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Effect of Gas Holdup and Gas Velocity on Volumetric Mass Transfer Coefficient in Bubble Column

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Abstract. Bubble columns are widely used in various industrial processes such as wastewater treatment, fermentation, and gas-liquid reactions due to their simplicity and effectiveness in mass transfer operations. In this study, we investigate the influence of gas holdup and gas velocity on the volumetric mass transfer coefficient in a bubble column reactor. The volumetric mass transfer coefficient is a critical parameter that affects the efficiency of gas-liquid mass transfer processes. Through experimental analysis and computational modeling, we systematically examine the relationship between gas holdup, gas velocity, and the volumetric mass transfer coefficient. In this study, volumetric mass transfer coefficient kL.a was calculated using air in water. The data obtained are in the range of superficial gas velocity (0.03-0.2398) m/s for air water system. The experiments were carried out using 0.1 m column diameter with 2 mm hole diameter and 79 holes gas distributor. From the experimental data it was found that kL.a increased with increasing of gas holdup and increasing of superficial gas velocity.

1. Introduction

Gas holdup and gas velocity play a crucial role in determining mass transfer coefficients in gas-liquid systems. Surfactants can affect gas holdup, with lower concentrations leading to higher gas holdup. Correlations have connected gas holdup and mass transfer coefficient with factors like superficial gas velocity, liquid surface tension, and average bubble diameter. The impact of surfactants on mass transfer properties in co-current downflow columns has been studied to understand hydrodynamics better.

The transition from homogeneous to heterogeneous flow patterns in bubble columns is essential for determining the optimal superficial gas velocity for efficient mass transfer. Column aspect ratio and liquid height influence this transition phase, with varying effects based on specific system conditions. New correlations have been suggested to predict properties of the transition phase accurately, providing insights into gas-liquid system dynamics.

Studies on aviation fuel scrubbing applications show that oxygen mass transfer performance is linked to hydrodynamics. Factors like bubble size distribution, sparger design, and gas superficial velocity impact oxygen mass transfer. Understanding these factors helps optimize mass transfer processes.

In industries using carbon dioxide, volumetric mass transfer coefficients are crucial in gas-liquid systems. Factors like membrane surface wettability can influence bubble size distribution and mass transfer rates.

Understanding these nuances is vital for enhancing mass transfer efficiency in various applications.

Analyzing the influence of gas holdup and gas velocity on mass transfer coefficients provides valuable insights for optimizing gas-liquid systems for better performance and efficiency. See references: [4], [5], [9], [10].

The main focus of this research is to explore how gas holdup and gas velocity impact the mass transfer coefficient within a bubble column configuration. By investigating the influence of variations in superficial gas velocity on the mass transfer coefficient (kLa). Through this study, our goal is to establish empirical correlations utilizing dimensionless parameters (Sh, Re, Bo, We) that can accurately forecast the mass transfer coefficient. By meeting these objectives, we aspire to deepen our comprehension of the factors that influence mass transfer in bubble columns and offer valuable insights for future investigations in this area. [7], [13], [14], [16].

The primary objective of this investigation is to delve into how gas retention and gas speed influence the mass transfer coefficient within gas-liquid reactors. By examining the intricate interplay between these factors, our aim is to broaden our understanding of the core principles that govern mass transfer in bubbly flow regimes (Figure 3). The study will specifically concentrate on the impact of varying gas retention and gas speed on the mass transfer coefficient, with a particular focus on optimizing aeration systems for water resource recovery facilities. Drawing parallels between bubble columns and wastewater aeration tanks, we seek to elucidate the key factors that affect mass transfer efficiency. Through an experimental setup utilizing a bubble column, we will scrutinize parameters such as superficial gas speed for air-water systems to evaluate their influence on mass transfer coefficients. By collecting data and analyzing outcomes, our goal is to establish correlations that can forecast mass transfer coefficients using dimensionless groups or artificial neural networks. The ultimate objective is to offer insights that can guide future research endeavors or practical implementations in enhancing mass transfer in gas-liquid reactors. [2], [13], [16], [20].

