
THE SPECIFIC INTERFACIAL AREA IN AN AIRLIFT TOWER REACTOR

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Received June 6, 1989

Accepted September 11, 1989

This study deals with the oxygen transfer in the gas-liquid dispersion systems. The sulfite oxidation method was used to determine the specific interfacial area in the airlift tower reactor with and without motionless mixers. The experimental results obtained were described by the correlation equations and compared with those already published in the literature.

In typical submerged aerobic fermentation processes, oxygen transfer from the gas phase to the liquid media is one of the major concerns for successful bioreactor design and scaleup. Therefore, effective interfacial area is an important variable when the design of the bioreactors is based on mass transfer considerations. For the sake of its simplicity, the sulfite oxidation method has often been used for the determination of the interfacial area between gas and liquid. The absorption of oxygen in aqueous sodium sulfite solutions in the presence of cobalt sulfate as a catalyst is accompanied by a fast chemical reaction in the liquid phase. Since its first application¹, sulfite oxidation method has been used to determine both the volumetric oxygen transfer coefficient²⁻⁶ and especially the interfacial area⁷⁻¹¹. A correct application of this method requires a knowledge of kinetic data. The kinetics of oxidation of aqueous sulfite solutions has been studied by many authors¹²⁻¹⁶. It must be noted that owing to the existence of oxygen probes, the dynamic methods are preferred to the determination of volumetric oxygen transfer coefficient in the present time.

The objective of this study was to determine the specific interfacial area in an airlift tower reactor with and without motionless mixers. It is namely known that airlift fermentors without mechanical agitation have higher efficiency in mass transfer in a comparison with mechanically stirred fermentors at the same power inputs.

THEORETICAL

The reaction order in oxygen during its absorption in sodium sulfite solutions depends on the oxygen concentration in the liquid phase at the interface¹². If the

reaction of oxygen with sodium sulfite is second order in oxygen, the specific interfacial area can be evaluated from the relationship in the form

$$a = \dot{n}/V_{GL}(c^+)^{3/2} (2Dk_2/3)^{1/2}. \quad (1)$$

If it is assumed that the gas phase resistance is negligible and Henry's law is valid, then the interfacial concentration of oxygen will be equal to the equilibrium concentration in the liquid which is proportional to its partial pressure in the gas phase. In order to determine the equilibrium concentration of oxygen in the liquid at the gas-liquid interface, Linek and Vacek¹⁶ derived the following correlation

$$H = 1.715 \cdot 10^{10} \exp [0.9407c(\text{SO}_4^{2-})/(1 + 0.1933c(\text{SO}_4^{2-})) - 1602.1/T] \quad (2)$$

which was rearranged in SI units. The value of the second order reaction rate constant, k_2 , can be taken from the literature. Owing to the impurities present in sulfite solutions, it is, however, recommended to determine the reaction rate constant experimentally.

EXPERIMENTAL

Reactions of air oxygen with sodium sulfite solutions were carried out in an airlift tower reactor. Vertical cylindrical glass pipe of a 105 mm diameter was used as the jacket of the reactor. Three inner draft tubes were situated over the gas distributor and their diameter was 33.5 mm and their length was 400 mm. The stainless steel plate perforated by 12 holes of 1 mm diameter was used as the gas sparger. The ratio of the hole area to the outside pipe cross-sectional area was 0.11%. The other part of experiments was performed in the same airlift reactor which, however, contained elements of motionless mixer (Kenics type). Seven elements of motionless mixer were inserted in each of draft tubes. The elements of motionless mixers were made of plexiglass and their width was equal to the diameter of the draft tube, while their length was 1.5 times their width. The airlift reactor used together with elements of motionless mixer were illustrated schematically in the preceding work¹⁷.

