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Volumetric Mass Transfer Coefficient of SO_2 Gas Absorption into Aqueous Sodium Sulphite Solution in Plate Column

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Abstract

The volumetric mass transfer coefficient (K_G.a) for SO_2 removal from gas mixture into aqueous Na_2SO_3 solution was studied in a plate column at constant temperature (± 25 ℃), and liquid holdup. The K_G.a values were evaluated over ranges of operating independent variables: gas flow rate (Q_G), SO_2 concentration in inlet gas ($C_{SO2,\,in}$), and concentration of aqueous Na_2SO_3 solution (C_{Na2SO3}). The experimental results showed that K_G.a decreased with increasing of $C_{SO2,\,in}$, increased with increase of Q_G, and C_{Na2SO3}. The influence of gas flow rate on K_G.a is more than the influence of SO_2 concentration in inlet gas, and concentration of aqueous Na_2SO_3 solution respectively. Computer program Statgrhaphics/Experimental design was used to find the linear fitted models of the K_G.a in terms of the dimensional and dimensionless of independent operating variables. The Q_G, $C_{SO2,\,in}$, and C_{Na2SO3} have significant effects on K_G.a, while the interactions of them have no significant effects on it, and could be neglected. The R-squared statistic indicates that the model as fitted explains 90.4949% of the variability in K_G.a.

Keywords: Plate column, SO_2 absorption, Na_2SO_3 solution, K_G.a

Nomenclature:

$C_{SO2,\,in}$ = SO_2 concentration in inlet gas v/v %

$C_{SO2,\,out}$ = SO_2 concentration in outlet gas v/v %

C_{Na2SO3} = concentration of Na2SO3 aqueous solution mol/l

K_G.a = volumetric mass transfer coefficient s^{-1}

Q_G = gas flow rate m^3/s

V_L = liquid holdup in plate column m^3

Subscripts:

G = gas mixture

L = liquid

Na_2SO_3 = aqueous sodium sulphite solution

SO_2, in = sulphur dioxide inlet gas

SO_2, out = sulphur dioxide outlet gas

1. Introduction

Flue gas desulfurization (FGD) is presently receiving much attention in many countries. Removal of sulphur dioxide gas from flue gas is very important in the controlling of atmospheric pollution. The wide spread processes used for this purpose are the wet process absorption where the flue gas absorbed in lime slurries, the additives sometimes are used with slurries to increase the absorption rate, and dry process absorption when limestone and lime injected into the hot flue gas. These processes, besides being non regenerative, create the problem of disposal of large quantities of waste (Dutta, Basu, Pandit, & Ray, 1987; Duric, Omerovic, Brankov, Dzaferovic, & Stanojevic, 2011). Several regenerable processes of sulphur dioxide removal involving absorption into aqueous sodium citrate solution (Erga, 1980; Skribic, Cvejanov, & Paunovic, 1991) which have been received most attention in recent times due to regenerative viability of absorbent solution (Bravo, Camacho, Moya, & Aguado, 1993). Process developed by several investigators and has been used for various scales and even in commercial scale.The leading SO_2 recovery process is presently the Wellman-Lord (WL) process shall here be used in this study (Erga, 1988). In the WL process SO_2 is absorbed in an aqueous sodium sulphite solution producing sodium bisulphate:

$$SO_2 + SO_2^{-2} + H_2O \leftrightarrow 2\ HSO_3^- \quad (1)$$

The SO_2 is a very toxic gas, has hard effects on the health and environment. The current OSHA standard for SO_2 is (5 ppm.) of air average over an eight-hour work shift. Several investigators studied absorption into different absorbents such as: aqueous reactive slurries of calcium and magnesium hydroxide (Sada, Kumazawa, Sawada, & Hashi-Zume, 1981; Dagaonkar, Beenackers, & Pangarkar, 2001), aqueous sodium hydroxide and sodium sulphite solution (Hikita, Asal, & Tsuji, 1977), aqueous solution of sodium carbonate (Witte & Kind, 1986), Urea solution (Barbooti, Ibraheem, & Ankosh, 2011), and aqueous sodium citrate solution (Skribic, Cvejaanov, & Paunovic, 1993).

