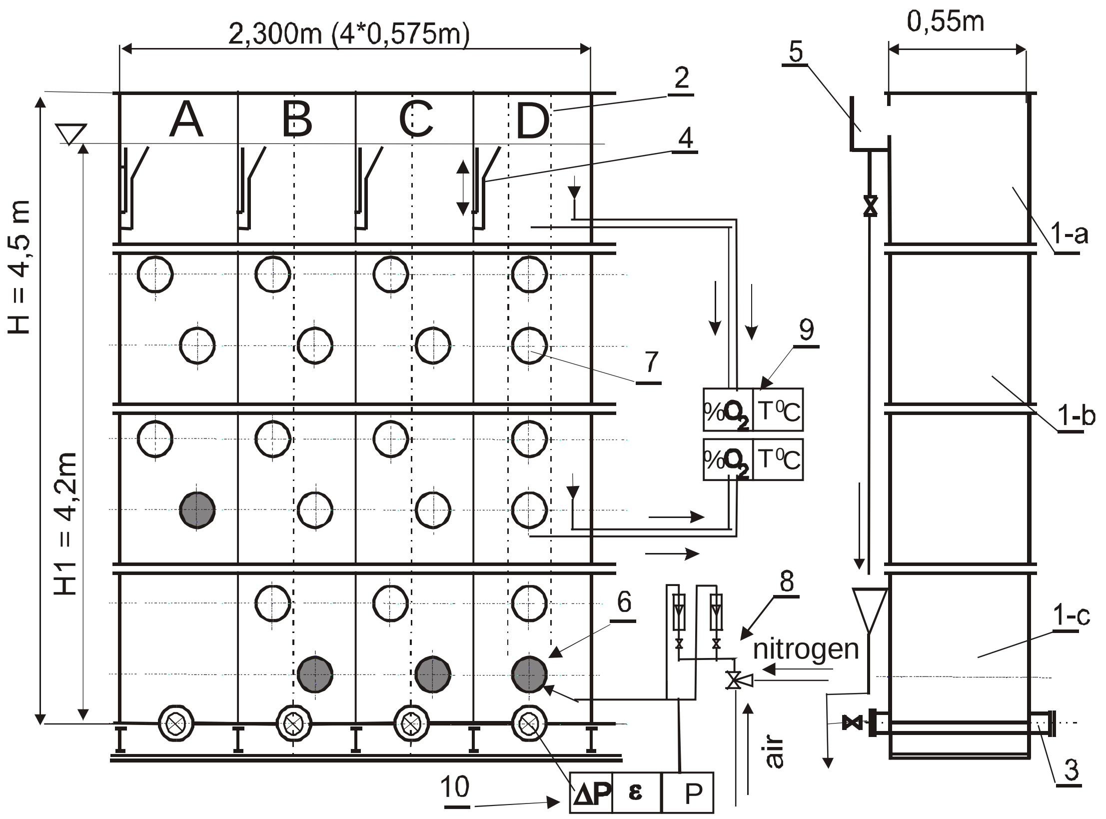

Fig. 1. Schematic diagram of experimental apparatus: 1 a, b, c – section, 2 – internal baffles, 3 – gas sparger, 4 – overflow,

