Mass Transfer Performance and Correlations for CO_2 Absorption into Aqueous Blended of DEEA/MEA in a Random Packed Column

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About iCCS in Hunan University, China

Current Members : 40

- 7 Professors
- 1 Engineer
- 2 Post-doctors
- 30 Current Graduates

Research Interests:

- Solvents for CO_2 Capture
- Kinetics & Mass Transfer
- Process Development
- CO_2 Capture Pilot Test
- CO_2 Utilization

Aqueous Amine CO_2 Capture at iCCS

- **Amine screening &Thermodynamics**
- **Kinetics&Mass transfer**
- **Membrane & Packing Contactor**
- **Degradation & Corrosion**
- **Heat Cost of Amine Regeneration**
- **Process Simulation & Pilot Test**

Other Research Topics at iCCS

- Solid Adsorption CO_2 Capture
- Oxy-fuel Process CO_2 Capture
- CO_2 Physical & Chemical Utilization

CCUS R & D Projects at iCCS HNU China

- **National Science and Technology Support Plan (MOST of China. 2012BAC26B01) RMB 48.8M**
- **National Natural Science Foundation of China (NSFC. 21376067, U1362112, 21536003) RMB 7.2M**
- **The Innovative Research Team Development Plan-(MOE of China. IRT1238) RMB 3.0M**
- **Shaanxi Yanchang Petroleum Co.,LTD Technology Development, RMB 3.0M**
- **National 1000-Talent plan and 985-subject through Hunan University RMB 8.8M**
- **……..**

Published Journal Papers

98 Papers（2011-2017）

Published Journal	No.
AIChE Journal	7
Chem. Eng. Sci.	8
Ind. Eng. Chem. Res.	9
Int. J. Greenh. Gas. Cont.	12
Applied E., Fuel, E. &Fuel, S&P.Tech., CEJ, JMS, C*ET, CanJChE., ...*	62

Outline of this work

1. Background

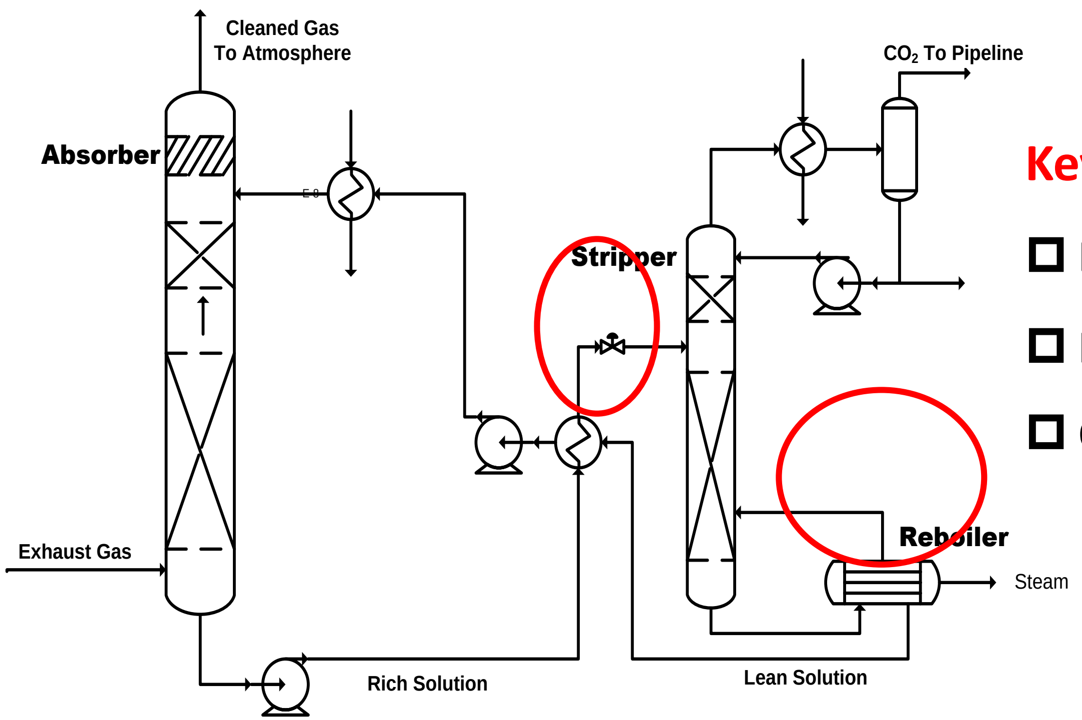
2. Experimental section

3. Results and discussion

4. Conclusions

5. Acknowledgement

Traditional absorption-stripping process



Key Strategies:

- ☐ Development of efficient absorbent
- ☐ Improvement of contactor
- ☐ Optimization of process configuration

1.Background

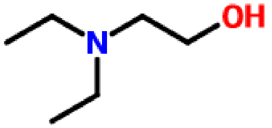
- Conflict between good CO_2 absorption and regeneration performance

The application of blended amines can combine the advantage of each amine

Primary amines: MEA

Advantages: High CO_2 absorption rate, low price of solvent

Tertiary amines: DEEA



Advantages: Low energy requirement, high resistance for degradation and corrosion; can be prepared from renewable and cheap resources (such as ethylene and ethanol)

DEEA/MEA-CO_2 (3 M 1:1)

Shown excellent CO_2 absorption/regeneration performance and cyclic capacities (Luo et al. *Sep. Purif. Technol.* 2016, 169:279-288)