The aim of present work to estimate the volumetric mass transfer coefficient ($K_G.a$) of SO_2 gas into aqueous sodium sulphite solution using the following equation:

$$K_G.a = \frac{Q_G}{V_L} \ln\frac{C_{SO_{2,in}}}{C_{SO_{2,out}}} \quad (2)$$

2. Experimental

Experiments were performed on absorption of SO_2 from SO_2/N_2 gas mixture into aqueous sodium sulphite solution, at constant liquid holdup, and temperature ($\pm$ 25 ℃) in plate column, according to experimental plan as shown in Table 1.

Table 1. Experimental plan for SO_2 gas absorption into aqueous Na_2SO_3 solution in plate column

Experiment No.	Gas flow Rate (Q_G)	concentration of aqueous Na_2SO_3 solution (C_{Na2SO3})	SO_2 concentration in inlet gas mixture ($C_{SO2,\ in}$)
	(m^3/s)	(mol/l)	(v/v %)
1	0.0025	0.5	0.15
2	0.0025	1.5	0.15
3	0.0015	1.5	0.15
4	0.0015	0.5	0.15
5	0.0015	1.5	0.55
6	0.0015	0.5	0.55
7	0.0020	1.0	0.35
8	0.0025	1.5	0.55
9	0.0020	1.0	0.35
10	0.0025	0.5	0.55
11	0.0020	1.0	0.35

The equipments used in present work are shown in Figure 1. The main equipment is plate column (1), and complementary equipments are as follows:

N_2-gas cylinder (2), SO_2-gas cylinder (3), Mixing chamber (4), SO_2-gas rotameter (5), N_2-gas rotameter (6), condenser (7), SO_2-gas analyzer (8), Evaporator (9), mixing tank for preparing Na_2SO_3 solution (10), and Na_2SO_3 solution feed pump (11).

