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## The 5th International Symposium on Environmental Economy and Technology



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## Enriching blast furnace gas by removing carbon dioxide

Chongmin Zhang<sup>1,\*</sup>, Zhimin Sun<sup>1</sup>, Shuwen Chen<sup>1</sup>, Baohai Wang<sup>2</sup>

1. Key Lab of Chemical Metallurgy, University of Science and Technology Liaoning, Anshan 114051, China. E-mail: [zcmin@ustl.edu.cn](mailto:zcmin@ustl.edu.cn)

2. Anshan Iron and Steel Corp. (AnSteel), Anshan 114000, China

### Abstract

Blast furnace gas (BF gas) produced in the iron making process is an essential energy resource for a steel making work. As compared with coke oven gas, the caloric value of BF gas is too low to be used alone as fuel in hot stove because of its high concentrations of carbon dioxide and nitrogen. If the carbon dioxide in BF gas could be captured efficiently, it would meet the increasing need of high caloric BF gas, and develop methods to reusing and/or recycling the separated carbon dioxide further. Focused on this, investigations were done with simple evaluation on possible methods of removing carbon dioxide from BF gas and basic experiments on carbon dioxide capture by chemical absorption. The experimental results showed that in 100 minutes, the maximum absorbed doses of carbon dioxide reached 20 g/100 g with ionic liquid as absorbent.

**Key words:** carbon dioxide capture; BF gas; absorption; PSA; ionic liquid

### Introduction

In recent decades, the climate warming caused by over exhaust of CO<sub>2</sub> has become one of the most concern issues. On the other hand, both CO and CO<sub>2</sub> are valuable carbon resources in the nature, thus the capture, storage and recycling of CO<sub>2</sub> are significant (Shi et al., 2006).

Nowadays, China has become the biggest producer in iron and steel materials in the world. Much attention must be paid to an environmentally benign steel making process to decrease the pollution of the atmosphere surroundings. In the iron making process of blast furnace, a large quantity of blast furnace gas (BF gas) which is a by-product will be inevitably produced. Due to high concentration of CO<sub>2</sub> and nitrogen and feature of low caloric value, BF gas is limited in use in some extent. Because its combustible component is only about 18%–25%, BF gas is a kind of low caloric fuel gas. For example, by using BF gas as fuel of hot stove alone, it is impossible to get the high temperature of hot blast over 1473 K (Zhang et al., 1999). Thus certain proportion coke oven gas with high caloric has to be used and mixed with BF gas, or pre-heating process to the fuel gas and fuel air have to be adopted. Then, in the combustion process of hot stove, the original CO<sub>2</sub> in the BF gas, without any positive effect, only absorbs physical heat and consumes energy. It is important to promote a deep investigation on capturing CO<sub>2</sub> from BF gas and hence concentrating BF gas. In European Union,

an ULCOS steel making system is under construction in which separation of CO<sub>2</sub> is also considered (Birat and Hanrot, 2006).

Separation of CO<sub>2</sub> can be mainly divided into four types, distillation, absorption, film separation and adsorption (Meisen and Shuai, 1997; Douglas and Costas, 2005). Distillation at low temperature is suitable for the gas of CO<sub>2</sub> concentration above 60% but it is unfit for BF gas because no CO<sub>2</sub> concentration in BF gas is higher than 25%. In spite of advantages of simple, low energy consumption, film separation needs pretreatment to virgin gas which is difficult to BF gas for its huge amount. Since its commercial application in 1986, pressure swing adsorption (PSA) has been developed well for the cycle process with advantages of low consumption of energy, simple in the flow and easy to realize automatic operation. PSA cycle has some disadvantages such as pressure drop and small processing capacity (Choi et al., 2003; Rege et al., 2005). According to the feature of BF gas with large quantity and low concentration of CO<sub>2</sub>, absorption was chosen in this study.

## 1 Materials and methods

### 1.1 Materials used in syntheses of absorbents

The main chemical reagents used in these experiments are listed in **Table 1**.

