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UTILIZATION OF SODIUM SULFIT DROPLET FOR OXYGEN ABSORPTION

PEMANFAATAN TETESAN NATRIUM SULFIT UNTUK ABSORPSI OKSIGEN

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ABSTRAK

Penyerapan gas oleh tetesan cairan dalam kolom semprot adalah salah satu metode umum untuk pembersihan gas di proses industri. Desain sederhana, penurunan tekanan rendah, dan kemungkinan penerapannya dalam sistem cair yang mengandung padatan adalah manfaat dari metode ini. Koefisien perpindahan massa penyerapan gas-cair tergantung pada ukuran tetesan, konsentrasi cairan atau gas dan sistem fisik-kimia. Percobaan untuk mempelajari transfer massa menggunakan sistem udara-oksigen/sulfit telah dilakukan. Tetesan terdispersi dihasilkan dengan memompa cairan melalui jarum dengan laju alir tertentu. Kamera Kecepatan Tinggi dengan metode shadowgraph dan pengolahan gambar digunakan untuk pengukuran ukuran tetesan dan kecepatan secara akurat. Bentuk tetesan relatif tidak bulat karena gerakan berosilasi. Tetesan sedikit dipercepat setelah terlepas dari jarum. Konsentrasi oksigen ditentukan dengan metode spektrofotometri. Koefisien perpindahan massa cair dari percobaan ini adalah 2 kali lebih rendah dari model karena reaksi rendah antara oksigen dan sulfit. Koefisien perpindahan massa dari eksperimen dihitung dari data eksperimen, dan dibandingkan dengan persamaan model dari literatur.
Kata Kunci: *absorpsi oksigen, tetesan natrium sulfit, koefisien perpindahan massa*

ABSTRACT

Gas absorption by liquid droplets in a spray column is one common method for gas cleaning. The simple design, low pressure drop, and the possibility of its application in liquid systems containing solids are benefits of this method. The mass transfer coefficient of gas-liquid absorption depends on droplet size, concentration of liquid or gas and the physic-chemical system. Experiments to study the mass transfer using the air-oxygen/sulphite system have been performed. The dispersed droplets were generated by pumping the liquid through a needle with certain flowrate. A High Speed Camera with shadowgraph method and image processing was used for measurement of droplet size and velocity accurately. The shapes of the droplets were relatively not spherical because of oscillating movement. The droplets are slightly accelerated after detach from the needle. The oxygen concentrations were determined by means of spectrophotometric method. The liquid mass transfer coefficients of this experiment are 2 times lower than the model because of the low reaction between oxygen and sulphite . The mass transfer coefficient of the experiment is calculated from the experimental data, and compared with the model equations from the literature.
Keywords: oxygen absorption, sodium sulfit droplets, mass transfer coefficient

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I. INTRODUCTION

Mass transfer from and to droplets is a phenomenon that often occurs in the chemical industry e.g., gas absorption. Liquid dispersed as droplets in a gas e.g. in stripper or scrubbers are important applications of mass transfer between gas and liquid phases. Gas absorption in a spray column is widely used particularly due to a simple design, low pressure drop, and the possibility of its application in liquid systems containing solids. A better understanding of the factors influencing the transfer between the dispersed phases with the continuous phase is needed for the design of spray tower as well as predictions of individual phase mass transfer, taking into account the spray formation process.

Some researchers have studied mass transfer from CO_2-water system in the form of water droplets (Bin et al. 2016; Srinivasan and Aiken 1988; Xiaomei et al. 2017; flow in packed column (Xiao M. W. et al. 2018), and in wetted wall (Hanna and Helena 2017). Other investigations for the oxygen absorption have also been done in lab scale fermenter (Rajesh G, et al. 2012) and in using nanoparticle (Jia-Zong et al. 2015). In the cases where the internal resistance is important, for a droplet stream system, only Srinivasan and Aiken reports for CO_2 absorption system with a stream of water droplets.