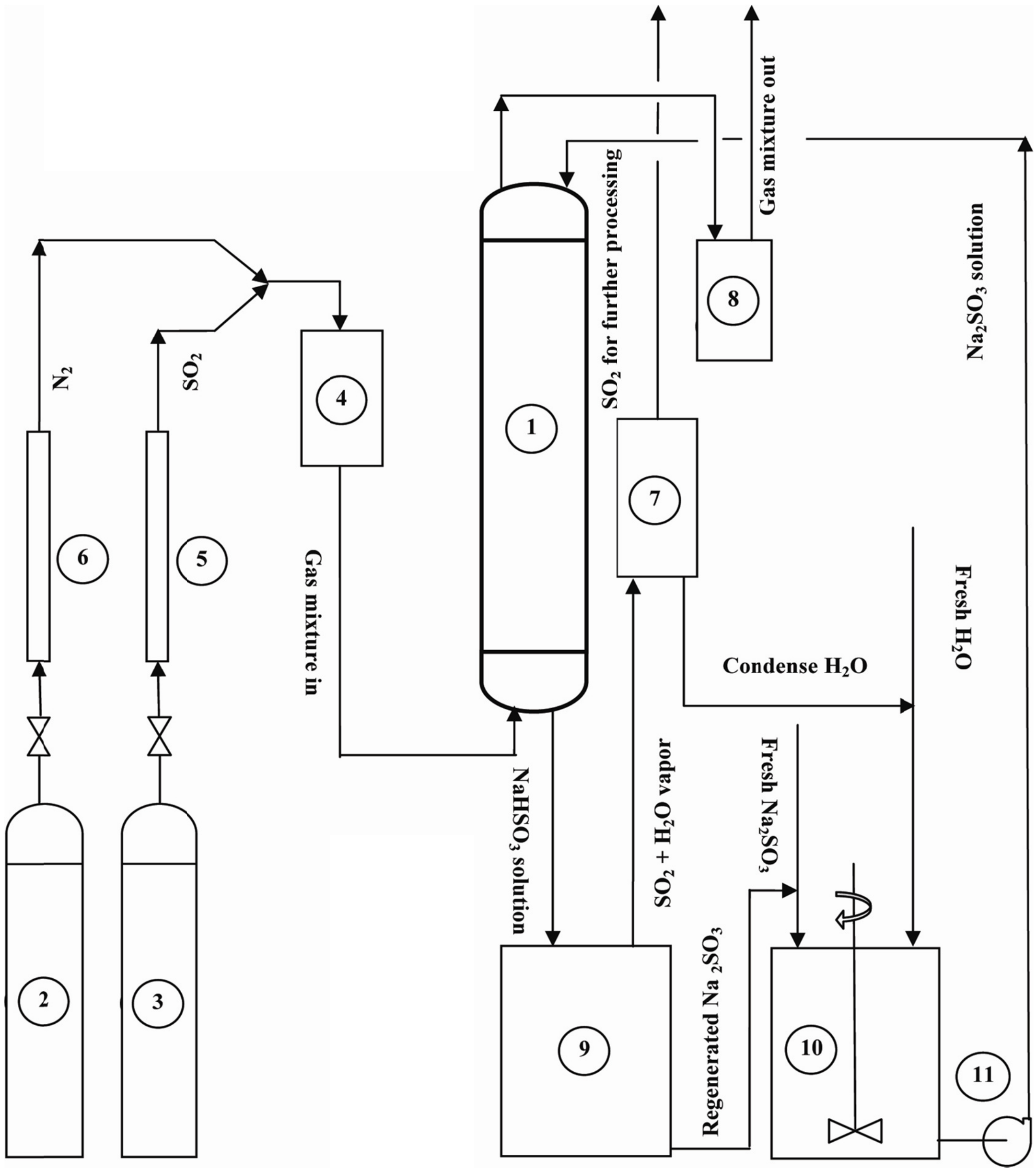

Figure 1. Experimental apparatus of SO_2 absorption into Na_2SO_3 aqueous solution in plate column

During the normal operation, the main reaction takes place in plate column (1) of 150 mm inside diameter, and 1000 mm height. The gas mixture enter the column from lower part while, the aqueous sodium sulphite solution enter the upper part of the column. The sulphur dioxide from gas mixture absorbed into aqueous sodium sulphite solution, producing sodium bisulphate solution, which discharge from downer part of the plate column into evaporator (9). The loaded aqueous solution is thermally regenerated by evaporation of $H_2O + SO_2$, thereby reversing reaction (1). After condensing the water vapor, nearly pure gaseous SO_2 is left as an overhead product, ready for further processing. Solid Na_2SO_3 which precipitates in the evaporator is redissolved in condensate/water in the mixing tank (10), to proper concentration for a new absorption-regeneration cycle.

3. Results and Discussion

The estimated values of volumetric mass transfer coefficients ($K_G.a$) and the experimental design plan are shown in Table 2.

Table 2. Data base for experimental design and results of $K_G.a$ for SO_2 gas absorption into aqueous Na_2SO_3 solution in plate column

Experiment No.	Gas flow Rate (Q_G)		Concentration of aqueous Na_2SO_3 solution (C_{Na2SO3})		SO_2 concentration in inlet gas mixture ($C_{SO2, in}$)		Volumetric mass transfer coefficient ($K_G.a$)
	(m^3/s)		(mol/l)		(v/v %)		(s^{-1})
1	+	0.0025	-	0.5	-	0.15	2.715
2	+	0.0025	+	1.5	-	0.15	3.581
3	-	0.0015	-	1.5	-	0.15	2.149
4	-	0.0015	-	0.5	-	0.15	2.062
5	-	0.0015	+	1.5	+	0.55	1.963
6	-	0.0015	-	0.5	+	0.55	1.491
7	0	0.0020	0	1.0	0	0.35	2.424
8	+	0.0025	+	1.5	+	0.55	2.609
9	0	0.0020	0	1.0	0	0.35	2.273
10	+	0.0025	-	0.5	+	0.55	2.029
11	0	0.0020	0	1.0	0	0.35	2.323