Theories

Reaction mechanism for blended CO_2-DEEA-MEA system

$$DEEA + H^+ \xleftrightarrow{K_1} DEEAH^+$$

$$CO_2 + DEEA + H_2O \xleftrightarrow{K_2 k_{2,MDEA} k_{-2,MDEA}} DEEAH^+ + HCO_3^-$$

$$MEA + H^+ \xleftrightarrow{K_3} MEAH^+$$

$$CO_2 + MEA \xleftrightarrow{K_4 k_{2,MEA} k_{-2,MEA}} MEACOO^- + H^+$$

$$MEACOO^- + H_2O \xleftrightarrow{K_5} MEA + HCO_3^-$$

$$CO_2 + H_2O \xleftrightarrow{K_6} HCO_3^- + H^+$$

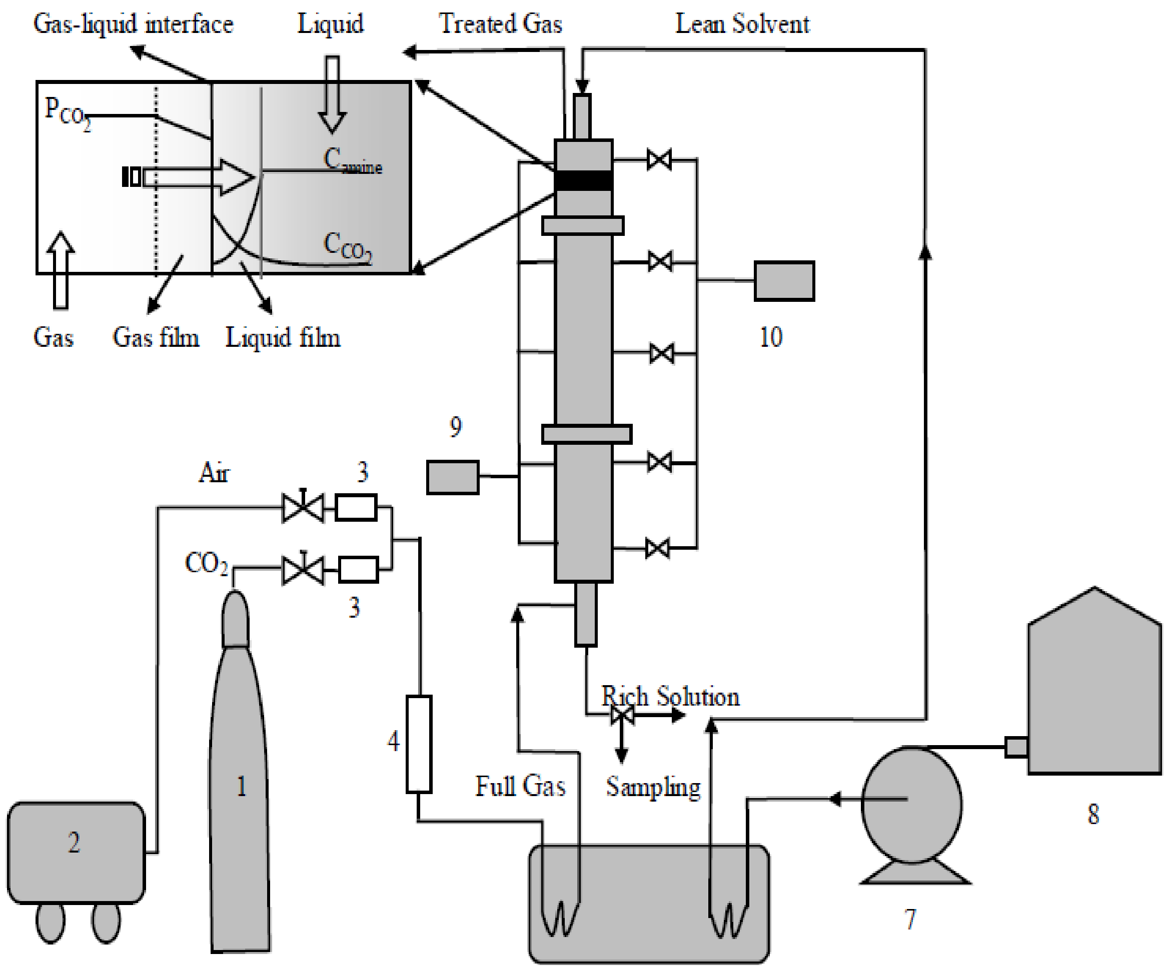
$$CO_2 + OH^- \xleftrightarrow{K_7 k_{27} k_{-2,7}} HCO_3^-$$

$$HCO_3^- \xleftrightarrow{K_8} CO_3^{2-} + H^+$$

$$H_2O \xleftrightarrow{K_9} OH^- + H^+$$

Objectives: to know the Mass Transfer Performance

2.Experimental section



Schematic diagram of absorption experimental process

2.Experimental section

Determination of the mass transfer coefficient $K_G a_v$

Based on the two-film theory, material balance, and mass flux equation

$$N_A a_V = K_G a_V (P_A - P_{A*}) = K_G a_V P(y_{A,G} - y_A^*)$$

$$N_A a_V dh = G_1 dY_A$$

$$\Rightarrow \quad K_G a_v = \frac{G}{P\left(y_{A,G} - y_A^*\right)} \frac{dY_A}{dz} \quad \Rightarrow \quad K_G a_v = \frac{G}{P y_{A,G}} \frac{dY_A}{dz}$$