Until now the oxygen mass transfer in sulphite solution particularly in the form of droplets or a stream of droplets has not been investigated, which is the primary motivation in this study. Since the characterization of droplet size and droplet velocity are very important parameters for calculating the mass transfer coefficient, a highly precise measurement of that parameter is one basis for deriving exact mass transfer coefficients.

In this study, an apparatus for measuring the droplet size and the droplet velocity was established with shadowgraph method and image processing. The mass transfer coefficient of the experiment is determined from the experimental data, and compared with the model equations from the literature. The objective of this study was to determine the mass transfer coefficient between oxygen and sulfite.

II. METHODOLOGY

A single droplet is produced by pumping the solution through a needle with certain flowrate, i.e. 1.0, 1.5 and 2.0 ml/minute. For measuring the exact diameter of droplet and the droplet velocity an image processing system with long distance microscope and high speed camera was used (Figure 1.).

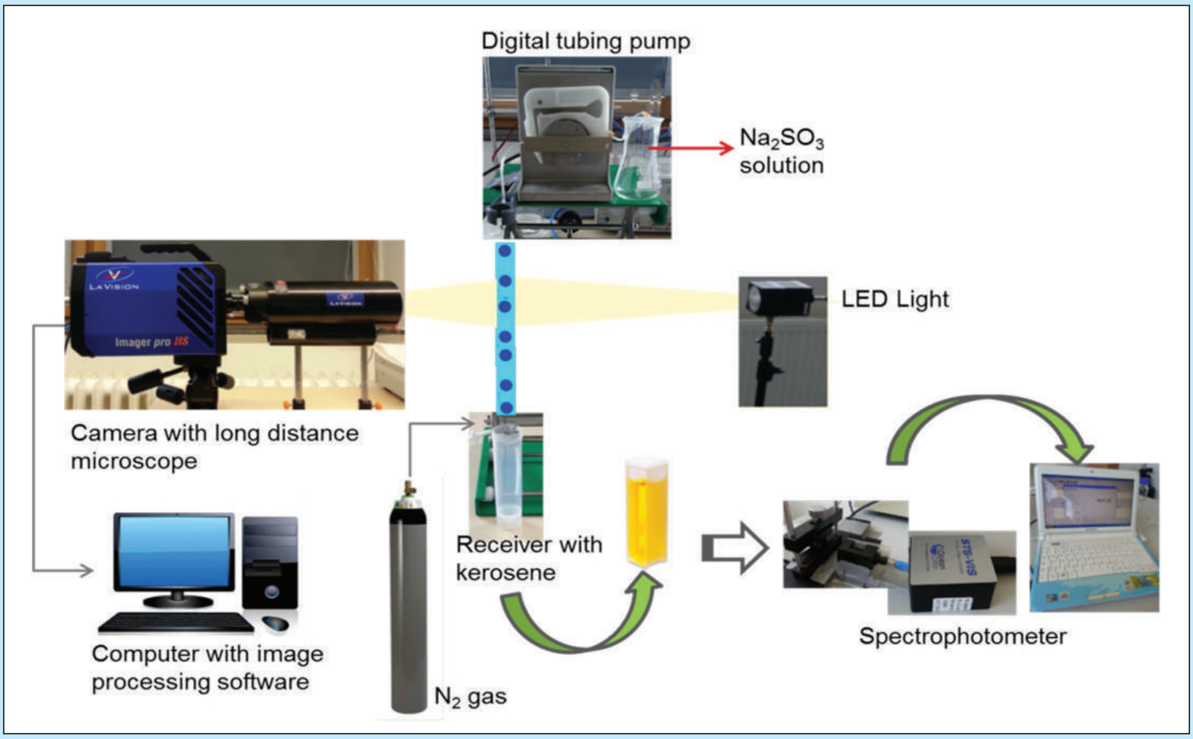


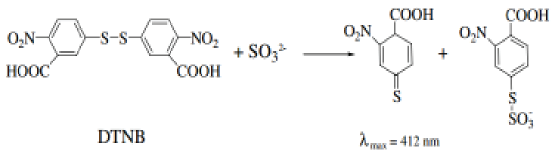
Figure 1
Experimental set-up for Absorption of oxygen by Na_2SO_3 droplet.