By using computer program (Statgraphics/experimental design) to find the linear model of $K_G.a$ in terms of independent variables: gas flow rate (Q_G), SO_2 concentration in inlet gas mixture ($C_{SO2, in}$), and concentration of aqueous Na_2SO_3 solution (C_{Na2SO3}). The fitted model with dimensional independent variables as follows:

$$K_G.a = 0.722 + 817.250\ Q_G - 1.509\ C_{SO2,\ in} + 0.501\ C_{Na2SO3} \quad (3)$$

The fitted model with dimensionless independent variables is presented in the following form:

$$K_G.a = 2.329 + 0.409\ Q_G - 0.302\ C_{SO2,\ in} + 0.251\ C_{Na2SO3} \quad (4)$$

The validity of the linear models is as follows:

Model in Equation (3)	Model in Equation (4)
$0.0015 \le Q_G \ge 0.0025$ m^3/s	$-1 \le Q_G \ge +1$
$0.15 \le C_{SO2,\ in} \ge 0.55$ v/v %	$-1 \le C_{SO2,\ in} \ge +1$
$0.5 \le C_{Na2SO3} \ge 1.5$ mol/l	$-1 \le C_{Na2SO3} \ge +1$

The independent variables: gas flow rate, SO_2 concentration in inlet gas mixture, and concentration of aqueous Na_2SO_3 solution have significant effects on volumetric mass transfer coefficient ($K_G.a$), while the interaction of independent variables have no significant effects on $K_G.a$, and could be neglected. The influence of gas flow rate on $K_G.a$ is higher than that of SO_2 concentration in inlet gas mixture, and concentration of aqueous Na_2SO_3 solution as shown in following Figure 2:

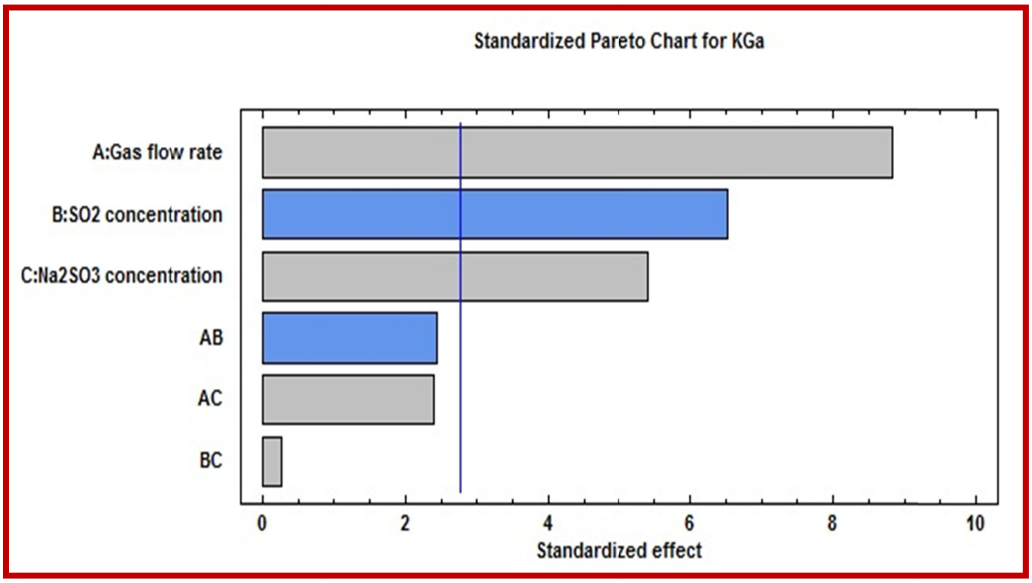

Figure 2. The standard effect of the independent variables on volumetric mass transfer coefficient (K_G.a)