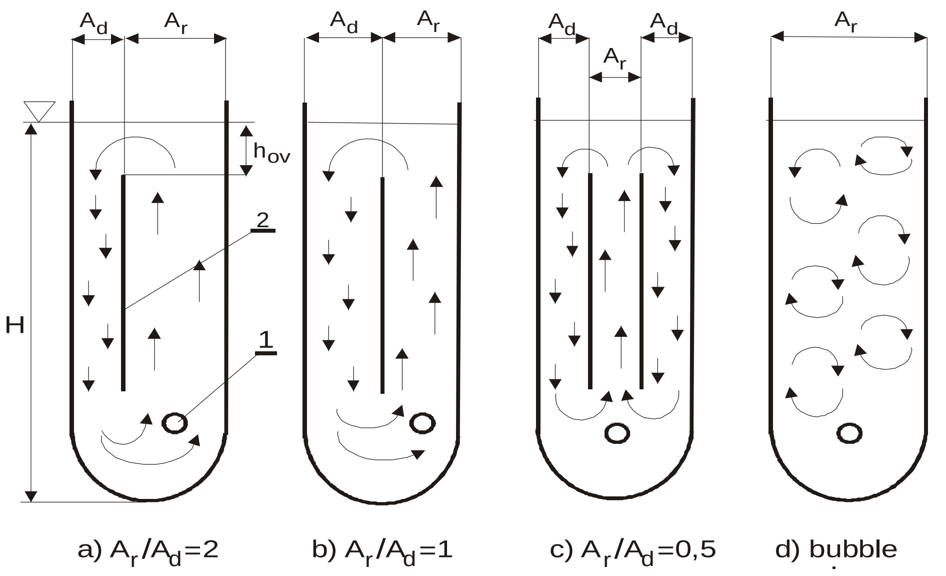

Fig. 2. Geometry of rectangular airlift column: 1- sparger, 2 - baffle

As experimental media tap water and aqueous solutions of NaCl, CMC and Spumol were used. The properties of experimental media are given in Table 1.

Table 1. Properties of experimental media.

Liquid	ρ_L [kg/m^3]	μ_L*10^3 [Pas]	σ_L [N/m]
Tap water	1000	1	72,2
NaCl water solution	1000	1	72,5
Spumol water solution	1000	1,4	34,5
0,5% CMC	1000	14,6	72,50

The air flow rates used in the experiments ranged from 1,0 to 25,0 m^3/h, which corresponds to average superficial gas velocity in the riser u_{Gt} ranging from 0,00086 to 0,064 m/s.

3. Results and discussion

A wide range of measurements enabled the determination of the effect of superficial gas velocity in the riser u_{Gt} , properties of the liquid and geometry of rectangular columns on the gas hold-up. The experiment covered 41 measuring series with 498 experimental points. The analysis of all results of above-mentioned measuring series, allows us to propose the following correlation equation describing gas hold-up in the riser:

$$\varepsilon_{Gr} = 0,367\left(\frac{u_{Gr}\mu_L}{\sigma_L}\right)^{0,925}\left(\frac{g\mu_L{}^4}{\rho_L\sigma_L{}^3}\right)^{-0,25}\left(1+\frac{A_d}{A_r}\right)^{-1}\left(1+\frac{A_{ov}}{A_r}\right)^{0,1} \qquad (1)$$

Figure 3 shows the comparison of all experimental results of gas hold-up $\varepsilon_{Gr(exp)}$ with $\varepsilon_{Gr(calculated)}$ calculated in Eq. (1). A maximum error of the broad range of experimental data did not exceed ±15%. As follows from Eq. (1), superficial gas velocity and column geometry are the factors deciding the value of gas hold-up in the rectangular air-lift column. The shape of Eq. (1) is similar to the analogous equation proposed by (Kawalec-Pietrenko 1992) for small laboratory air-lift column.

The experimental data made it possible, as in the case of gas hold-up measurements, to determine the effect of the superficial gas velocity, liquid properties and column geometry on oxygen transfer coefficient k_La in the pilot-plant air-lift reactor of rectangular cross section.

The analysis of a wide range of experimental data presented on Fig.4 resulted in a simple correlation equation in which the oxygen transfer coefficient depends on gas hold-up. It has the form:

$$k_L a = 0,225 e_{Gr}{}^{0,95} \qquad (2)$$

Correlation equations (1) and (2) hold for range:
$8.6{*}10^{-4} \le u_{Gr} \le 6.4{*}10^{-2}$ m/s, $1.0{*}10^{-3} \le \mu_L \le 14.6{*}10^{-3}$ Pas,
$34.5{*}10^{-3} \le \sigma_L \le 72{*}10^{-3}$ N/m, $0.5 \le A_d/A_r \le 2.0$, $0.3478 \le A_{ov}/A_r \le 4.17$