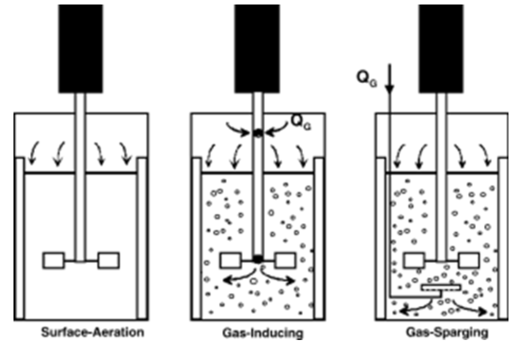


Figure 1. Operation modes of agitated reactors. [17]

The mass transfer coefficient in bubble columns is greatly influenced by gas retention and gas speed. Research has indicated that both gas retention and the liquid-phase mass transfer coefficient increase with higher gas speeds and the frothing capacity of the liquid. The size of the column has a minimal impact on these factors, highlighting the importance of gas speed and frothing ability. Equations have been developed to estimate gas retention and mass transfer coefficients for columns ranging from 0.1-0.3 m in diameter, underscoring the practical value of these results.

Additionally, studies have found that columns with a draft tube exhibit higher values of gas retention and mass transfer coefficients compared to those without a draft tube at the same gas speed, particularly when using a frothing liquid. This discrepancy underscores the significance of considering both gas retention and gas speed when analyzing mass transfer coefficients in various column configurations.

In conclusion, understanding the relationship between gas retention, gas speed, and frothing ability is essential for accurately predicting mass transfer coefficients in bubble columns. By incorporating these elements into empirical equations or correlations, researchers can enhance their capacity to design efficient chemical reactors or bioreactors based on specific mass transfer requirements. [7]. Table 1 shows Classification of gases based on their order of importance in using in bubble column in different process.

Table 1. Classification of gases based on their order of importance [2]

Gas .	Henry's law constant [mol/(m³·Pa)] .	Solubility in water* .	Importance .
O_2	1.2×10^{-5}	Low	Process performance and energy, i.e. effluent quality and costs
CO_2	3.3×10^{-4}	Low	pH calculations; GHG emissions
NO	1.9×10^{-5}	Low	GHG emissions
N_2O	2.4×10^{-4}	Low	
H_2S	1.0×10^{-3}	Intermediate	Corrosion, odour nuisance and inhibition effect on the anaerobic digestion
NH_3	5.9×10^{-1}	High	Odour nuisance and inhibition effect on the anaerobic digestion, resource recovery
CH_4	1.4×10^{-5}	Low	GHG emissions
H_2	2.6×10^{-6}	Low	Inhibition effect on the anaerobic digestion
Volatile organic compounds	–	–	Health effect and odour nuisance
N_2	6.4×10^{-6}	Low	Present in air, makes up bubble volume in anoxic zones, mitigation of GHG emissions

Moreover, research conducted by Vandu & Krishna [8] has shown that characteristics of the liquid, specifically surface tension, play a crucial role in gas retention and mass transfer in downward flow contact columns. Their experiments revealed that a decrease in surface tension results in the formation of smaller bubbles, leading to higher gas retention but lower kLa values. This highlights the significance of taking into account liquid properties when analyzing mass transfer coefficients.

In summary, these studies offer valuable insights into the factors affecting volumetric mass transfer coefficients in various systems, including bubble columns and downward flow contact columns. By comprehending how variables like gas velocity, liquid characteristics, and column dimensions impact kLa, researchers can effectively optimize mass transfer processes for different applications. [2], [7].

1.1 Effects of superficial gas velocity on kLa

The impact of superficial gas velocity on the mass transfer coefficient (kLa) is a key factor in determining the effectiveness of gas-liquid mass transfer processes. In bioreactors like bubble columns and airlift reactors, the gas velocity directly influences how quickly gases dissolve into the liquid phase. Research has demonstrated that increasing the superficial gas velocity can improve mass transfer by facilitating thorough mixing and expanding the contact area between the gas and liquid phases. This leads to heightened kLa values and enhanced oxygen transfer rates, which are crucial for supporting microbial growth.

It should be noted that different gases can have varying effects on mass transfer coefficients depending on their solubility and interactions with the liquid phase. For example, gases such as CO2 are extensively studied due to their involvement in acid-base equilibria, while gases like N2 have received less attention despite their presence in various biological processes. Understanding these nuances is essential for optimizing mass transfer processes in wastewater treatment applications and ensuring effective resource recovery (Figure 2).

Overall, fine-tuning superficial gas velocity is imperative for maximizing mass transfer coefficients in bioreactors. By precisely managing this parameter, researchers can boost oxygen delivery to microbial cultures, enhance process efficiency, and achieve superior performance in gas-liquid systems. [2], [14].