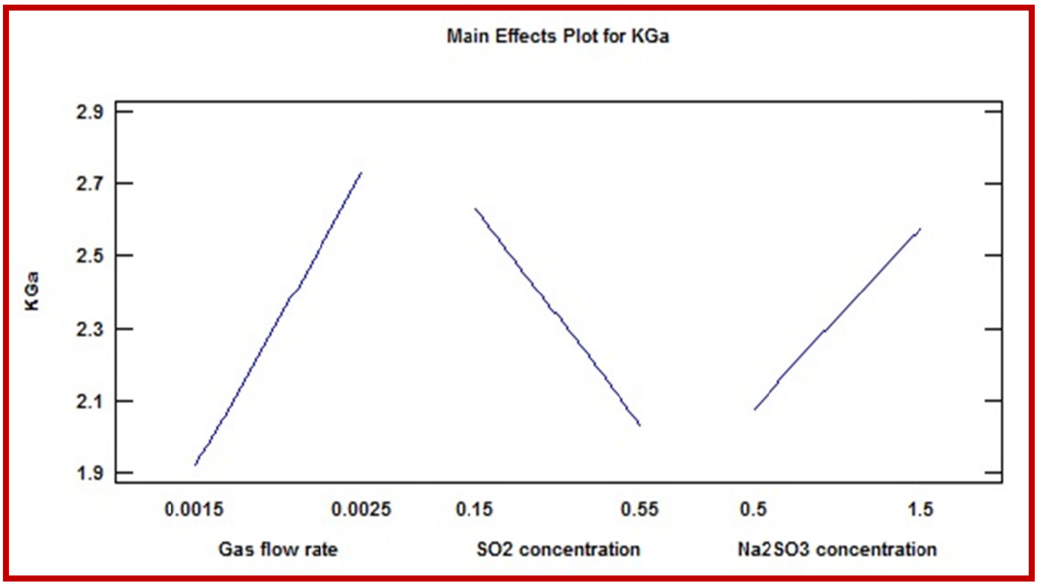

Figure 3. The main effects of independent variables on K_G.a for dimensional model in Equation (3)

The main effect of independent variables: gas flow rate, SO_2 concentration in inlet gas mixture, and concentration of aqueous Na_2SO_3 solution on K_G.a could be seen in Figure 3 and Figure 4, for dimensional and dimensionless models respectively. The K_G.a decreased by increasing in SO_2 concentration in inlet gas mixture, increased with increasing gas flow rate, and concentration of aqueous Na_2SO_3 solution.