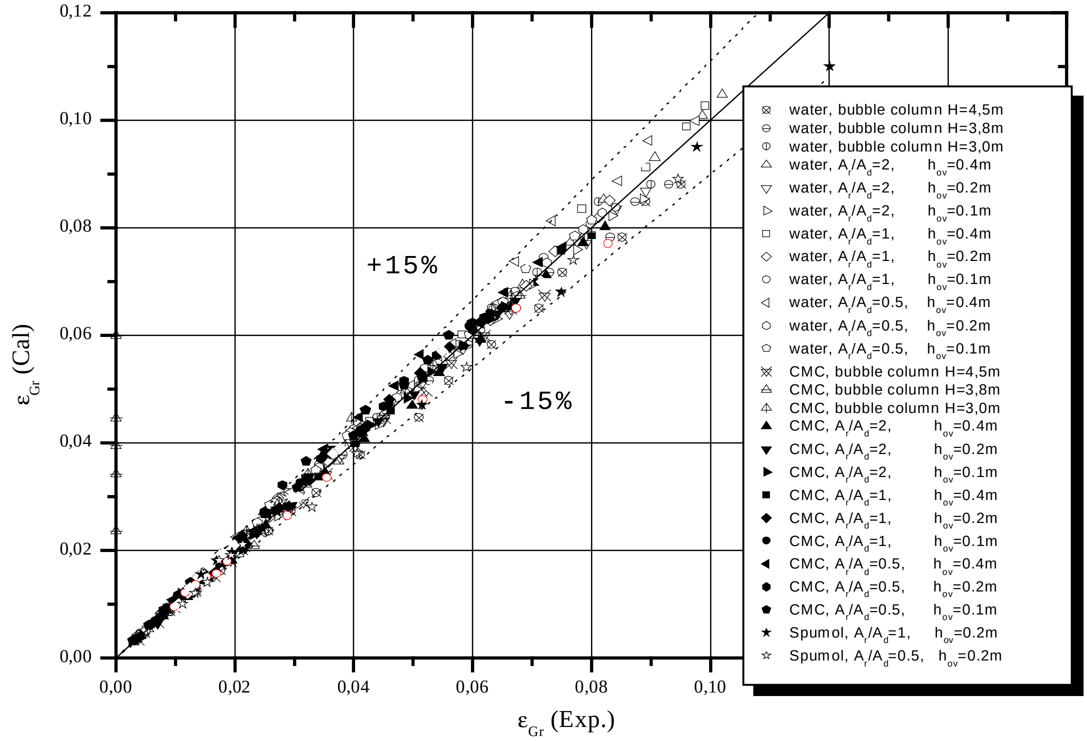

Fig. 3. Comparison of all experimental results of gas hold-up $\varepsilon_{Gr(exp)}$ with $\varepsilon_{Gr(calculated)}$ calculated in Eq. (1).

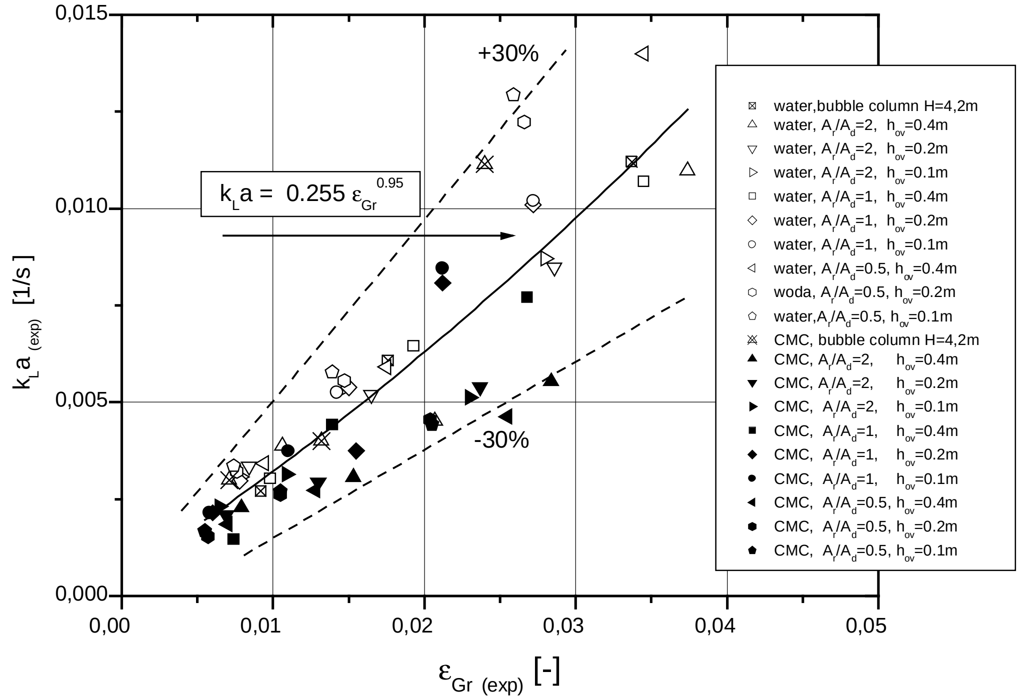

Fig. 4. Comparison of oxygen transfer coefficient k_La in the rectangular air-lift column calculated from eq. (2) with experimental values.