The droplets fall free in air with a falling height 10, 15 and 20 cm, respectively, and are finally deposited under kerosene. The concentration of sodium sulphite solution before and after the droplet contacted the air, is analysed by spectrophotometer. The data obtained is used for the calculation of the rate of absorption.

Sodium sulphite solution (100 mmol/l) was used as dispersed liquid. After absorption or after the droplets discharged from needle, the samples were taken on the receiver about 5 µl and added with 4 ml acetate buffer (pH 6) and 2 ml DTNB (5,5'-dithiobis 2-nitrobenzoic acid, 1 mmol/l). After that the solution is analysed by means of a calibrated spectrophotometer in order to determine the concentration of sulphite.

The reaction of sodium sulphite and oxygen proceed according to Eq (1), while reaction DTNB and sodium sulphite follow reaction Eq (2). Quantification of O_2 absorption rate is possible by measuring either the reactants or the products. Oxygen absorbed during a run was calculated from the change in sulphite concentration of the absorbing solution at the initial and the certain experimental condition (at different position). Sulphite concentrations were determined by spectrophotometric method.

$$2Na_2SO_3 + O_2 \rightarrow 2Na_2SO_4 \quad (1)$$



(2)

Mass Transfer Coefficient Calculation

As the gas phase mass transfer coefficient is much greater than the liquid mass transfer coefficient in this case, the absorption process is controlled by the liquid phase resistance (Srinivasan and Aiken 1988)

An model equation for liquid mass transfer coefficient was expressed by Srinivasan and Aiken:

$$k_L = 0.16\left(\frac{\mu^3 D}{\rho^2 d^3 \sigma}\right)^{1/2} Re^{1.313} \quad (3)$$

Where k_L represent mass transfer coeficient (m/s), μ is absolute viscosity (N.s/m^2), D is diffusivity (m^2/s), ρ is density (kg/m^3), d is droplet diameter (m), σ is surface tension (N/m) and Re is Reynold number.

Hereafter the liquid mass transfer coefficient obtained from Eq. (3) have been compared with the measurement, calculated with Eq. (4). The physical data used for the equations above are summarized in Table 1.

$$V_d \frac{dC}{dt} = k_L A_d (C^* - C) \quad (4)$$

Which, V_d represent droplet volume (m^3), C is concentration of oxygen (mol/L), C* is concentration of oxygen at equilibrium with respect to partial pressure in gas (mol/L), A_d is droplet surface area (m^2), t is contact time (s) and k_L represents the mass transfer coeficient (m/s).

Table 1
Physical data properties

Data	Value and Unit
Diffusivity of O_2[a], D_o	2.16 x 10^{-9} m^2/s
Surface tension[b], σ	72.58 x 10^{-3} N/m
Density of Na_2SO_3[b], ρ	1007.2 kg/m^3
Absolute viscosity[b], μ	93.96 x 10^{-4} N.s/m^2

[a] in sodium sulphite concentration of 0.25mol/L
[b] sodium sulphite concentration of 0.1mol/L

III. RESULTS AND DISCUSSION

A. Droplet size and velocity of droplet

The droplet sizes are independent of the position, but slightly different for changing flowrates, because of pushing force caused by flowrate and the constant surface tension of the solution (Table 2). The droplet velocities are not the same at different positions due to gravitation force. This phenomenon occurs because of the difference in droplet weight.