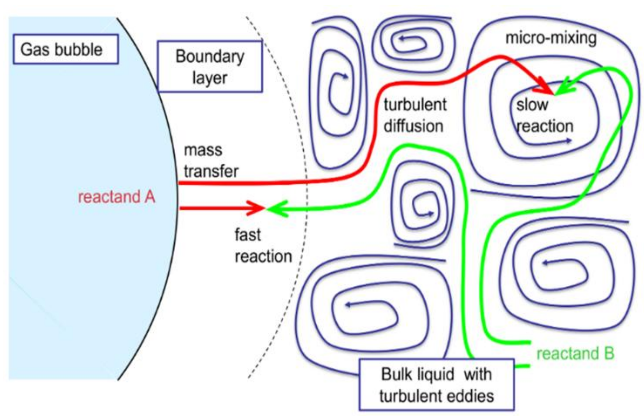


Figure 2. The main processes involved in the reactive mass transfer phenomena. [12]

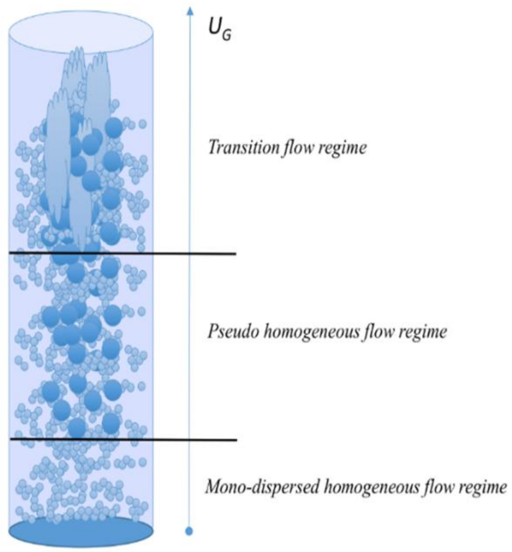
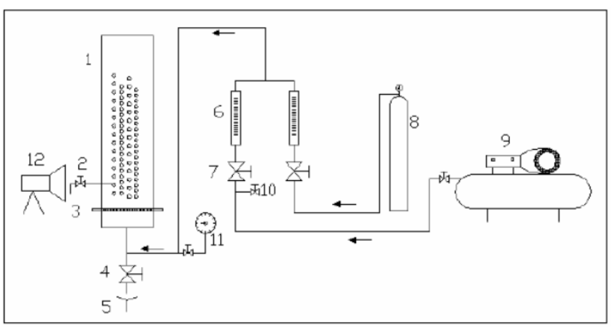


Figure 3. Flow regime transitions from the homogeneous flow regime towards the transition flow regime. [12]

2. Experimental Setup

The experimental setup for the bubble column was meticulously crafted to guarantee precise data gathering. Using a QVF Pyrex glass column with dimensions of 0.1 m in diameter and 1.5 m in height, the setup included a sparger at the base with 79 holes, each measuring 2 mm diameter, to ensure uniform gas distribution.(Figure 4)



1- QVF bubble column
2- Sampling valve
3- Gas distributor
4- Drain valve
5- Drain
6- Rotameters
7- Regulating valves
8- CO_2 cylinder
9- Air compressor
10- Vent valve.
11- Pressure Gauge
12- Photo camera

Figure 4. Experimental set-up for 0.1 m diameter column

Assuming stationery liquid phase, (2500 ml) of tap water was prepared by mixing the water with 0.7 grams sodium sulfate and 0.0025 grams cobalt for oxygen scavenging from water before each run. Before introducing the scanned water into the bubble column reactor, the rotameter set at (0.886, 2, 3, 5, and 7) m3/hr for air flow. A sample of water where taken from the bubble column reactor every (15 and 30) seconds in a (60 ml) bottle.

3. Results and Discussion

3.1. Impact of increasing superficial gas velocity on kLa

Table (2) shows the volumetric mass transfer coefficient kL.a for air-water system calculated using the equation developed by Vandu and Krishna (2003).

$$\frac{C_L}{C_L} = 1 - \exp\left(-\frac{K_L.a}{1-\varepsilon_G}\right) \quad (1)$$

Table(2).Calculated volumetric mass transfer coefficient kL.a(s-1) (Air-water).