Figure 4 shows a comparison of oxygen transfer coefficient k_La in the rectangular air-lift column calculated from eq. (2) with experimental values. A maximum error of the broad range of experimental data did not exceed ±30%.

The diagram in Figure 5 shows oxygen coefficient as a function of pneumatic power of gas input. A comparison of the experimental data obtained for the water-air system shows that they refer to a different range of P/V_D than those published in the literature concerning small laboratory columns. The extrapolation of experimental data confirms that they are in reasonable agreement with the data available from the literature.

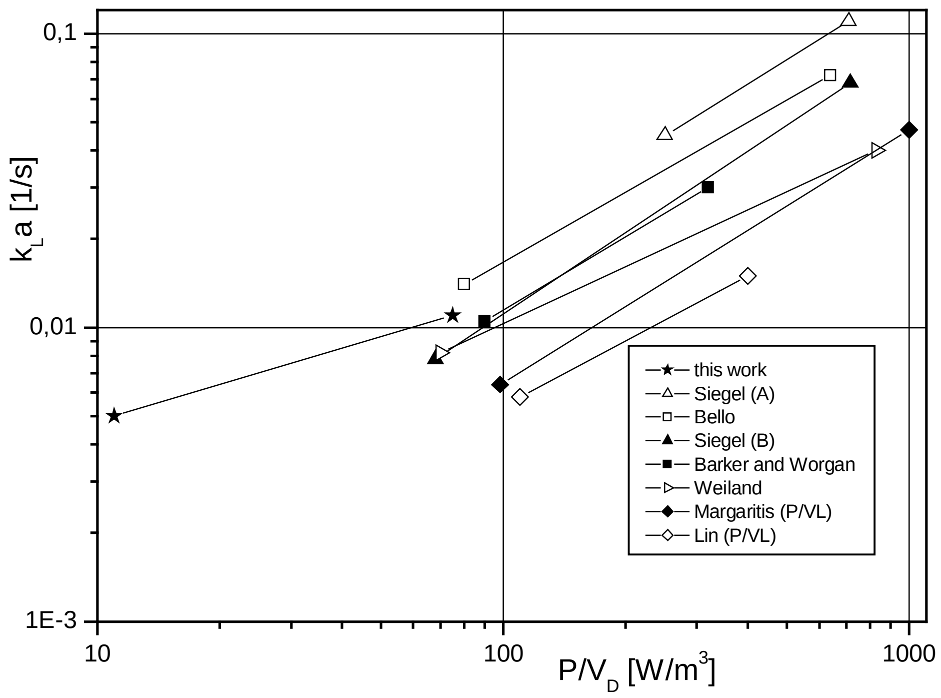

Fig.5. Comparison of data for volumetric mass transfer coefficient k_La as function of pneumatic power of gas input P/V_D.

4. Simulation of an eluate pretreatment in the air-lift column system

An experimental material was a mixture of eluates from the production of coryamine brown, coryamine black and polphalane black. The initial parameters of the mixture were as follows: TOC = 29600 mg/m^3. ABS = 4.5 and pH = 8.3. The mixture was stored and mixed in a 14 m^3 tank. From the tank it was pumped to a column system of total volume 5.4 m^3 at the flow rate 0.5 m^3/h. In subsequent columns the following operations were carried out:

- in column A with one baffle (A_r/A_d = 1, h_{ov} = 0.2 m), the mixture of eluates was coagulated. A coagulant was 20% water solution of $FeSO_4$ which was fed to the column in the dose of 200 ppm of active component (in terms of 0.5 m^3/h flow). Circulation of the mixture was attained by aeration at Q_1 = 0.5 m^3/h
- in column B with one baffle (A_r/A_d = 1, h_{ov} = 0.1m), flocculation and sedimentation of the deposit were carried out. A flocculating agent Rokrysol WF-2 was added in the

dose 25 ppm of active component (in terms of 0.5 m^3/h flow). Circulation of the mixture in the chamber was attained by aeration at $Q_2 = 0.2\ m^3/h$

- in column C with two baffles ($A_r/A_d = 0.5$, $h_{ov} = 0.2$ m), decolouration of the mixture was performed using a 30% water solution of hydrosulphite which was supplied to the downcomer at the flow rate of 3 dm^3/h. The mixture was circulated in the chamber by aeration at $Q_3 = 0.3\ m^3/h$
- in column D with two baffles ($A_r/A_d = 0.5$, $h_{ov} = 0.4$ m), only the mixture of pretreated eluates was aerated at the air flow rate $Q_4 = 1\ m^3/h$ in order to defoam and stabilise it.