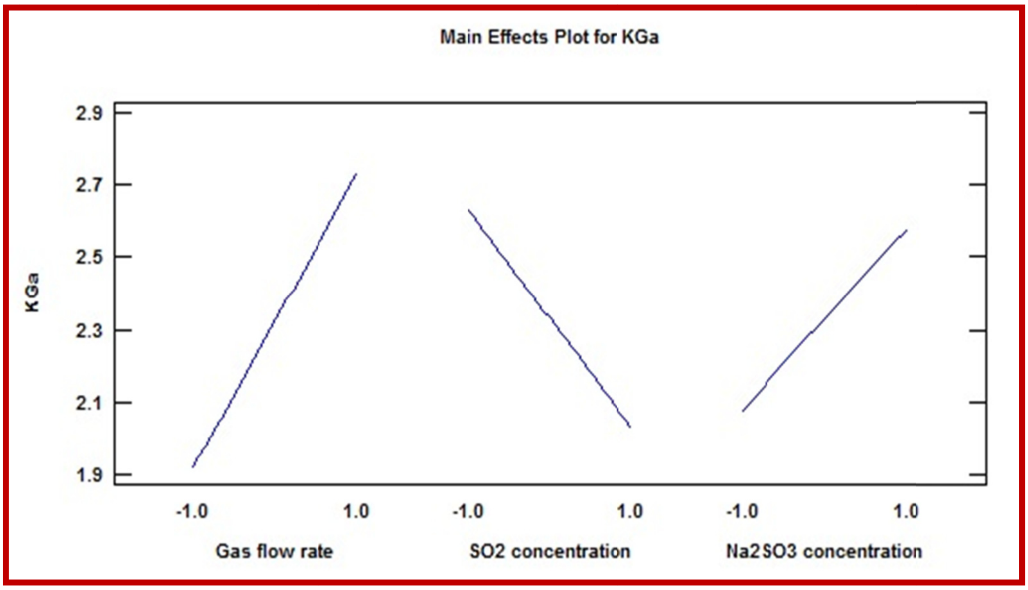

Figure 4. The main effects of independent variables on K_G.a for dimensionless model in equation (4)

The observed and predicted K_G.a from dimensional and dimensionless models in Equations (3) and (4) are shown in Figure 5. The R-Squared statistic indicates that the models as fitted explains 90.4949% of the variability in K_Ga. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 86.4212%. The standard error of the estimate shows the standard deviation of the residuals to be 0.19627.

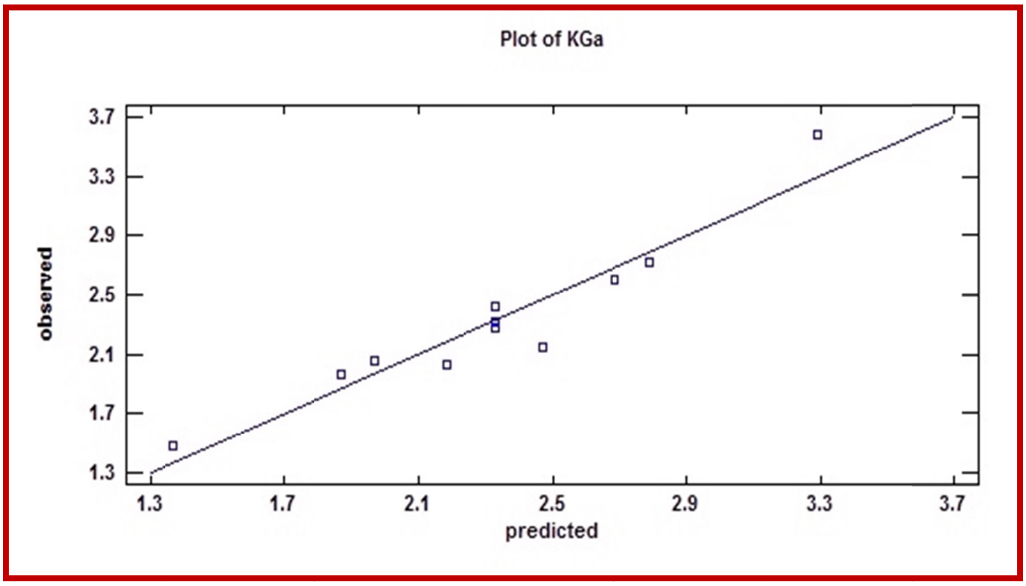

Figure 5. The observed and predicted K_G.a from dimensional and dimensionless models in Equations (3) and (4)

Figure 6. Represents the 3 D surface plot of volumetric mass transfer coefficient (K_G.a) of SO_2 absorption into aqueous Na_2SO_3 solution, Gas flow rate (Q_G), and concentration of aqueous Na_2SO_3 solution (C_{Na2SO3}). K_G.a increases with increasing in $Q_{G,}$ and C_{Na2SO3}.