Mass transfer coefficient

The absorption process is controlled by the liquid phase resistance because of the molecular diffusion coefficient of solutes are several orders of magnitude greater in gases than in liquids. The liquid phase mass

Table 2
Experimental data for different flowrates and droplet positions

Flowrate, [ml/min]		1			1.5			2	
Position, [cm]	10cm	15cm	20cm	10cm	15cm	20cm	10cm	15cm	20cm
Droplet Diameter,[m]	0.00352	0.00352	0.00352	0.00362	0.00362	0.00362	0.00368	0.00368	0.00368
Droplet Volume, [L]	2.28E-05	2.28E-05	2.28E-05	2.48E-05	2.48E-05	2.48E-05	2.61E-05	2.61E-05	2.61E-05
velocity, [m/s]	1.312	1.6369	1.879	1.312	1.6369	1.879	1.312	1.6369	1.879
Formation time, [s]	2.36	2.36	2.36	1.49	1.49	1.49	1.14	1.14	1.14
Falling time, [s]	0.142	0.174	0.201	0.142	0.174	0.201	0.142	0.174	0.201
Reynold	4951	6176	7090	5091	6352	7291	5176	6457	7412
Weber number	84	131	172	86	135	177	88	137	180
Schmidt number	431.89								
Ohnesorge number	0.0019	0.0019	0.0019	0.0018	0.0018	0.0018	0.0018	0.0018	0.0018
C* [mol/L]	0.000268								

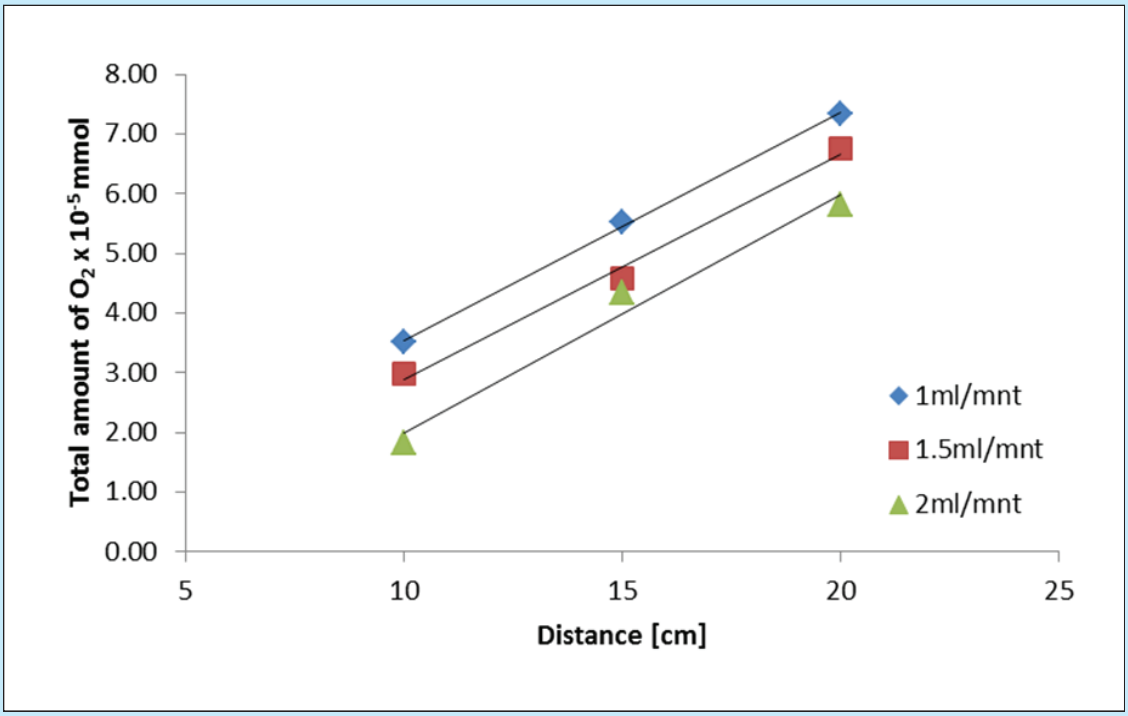


Figure 2
Amount of O_2 at formation and falling time.