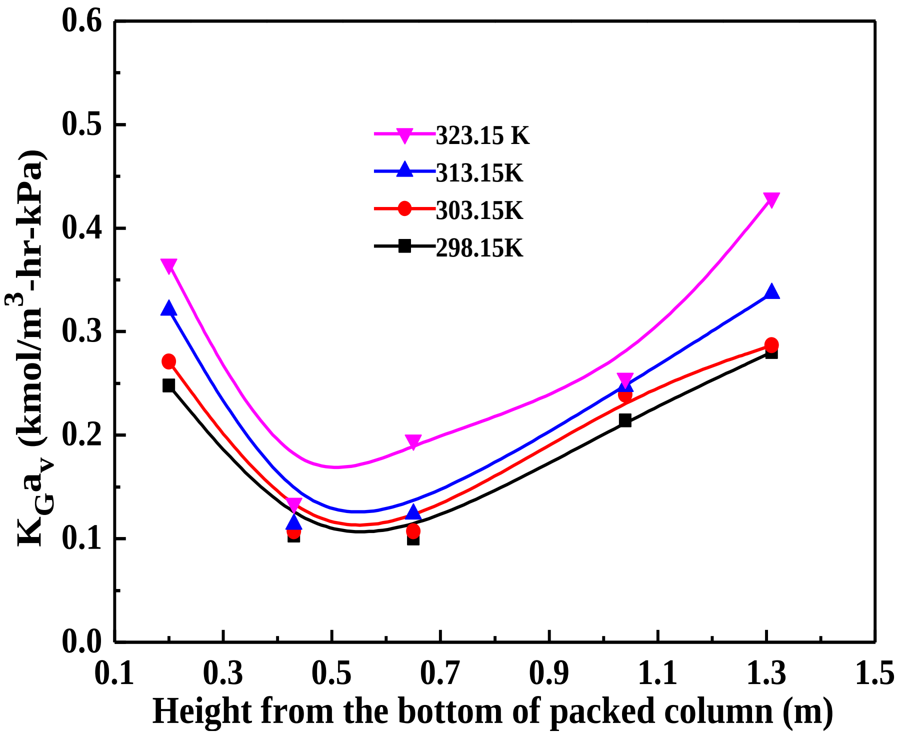
Determination of unit volume absorption rate Φ

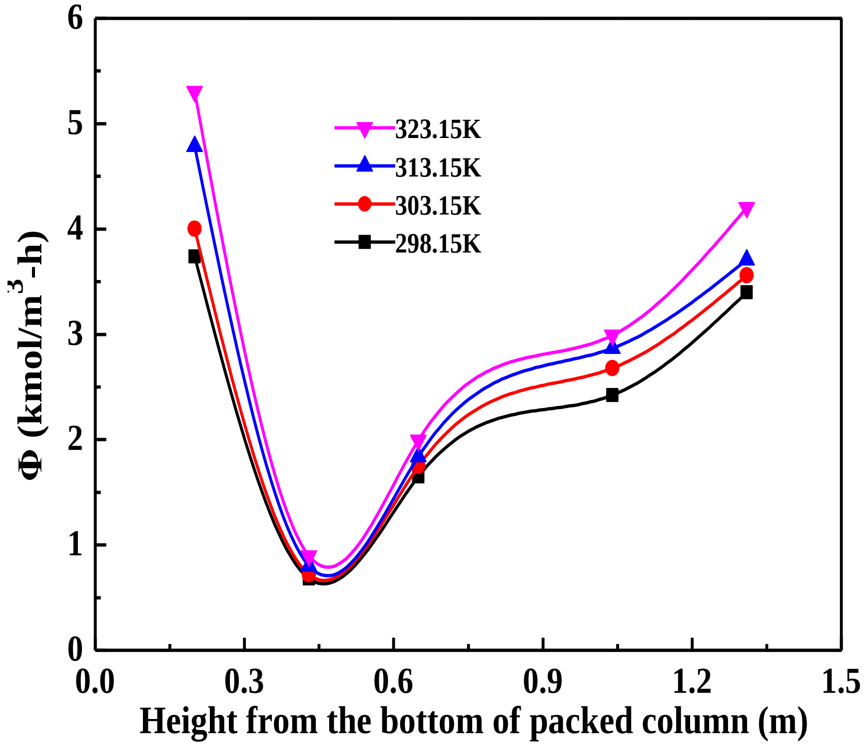
(1) $$\phi = K_G a_v P_{CO_2} \qquad P_{CO_2} = \frac{P_{CO_2,in} - P_{CO_2,out}}{\ln\left(P_{CO_2,in} / P_{CO_2,out}\right)}$$