At the outlet from the last column D samples of the mixture were taken and TOC and ABS were determined. Results are shown in Figure 6. As results from fig.6 during pilot-plant simulation of the pretreatment of effluents from dyestuff production about 90% pollutant reduction in the mixture measured by the TOC index and 72% colour reduction measured by the ABS value were obtained.

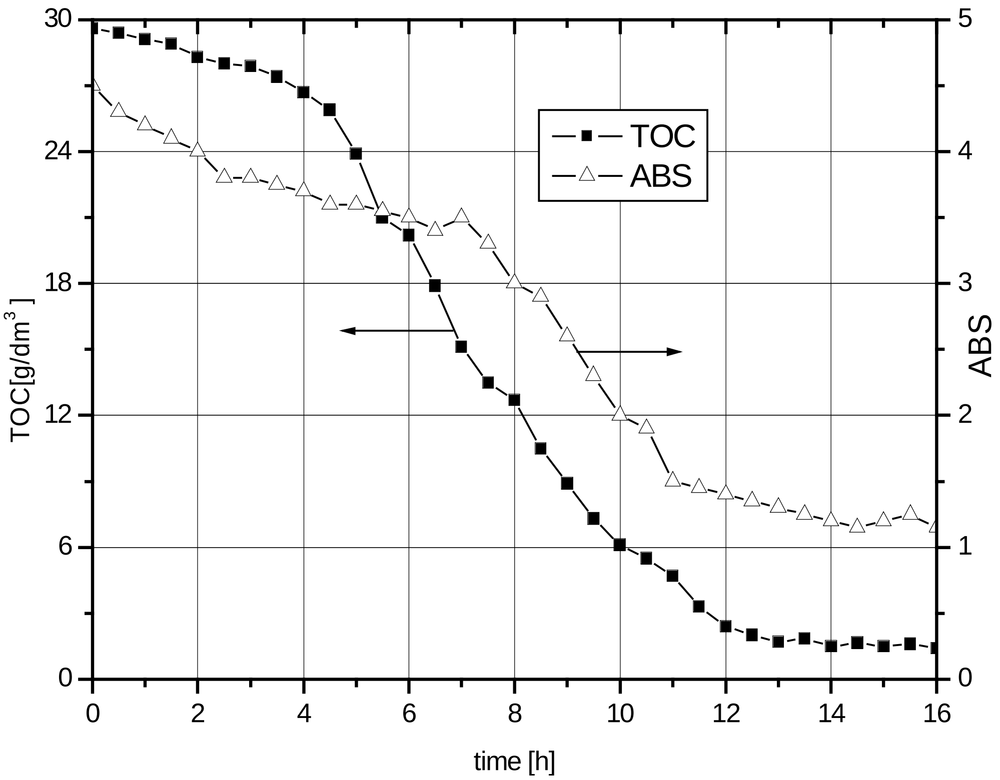

Fig 6. Dependence of TOC index and ABS values on time

5. Conclusion

Extensive experimental investigations of gas hold-up ε_{Gr} in the pilot-plant scale rectangular air-lift reactor were performed. The effect of superficial gas velocity u_{Gr}, liquid properties and column geometry on gas hold-up and volumetric mass transfer coefficient was presented. Correlation equations describing these values were proposed. It was far the first time in the literature on the subject that the correlation equations describing flow hydrodynamics of two-phase mixture and mass transfer in

pilot-plant scale air-lift column of rectangular cross section and volume exceeding $1m^3$ were developed. These equations are complementary to the analogous equations published in the literature for small laboratory air-lift columns.
A pilot-plant simulation of the pretreatment of effluents from dyestuff production achieving as a result about 90% pollutant reduction in the mixture, measured by the TOC index and 72% colour reduction measured by the ABS value.

Symbols:

A – cross sectional area, m^2
g - gravitational acceleration, m/s^2
k_La – volumetric oxygen transfer coefficient, s^{-1}
u – superficial velocity, m/s
ε – gas hold-up
μ_L – dynamic liquid viscosity coefficient, Pas
σ_L – surface tension, N/m

Subscripts

d – downcomer
G – gas
ov – overflow
r – riser

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