Experimental determination of the specific interfacial area was done by using sulfite oxidation method. The reactors were always filled with 5 litres of aqueous sodium sulfite solution. Initial concentrations of sulfite were approximately 0.75 kmol m^{-3} . CoSO_4 was added as a catalyst and its concentration was $0.001 \text{ kmol m}^{-3}$ in all runs. The pH of the sulfite solutions was adjusted by addition of 2 kmol m^{-3} sulfuric acid solution and was kept at 8.5. The temperature of liquid batch was maintained at 20°C . The total pressure in the gas phase (air) was always atmospheric. The oxygen absorption rate was calculated from the decrease of sulfite concentration during the experiment. Concentrations of sulfite were determined iodometrically. For both modifications of the reactor, the experiments were performed within the range of the air flow rates from 5 to 30 l min^{-1} which were measured by the flow meter at the pressure 120 kPa and temperature 20°C . Then corresponding values of the superficial gas velocities varied from 1.04 to 5.90 cm s^{-1} .

RESULTS AND DISCUSSION

The specific interfacial areas were evaluated from Eq. (1). The reaction rate constant, k_2 , was determined in a laboratory absorber with vertical row of spheres, which was described previously¹⁸, and its value $k_2 = 1.49 \cdot 10^7 \text{ m}^3 \text{ s}^{-1} \text{ kmol}^{-1}$ was in a reasonable agreement with the values obtained by Linek and Tvrđík¹⁴. If the validity of Nernst–Einstein equation might be assumed, then the diffusion coefficient of oxygen in sulfite solutions was evaluated at their viscosities and temperatures from the value $D = 1.96 \cdot 10^{-9} \text{ m}^2 \text{ s}^{-1}$ determined in water at 20°C in the preceding work¹⁹.

As shown in Fig. 1, the specific interfacial area increases with increasing air flow rate for both modifications of the reactor. The increasing gas velocity leads to an increase of the gas holdup (Fig. 2) and hence the interfacial area increases as well. In the range of superficial gas velocities from 1 to 3 cm s^{-1} , the influence of the presence of motionless mixers is not, however, marked. But the presence of the motionless mixers leads to the increase of the interfacial area in the region of superficial gas velocities within 4 and 6 cm s^{-1} . The experimental apparatus used were identical with those in preceding works^{17,20} in which the cultivations of yeast culture *Torulopsis ethanolitolerans* were studied. The oxygen transfer during cultivations was characterized by its volumetric liquid side mass transfer coefficient and the effect of motionless mixers on mass transfer was investigated. Similarly as in the

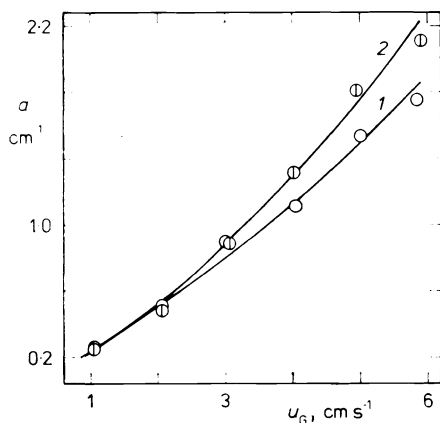


FIG. 1

Specific interfacial area as a function of superficial gas velocity. 1 reactor without motionless mixers, 2 reactor with motionless mixers

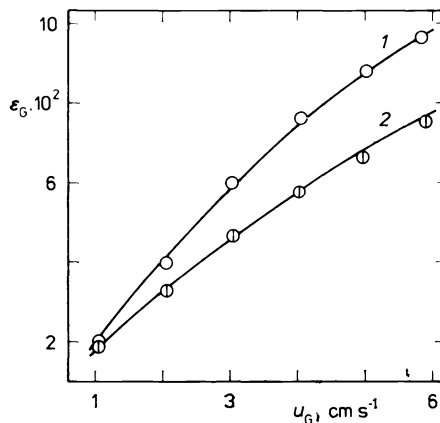


FIG. 2

Dependence of overall gas holdup on superficial gas velocity. 1 reactor without motionless mixers, 2 reactor with motionless mixers