(2) $$\phi = \frac{G_1 \Omega \left(Y_1 - Y_2\right)}{V_r}$$

3.Results and discussion

Effect of liquid feed temperature on K_Ga_v and Φ

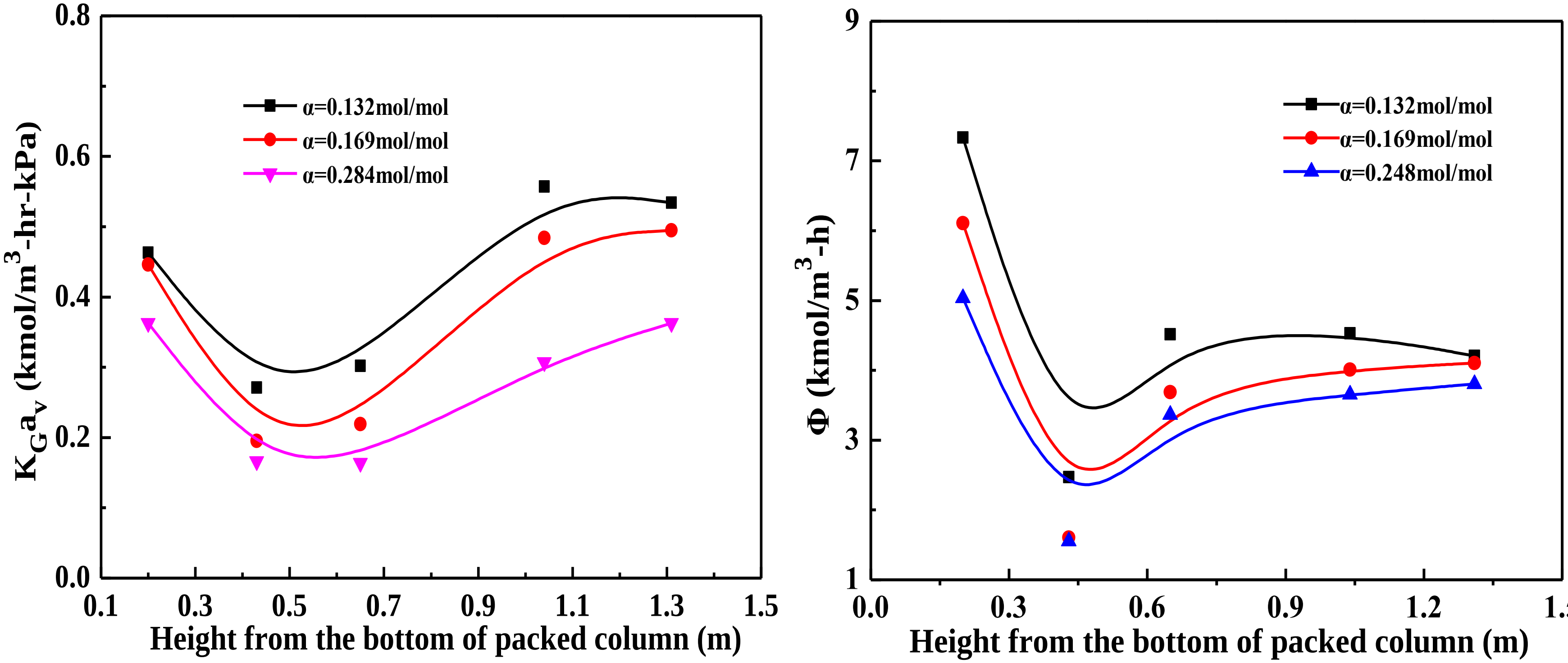




(solvent concentration 3 kmol/m^3; liquid flow rate 5.85 m^3/m^2-hr; CO_2 loading 0.32 mol/mol; inert gas flow rate 39.17 kmol/m^2-hr; CO_2 partial pressure 15 kPa)

3.Results and discussion

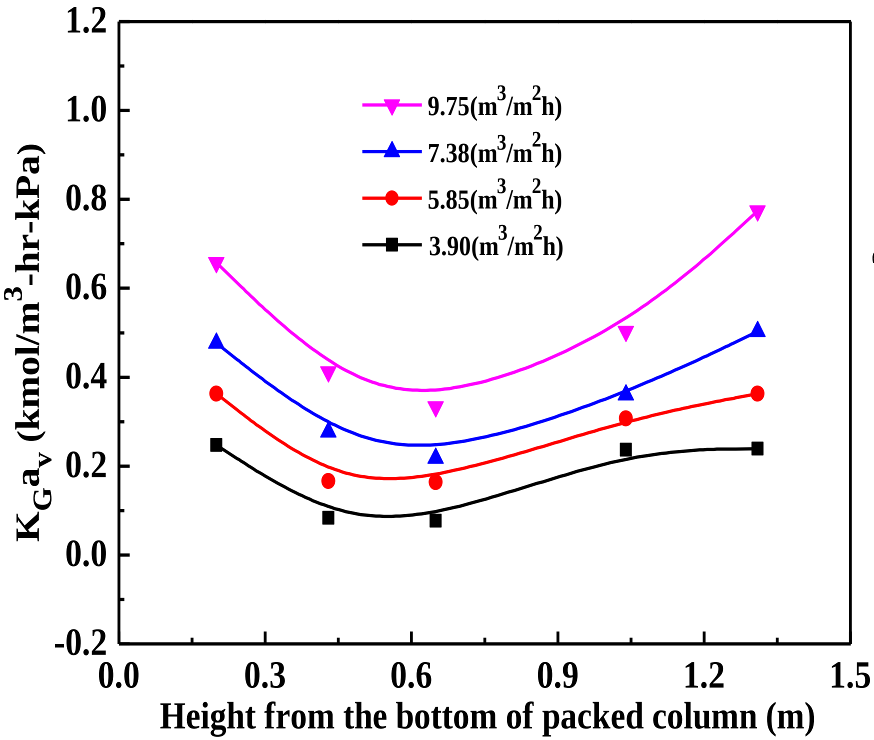
Effect of lean CO_2 loading on $K_G a_v$ and Φ