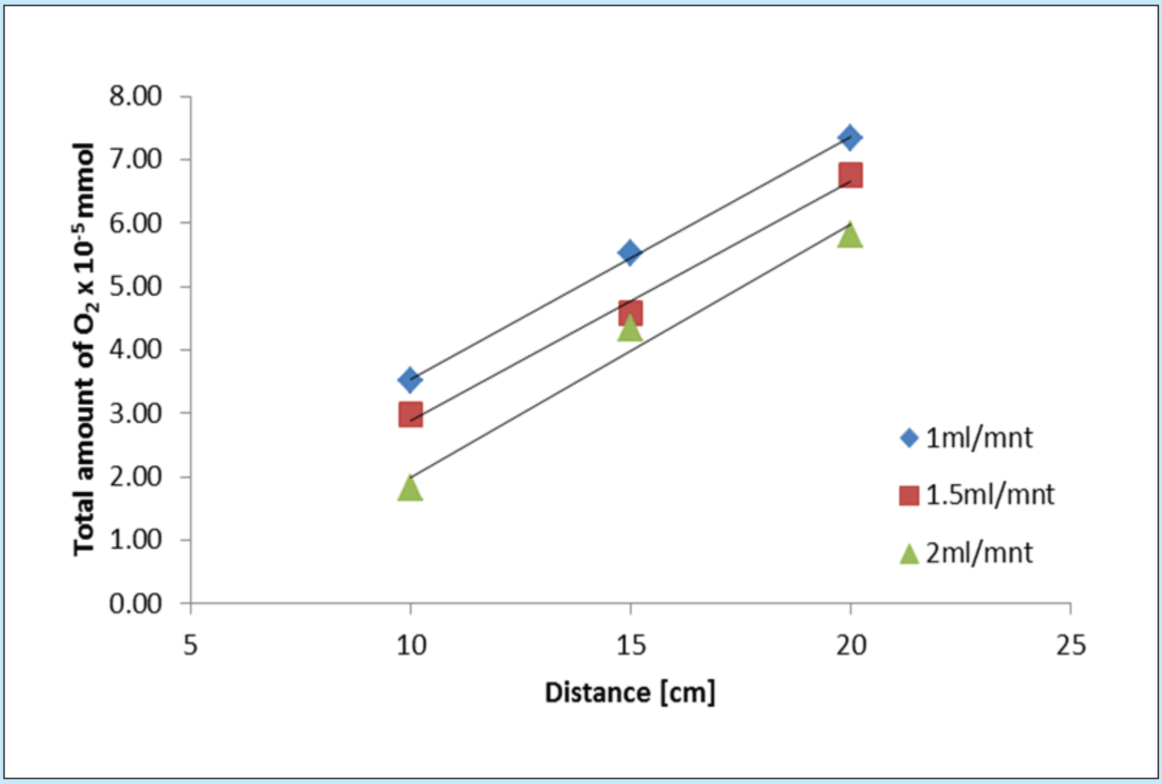


Figure 3
Comparison between mass transfer coefficient model and experiment.

transfer coefficient between liquid droplets and gas was derived based on the following assumption:

- The droplets are spherical during experiment.
- The droplet diameter and droplet formation time are constant during each experiment.

The experimental results are summarized in Figure 2 and 3.

In Figure 2, The amount of oxygen at formation and falling time increases as the length of falling increase and decreases as the flowrate of liquid come out from the needle increases. This phenomenon was happened because the sulphite droplet absorbed amount of oxygen increased as contact time regarding length of falling and the small droplet size has larger surface area than the bigger one in the same volume.

The experimental liquid mass transfer coefficients are 2 times lower than the model (Figure 3). It is assumed that reaction between oxygen and sulphite is low, and the total mass transfer is strongly influenced by the droplet formation. Experimental procedure and set-up has to be further improved to gain results that comply with the theory.

IV. CONCLUSIONS

The concentration of oxygen (at formation and falling time) increases as the length of falling increase and decreases. Improvement of the procedure and setting up of the experiment should be further improved to achieve results that meet with the theory, like adding a catalyst for enhancing the reaction, and like separately investigating the mass transfer during droplet formation and falling. The Molecular diffusion coefficient of solute in gas phase is higher in liquid phase and cause absorption process is controlled by the liquid phase resistance.

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