present work, the influence of the motionless mixers on volumetric oxygen transfer coefficient was not obvious at low air flow rates, while for fermentor with motionless mixers the volumetric coefficient of oxygen transfer was greater than for fermentor without motionless mixers in the region of air flow rates within 15 and 30 l min⁻¹. As it follows from Fig. 2, the gas holdup in the reactor with motionless mixers was lower in a comparison with reactor without motionless mixers. On the other hand, very fine bubbles arose in draft tubes with inserted elements of motionless mixer by secondary dispergation. On the contrary, the coalescence of primary bubbles occurred in the draft tubes without motionless mixers. Because the specific interfacial area depends on both overall gas holdup and the bubble size, it can be probably assumed that the effect of the decrease of bubble size by secondary dispergation prevailed over the decrease of the gas holdup. The values of the specific interfacial area obtained in both modifications of the airlift reactor were greater than those reported by Popovic and Robinson¹¹ who used a bubble column and an external-circulation-loop airlift reactors with gas sparger with 1 mm diameter holes. Mashelkar²¹ presented the data of the interfacial area obtained by photographic technique and fast chemical reaction method by several investigators. For a bubble column, the specific interfacial areas were less than approximately 1.25 cm⁻¹ in the range of the superficial gas velocity from 1 to 6 cm s⁻¹.

Furthermore, all data (a in m⁻¹) for the airlift reactor with and without motionless mixers plotted in Fig. 1 can be correlated to the main operating parameter, i.e. superficial gas velocity in m s⁻¹, in the form

$$a = 4.17 \cdot 10^3 u_G^{1.11} \quad (3)$$

for an airlift reactor without motionless mixers (correlation coefficient 0.997, maximum deviation 5.9%), and

$$a = 8.33 \cdot 10^3 u_G^{1.29} \quad (4)$$

for an airlift reactor with motionless mixers (correlation coefficient 0.996, maximum deviation 13.7%). From derived correlations (3), and (4) follows that the power of the superficial gas velocity is greater than in the case of bubble columns, Mashelkar and Sharma²² studied the specific interfacial area in bubble columns by absorption of carbon dioxide in aqueous sodium carbonate-bicarbonate buffer. Their data indicated that the values of interfacial area varied approximately as 0.7 power of the superficial gas velocity in the range within 12 and 34 cm s⁻¹. Popovic and Robinson¹¹ who used the sulfite oxidation method reported correlation $a \sim u_G^{0.856}$ for the range of superficial gas velocity from 0.5 to 10 cm s⁻¹.

As already discussed previously, the interfacial area in dispersion systems depends on the gas holdup. Akita and Yoshida²³ proposed correlation between the specific

interfacial area and the gas holdup as $a \sim \varepsilon_G^{1.13}$ for a bubble column. The data measured in the present work can be correlated as $a \sim \varepsilon_G^{1.20}$ for the airlift reactor without motionless mixers and as $a \sim \varepsilon_G^{1.57}$ for the airlift reactor with motionless mixers. It must be noted that overall gas holdup was measured by measuring a level of the aerated liquid during operation and that of clear liquid.

In conclusion, the absorption of oxygen in sodium sulfite solutions is accelerated by a passing fast chemical reaction. Therefore, the results obtained for system oxygen–sodium sulfite solution make it only possible to show the influence of motionless mixers inserted in draft tubes of the airlift reactor on the interfacial area, but they cannot be applied to fermentation processes. The values of the specific interfacial area may be used for purpose of design of the fermentors when gas–liquid system properties are similar. In spite of these facts, the chemical method can be used for a comparison of various types of fermentors from the point of view of their efficiency of oxidation.

SYMBOLS

a	specific interfacial area based on V_{GL} , m^{-1} , cm^{-1}
c^+	dissolved oxygen concentration at equilibrium, $kmol\ m^{-3}$
$c(SO_4^{2-})$	concentration of sodium sulfate, $kmol\ m^{-3}$
D	diffusivity of oxygen in the liquid, $m^2\ s^{-1}$
H	Henry coefficient for oxygen solubility, $Pa\ m^3\ kmol^{-1}$
k_2	second order reaction rate constant, $m^3\ s^{-1}\ kmol^{-1}$
\dot{n}	molar absorption rate of oxygen, $kmol\ s^{-1}$
V_{GL}	volume of gas–liquid dispersion, m^3
T	temperature, K
u_G	superficial gas velocity, $m\ s^{-1}$, $cm\ s^{-1}$
ε_G	overall gas holdup

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Translated by the author.