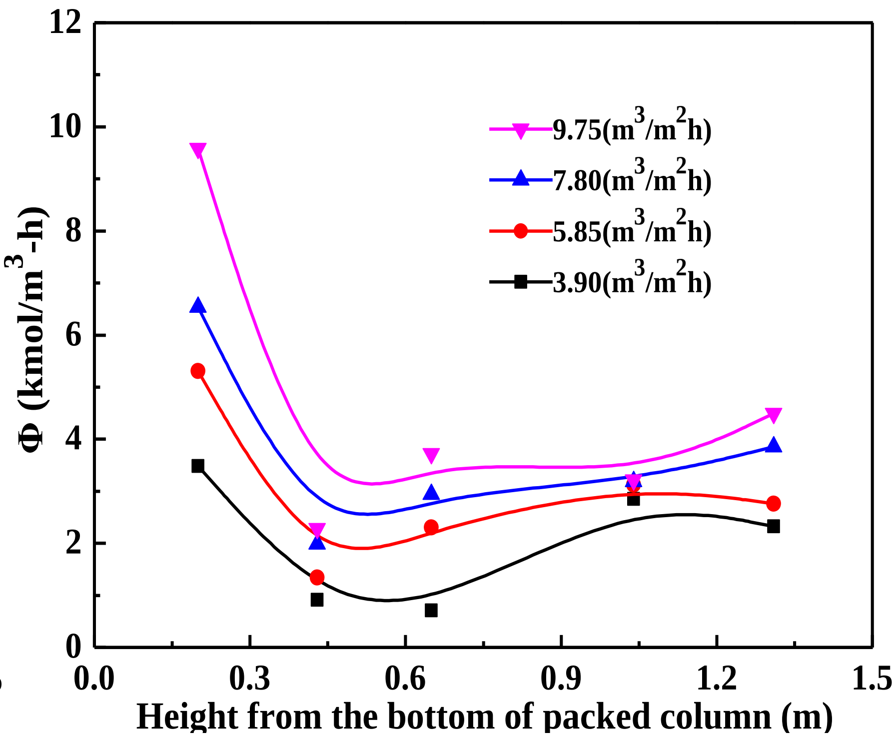


(solvent concentration 3 kmol/m³; liquid flow rate 5.85 m³/m²-hr;inert gas flow rate 39.17 kmol/m²-hr; CO_2 partial pressure 15 kPa, liquid feed temperature 313.13 K)

3.Results and discussion

Effect of liquid flow rate on K_Ga_v and Φ



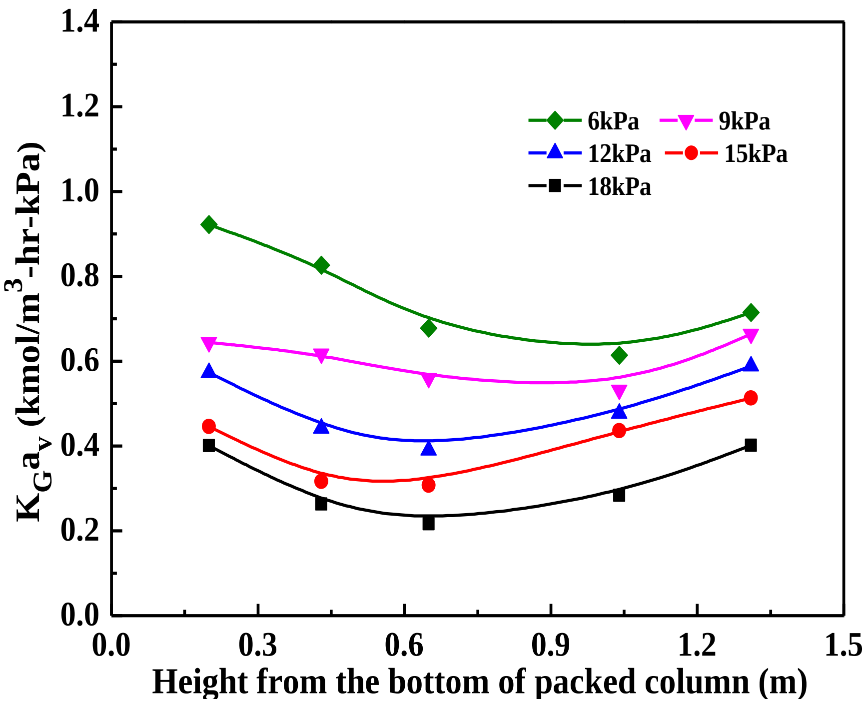


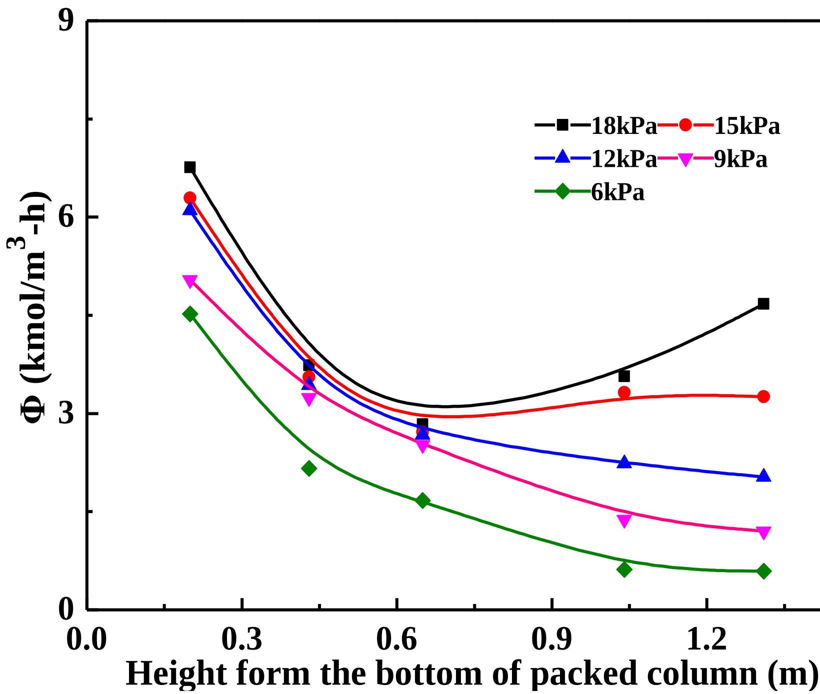
(solvent concentration 3 kmol/m^3; inert gas flow rate 39.17 kmol/m^2-hr;

CO_2 partial pressure 15 kPa, liquid feed temperature 313.13 K)