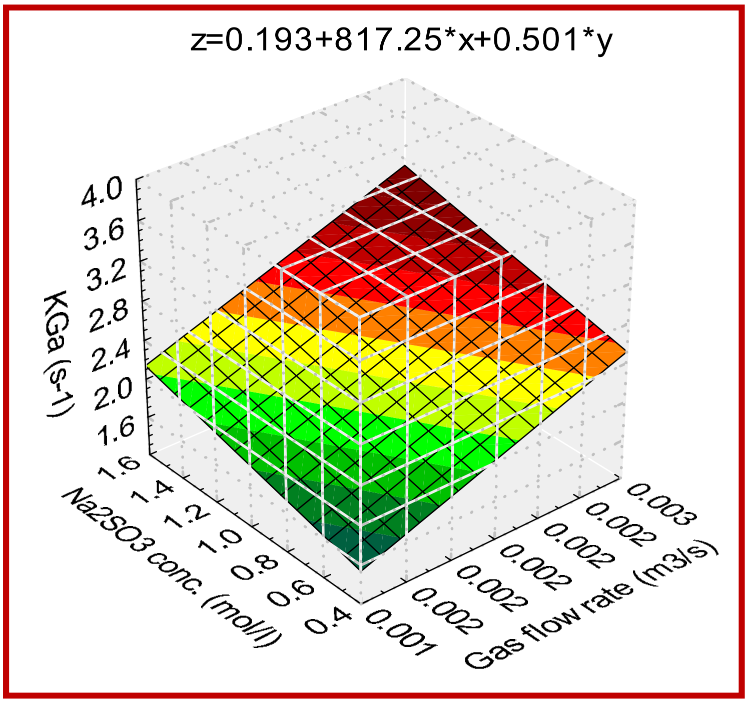

Figure 6. Variation of K_G.a for SO_2 absorption with gas flow rate (Q_G), and concentration of aqueous Na_2SO_3 solution (C_{Na2SO3})

The relationship between K_G.a for SO_2 gas absorption into aqueous Na_2SO_3 solution and independent variables: gas flow rate (Q_G), and SO_2 concentration in inlet gas mixture ($C_{SO2,\ in}$) could be seen at Figure 7. The K_G.a increases with increasing in Q_G, and decreases with increasing of $C_{SO2,\ in}$.

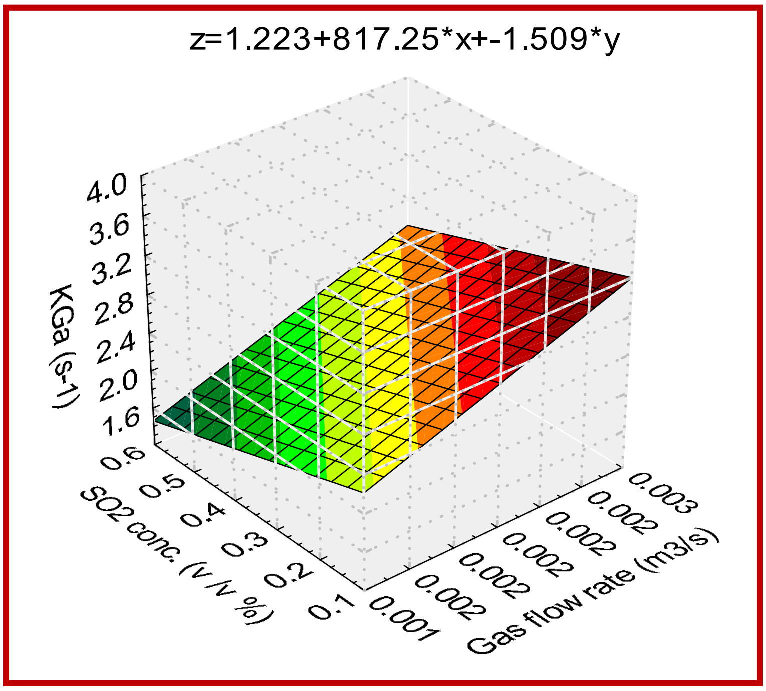

Figure 7. Variation of K_G.a with SO_2 concentration in inlet gas mixture ($C_{SO2,\ in}$) and gas flow rate (Q_G)

The volumetric mass transfer coefficient (K_G.a) increases with increasing of concentration of aqueous Na_2SO_3 solution (C_{Na2SO3}), and decreasing with increasing the SO_2 concentration in gas mixture ($C_{SO2, in}$) as shown in the following Figure 8.