No.	U_G	ε_G	$K_L.a$	R%
1	0.03	0.0648	0.00869	87.8
2	0.0685	0.2087	0.02038	91.7
3	0.1027	0.2563	0.0271	97.4
4	0.1713	0.37	0.028169	99.1
5	0.2398	0.4285	0.038322	98.6

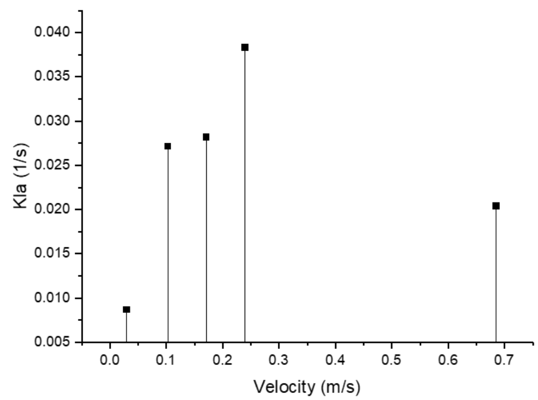


Figure (5) shows the volumetric mass transfer coefficient kL.a in relation to superficial gas velocity.

As in Fig (5), the importance of elevating superficial gas velocity on the mass transfer coefficient (kLa) cannot be understated when analyzing gas-liquid systems. As demonstrated in a variety of research studies, such as one examining triple-impeller setups in a stirred container equipped with vertical tubular coils, it is evident that gas flow rates have a direct impact on kLa values. For example, when comparing different impeller configurations with coil baffles, it was noted that at low gas velocities, the kLa values saw a 15% increase with the use of coil baffles over planar baffles. However, at higher superficial gas rates, this increment rose to 30%. This serves to emphasize the crucial role played by gas velocity in improving mass transfer efficiency.

Furthermore, experiments involving the incorporation of palm oil as an organic phase in xanthan solutions revealed a significant uptick in kLa values following the addition of palm oil. With a 10% oil fraction, kLa values surged by up to threefold compared to pure xanthan solutions, illustrating the beneficial influence of organic phases on mass transfer coefficients. In addition, investigations into aviation fuel scrubbing highlighted a direct connection between oxygen volumetric mass transfer coefficients and superficial velocities. The rise in superficial velocity resulted in higher kLa values due to enhancements in oxygen mass transfer coefficients and an increase in gas-liquid contact area. Taken together, these findings stress the critical role of superficial gas velocity in impacting mass transfer coefficients within gas-liquid systems. By comprehending and optimizing gas flow rates, researchers can elevate mass transfer efficiency and enhance overall system functionality. See references: [1], [3], [19].

3.2 Impact of increasing Gas holdup on kLa

the volumetric mass transfer coefficient (kLa), plays a significant role in how efficiently gas and liquid interact in bubble column reactors. This research looks into how increasing the amount of gas in the reactor influences kLa. Gas holdup, which measures the volume of gas in the reactor, impacts the surface area where gas and liquid can exchange molecules. By adjusting the gas holdup in the reactor and measuring kLa, we find that there is a complex relationship between gas holdup and the efficiency of mass transfer.

Fig (6) shows the relation between gas holdup and mass transfer coefficients and can be concluded that increasing gas holdup can be lead to signfecent increasing in volumetric mass transfer coefficients and that can be seen in the work of [24] [25] .

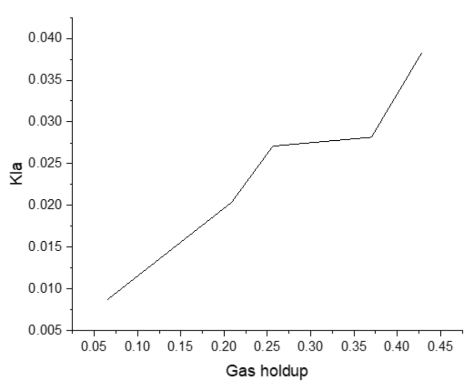


Figure (6) shows the volumetric mass transfer coefficient kL.a in relation to superficial gas holdup.

4. Conclusion

The study examined gas-liquid mass transfer properties when scrubbing aviation air in water. Factors like gas holdub, velocity, and fuel quantity impacted mass transfer, affecting dissolved oxygen concentration. Increasing superficial velocity led to higher mass transfer rates. Superficial gas velocity was found to influence kLa values, with systems improving mixing efficiency. Gas holdup profiles showed higher values for gas-entrainment. The study underscores the importance of gas holdup and velocity in mass transfer coefficients and suggests future research could focus on enhancing the acting of mass transfer correlations

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