3.Results and discussion

Effect of CO_2 partial pressure on K_Ga_v and Φ

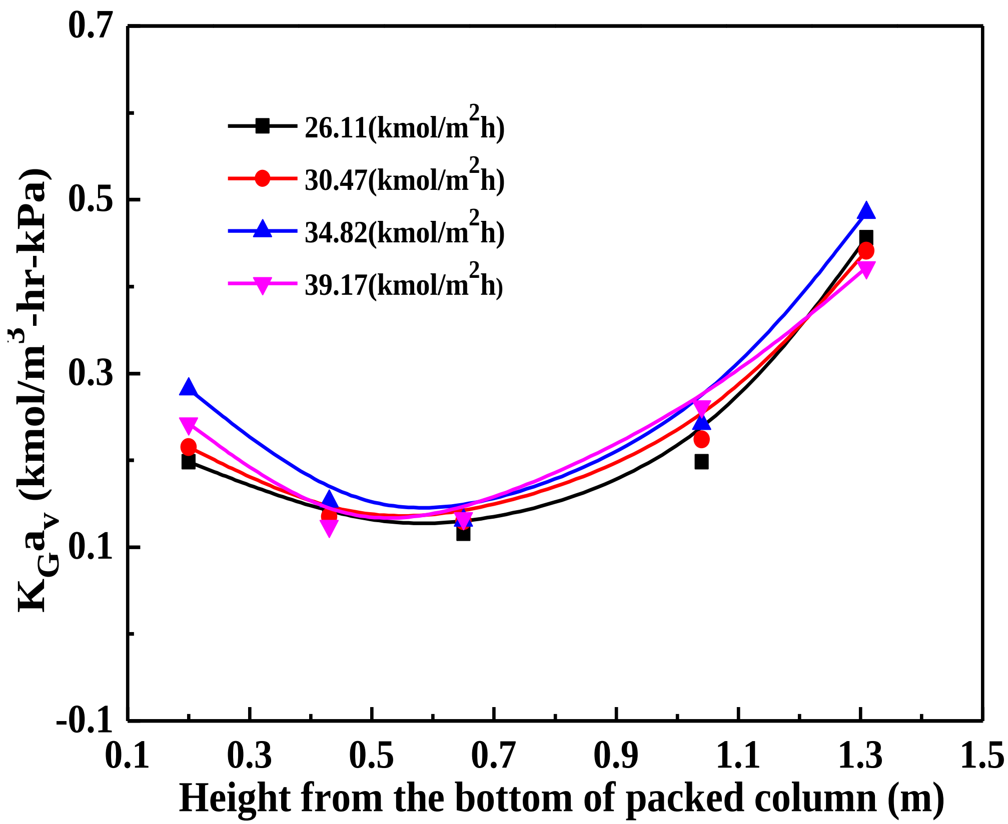




(solvent concentration 3 kmol/m^3; lean CO_2 loading 0.18 mol/mol; inert gas flow rate 39.17 kmol/m^2-hr; liquid flow rate5.85 m^3/m^2-hr; liquid feed temperature 313.13 K)

3.Results and discussion

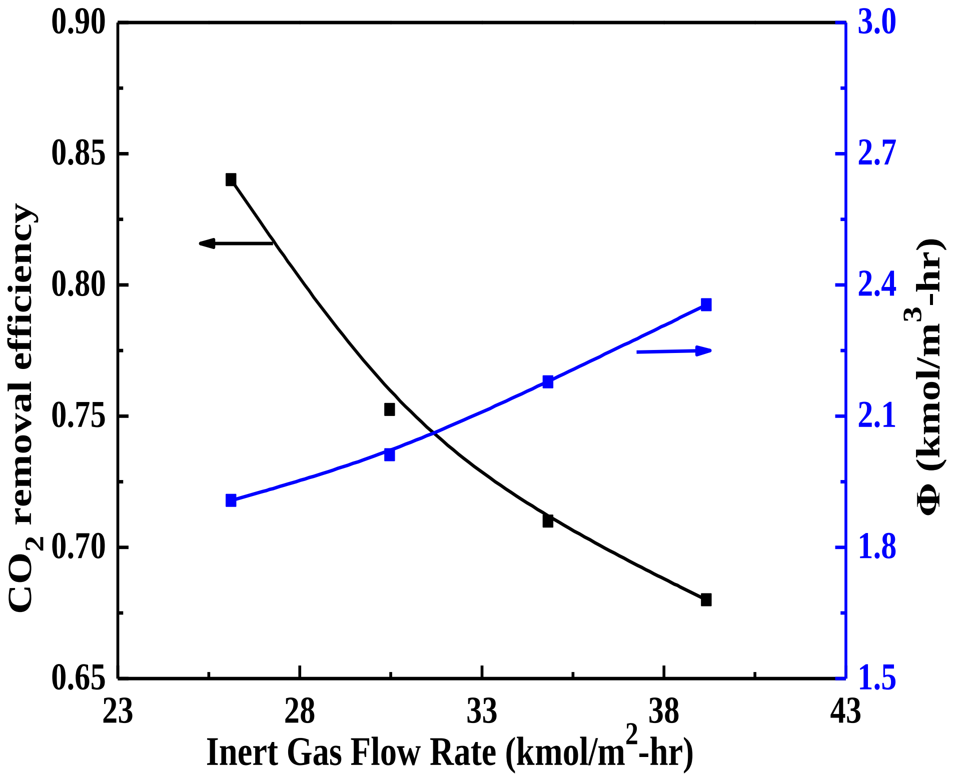
Effect of inert gas flow rate on K_Ga_v



(solvent concentration 3 kmol/m^3; lean CO_2 loading 0.22 mol/mol; liquid flow rate 5.85 m^3/m^2-hr; CO_2 partial pressure 15 kPa; liquid feed temperature 313.13 K)