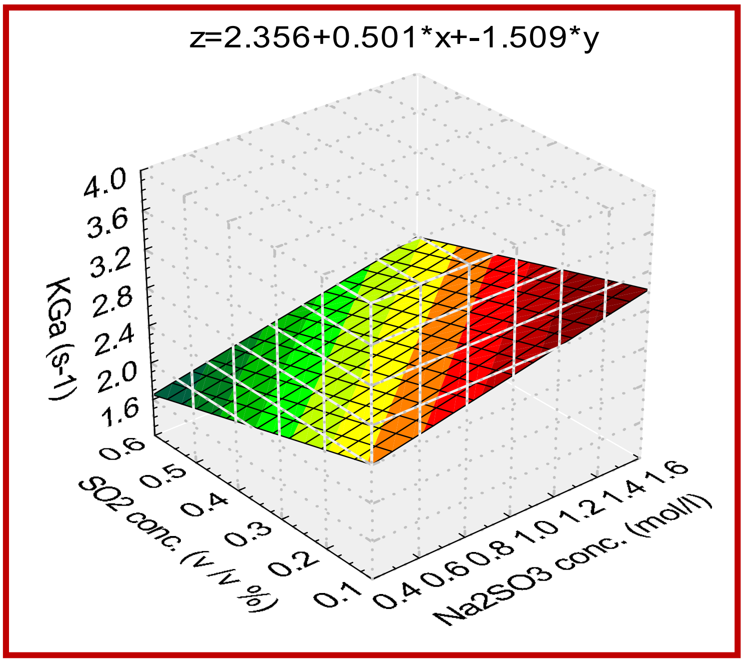

Figure 8. Variation of K_G.a of SO_2 absorption with C_{Na2SO3} and SO_2 concentration of inlet gas mixture ($C_{SO2, in}$)

The K_G.a for SO_2 gas removal from flue gas into aqueous Na_2SO_3 solution was investigated in packed column with various operating conditions of independent variables (Wang, Yang, & Zhang, 2010). The K_G.a values for SO_2 in flue gas of coal fired power plant were measured and calculated by aqueous ammonia in packed column as well (Qiu, Zhang, Guo, Li, Zheng, & Gong, 2010). The measured results of both investigators showed that the independent variables: gas flow rate, SO_2 concentration in flue gas, and absorbents concentrations have significant effects on K_G.a of SO_2 absorption. These results are practically similar to the present results showing significant effects of independent variables on K_G.a of SO_2 gas removal by different of aqueous solutions.

4. Conclusions

- Absorption of SO_2 gas from gas mixture (SO_2/N_2) into aqueous Na_2SO_3 solution were performed using different operating conditions of independent variables: gas flow rate, SO_2 concentration in inlet gas mixture, and concentration of aqueous Na_2SO_3 solution.
- The K_G.a of SO_2 gas absorption into aqueous Na_2SO_3 solution was calculated. The results showed that K_G.a increases with increasing gas flow rate and concentration of aqueous Na_2SO_3 solution, and by decreases with increasing in the SO_2 concentration in inlet gas mixture.
- Using computer program (Statgraphics/Experimental design) to find the fitted linear models for dimensional and dimensionless of independent variables: Q_G, C_{Na2SO3}, and C_{SO2}, in. The two fitted models for Ka.a reveal that Q_G, C_{Na2SO3}, and C_{SO2},in have significant effects on KG.a, while the interaction of them have no significant effects on it, and could be ignored as shown in Figure 2.
- The R-squared statistic indicates that the models as fitted explains 90.4949% of the variability in K_G.a. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 86.4212%. The standard error of the estimate shows the standard deviation of the residuals to be 0.19627.
- The K_G.a of SO_2 absorption could be improved by increasing of gas flow rate, and concentration of aqueous Na_2SO_3 solution, and by decreasing the SO_2 concentration in inlet gas mixture.
- Pilot plant designed based on the results of present work, and erected at sulphuric acid production factory in Baghdad to reduce the emission of SO_2 to atmosphere for preventing the air pollution.

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