3.Results and discussion

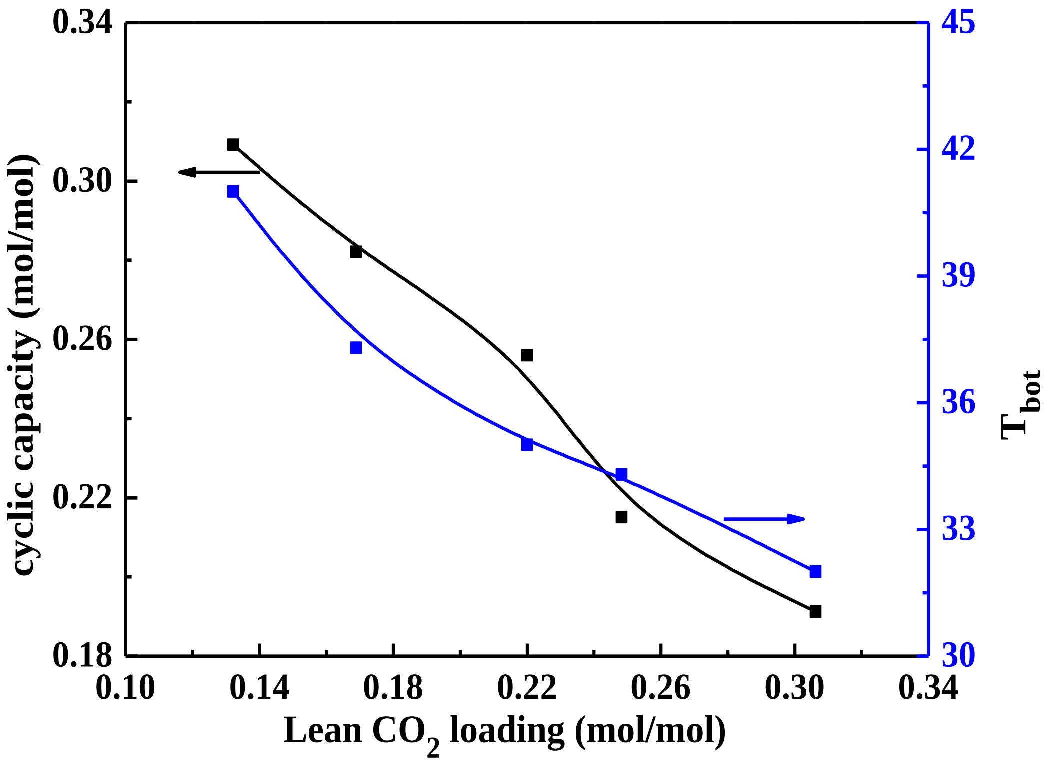
Effect of inert gas flow rate



(solvent concentration 3kmol/m^3; lean CO_2 loading 0.28mol/mol; liquid flow rate 5.85m^3/m^2-hr; CO_2 partial pressure 10kPa; liquid feed temperature 313.13K)

3.Results and discussion

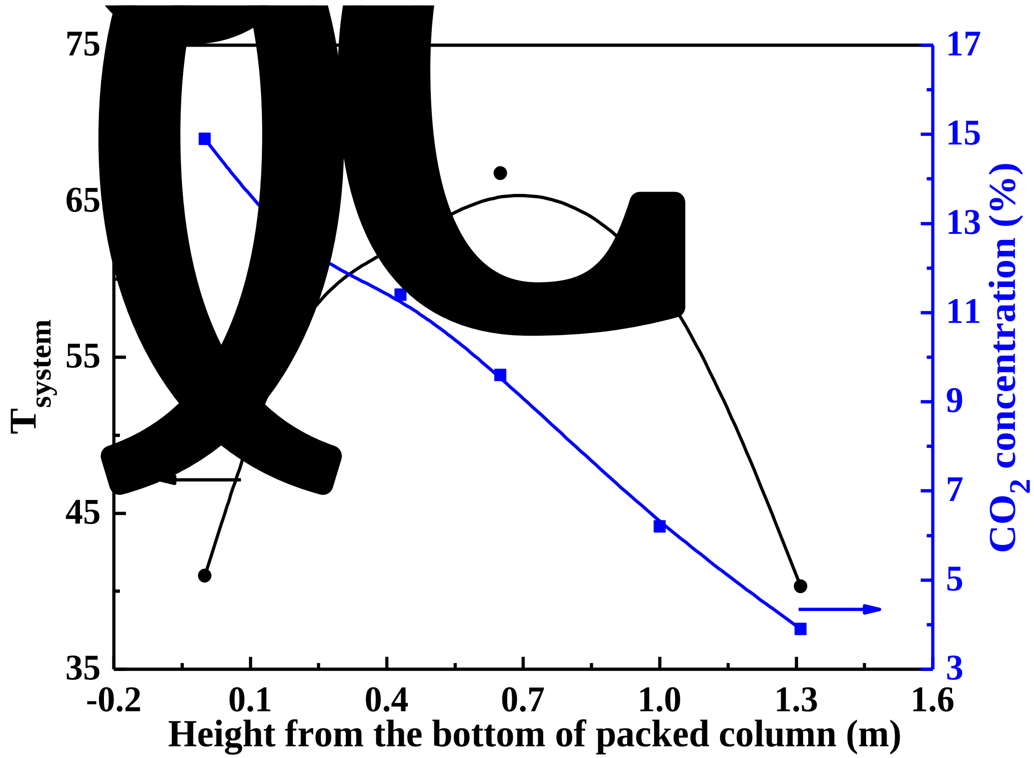
Effect of lean CO_2 loading



(solvent concentration 3kmol/m^3; liquid flow rate 5.85m^3/m^2-hr; inert gas flow rate 39.17kmol/m^2-hr; CO_2 partial pressure 15kPa, liquid feed temperature 313.13K)

3.Results and discussion

Temperature and CO_2 concentration profile



(solvent concentration 3kmol/m^3; lean CO_2 loading 0.13mol/mol; liquid flow rate 5.85m^3/m^2-hr; inert gas flow rate 39.17kmol/m^2-hr; CO_2 partial pressure 15kPa; liquid feed temperature 313.13K)

Correlations

An accurate correlation for the calculation of $K_G a_v$ is very essential for the design of the absorber and predicting the effects of operational parameters

$K_G a_v$ is a function of the liquid flow rate (L), CO_2 partial pressure (P_{CO2}), and free amine concentration [(αeq-α)C]

$$K_G a_v \propto L^b [\alpha_{eq} - \alpha] C / P_{CO_2}$$

Result of $K_G a_v$ correlations for each section of absorber

No.	Correlated equation	R^2	AAD
Section1	$K_G a_v 1 = L^{0.45}[1.5816 \times (\alpha_{eq} - \alpha) C / P_{CO_2} + 0.0526]$	0.8627	10.4%
Section2	$K_G a_v 2 = L^{0.45}[1.6524 \times (\alpha_{eq} - \alpha) C / P_{CO_2} - 0.0172]$	0.9408	10.2%
Section3	$K_G a_v 3 = L^{0.45}[1.7196 \times (\alpha_{eq} - \alpha) C / P_{CO_2} - 0.0329]$	0.8849	11.1%
Section4	$K_G a_v 4 = L^{0.45}[1.8896 \times (\alpha_{eq} - \alpha) C / P_{CO_2} + 0.0642]$	0.8795	9.8%
Section5	$K_G a_v 5 = L^{0.45}[0.3935 \times (\alpha_{eq} - \alpha) C / P_{CO_2} + 0.0192]$	0.7991	4.9%

Correlations

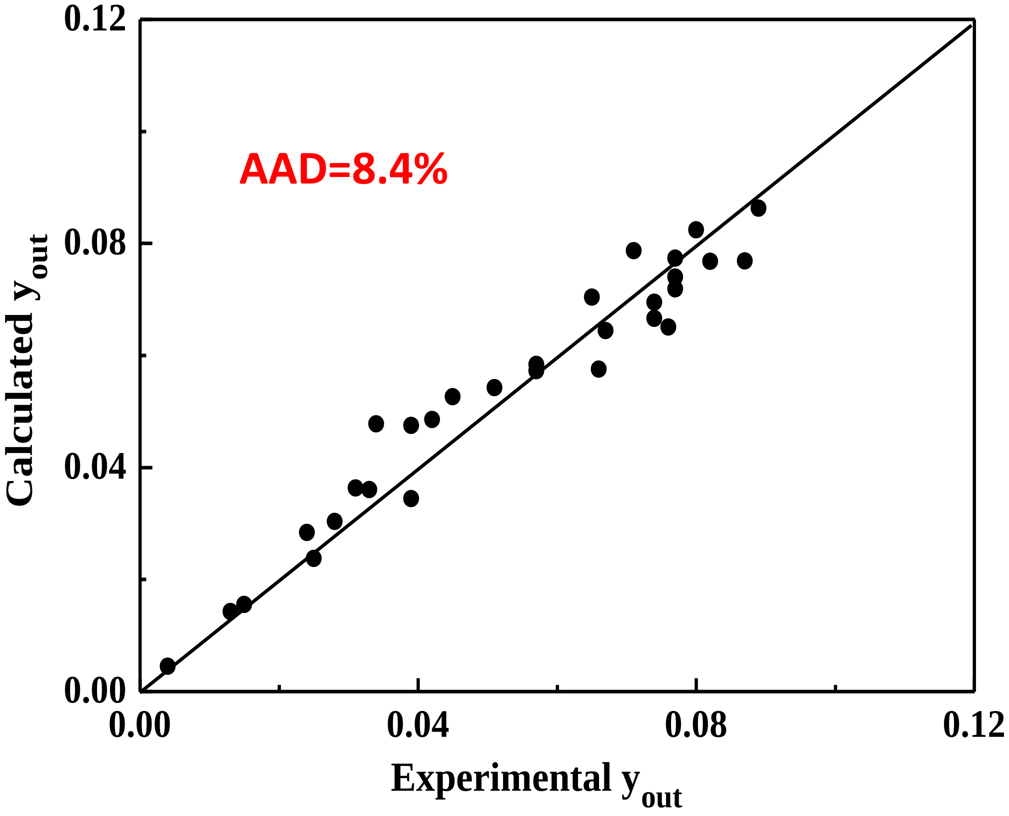
Comparison between y_{out} values calculated from proposed correlation and those from experimental results

Outlet gas concentration (y_{out}) is a key parameter for column design and simulation of the process.

$$P_{CO_2} = P\frac{y_{CO_2,in} - y_{CO_2,out}}{\ln\left(y_{CO_2,in} / y_{CO_2,out}\right)}$$

$$\mathrm{Ln}y_{out} = \mathrm{Ln}y_{in} - \frac{PV_r}{G\Omega}K_G a_v$$

$$\mathrm{Ln}y_{out} = \mathrm{Ln}y_{in} - \frac{1}{5}\frac{PV_r}{G\Omega}L^{0.45}\left(K_G a_v 1 + K_G a_v 2 + K_G a_v 3 + K_G a_v 4 + K_G a_v 5\right)$$



4.Conclusions

- The overall mass transfer coefficient (K_Ga_v) and unit volume absorption rate Φ increases as liquid feed temperature and liquid flow rate increase, and decreases with increasing CO_2 loading, while changes in inert gas flow rate have little effect.

- The bottom temperature of the column (T_{bot}) increases with CO_2 partial pressure and decreases with increasing CO_2 loading and liquid flow rate.

- The correlations between K_Ga_v and operating parameters were proposed in DEEA/MEA-CO_2 system.

- The y_{out} correlation was also studied in this work and found to be in satisfactory agreement with experimental results with AAD of 8.4%.

5.Acknowledgements

Co-workers（Dr. Gao X., Dr. PT., Dr. Luo X., Xu B. et al）

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Thank you

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