Using amines and organic acids, twelve kinds of ionic liquids were synthesized through neutral reactions follow-

\* Corresponding author. E-mail: [zcmin@ustl.edu.cn](mailto:zcmin@ustl.edu.cn)

**Table 1** Main chemical reagents in the work

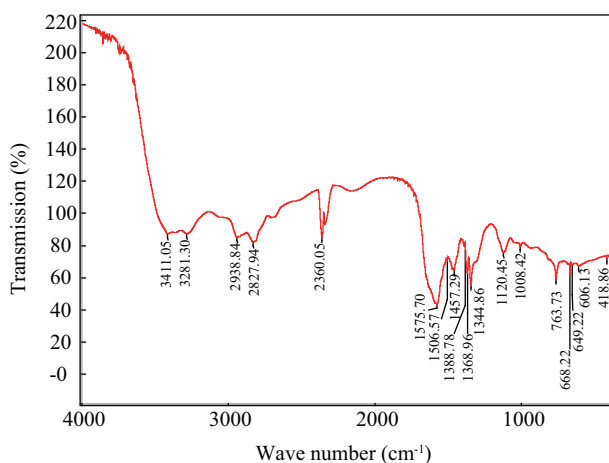
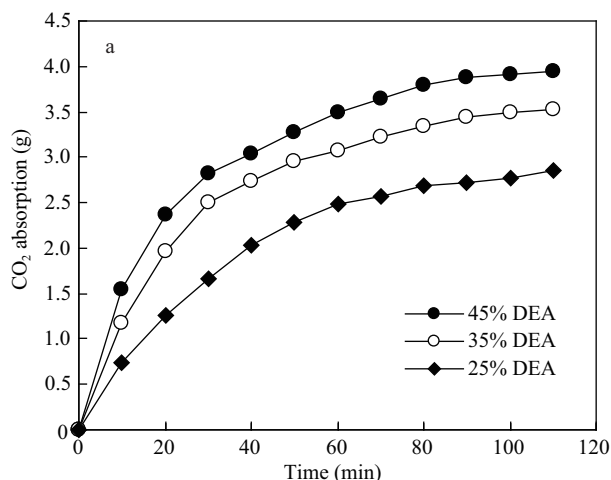
Name	Purity	Molecular formula
Methanoic acid	≥ 88%	HCOOH
Acetic acid	≥ 99.5%	CH <sub>3</sub> COOH
Propanoic acid	≥ 99.0%	CH <sub>3</sub> CH <sub>2</sub> COOH
Lactic acid	≥ 85.0%	C <sub>3</sub> H <sub>6</sub> O <sub>3</sub>
Ethylenediamine	≥ 99.0%	H <sub>2</sub> NCH <sub>2</sub> CH <sub>2</sub> NH <sub>2</sub>
DETA	≥ 98.0%	C <sub>4</sub> H <sub>13</sub> N <sub>3</sub>
Triethylenetetramine	≥ 98.0%	C <sub>6</sub> H <sub>16</sub> N <sub>4</sub>
Ethyl acetate	100.0%	CH <sub>3</sub> COOC <sub>2</sub> H <sub>5</sub>
Diethanol amine	≥ 99%	C <sub>4</sub> H <sub>11</sub> NO <sub>2</sub>
triethanol amine	≥ 99%	C <sub>6</sub> H <sub>15</sub> O <sub>3</sub>
N-methylimidazole	≥ 99%	C <sub>4</sub> H <sub>6</sub> N <sub>2</sub>
Bromobutane	≥ 99%	C <sub>4</sub> H <sub>9</sub> Br

ing the mechanism below.



During the syntheses processes, the reactions are exothermic and even a lot of white smoke were found.

An infra-red spectrogram of synthesized product—triethylene tetramine formate in this work is shown in Fig.

**Fig. 1** IR spectrogram of the synthesized product.

1. Form the spectrogram, some characteristic functional group such as  $\text{COO}^-$ ,  $-\text{NH}_3^+$ ,  $-\text{CH}_2$  and  $-\text{NH}_2$  can be found, which can prove that the synthesized product is an ionic liquid.

## 1.2 Experimental method of absorption

Weighing method was adopted in the experiments of absorption to carbon dioxide, which means the weights of absorbents in the absorption must be measured in every 10 min. The absorptive experiments were done at 298 K.

## 2 Results

### 2.1 Alkanolamines aqueous liquids as the absorbents

The experimental results of absorption to  $\text{CO}_2$  of Diethanolamine (DEA) and Triethylolamine (TEA) aqueous liquids are showed in Fig. 2.

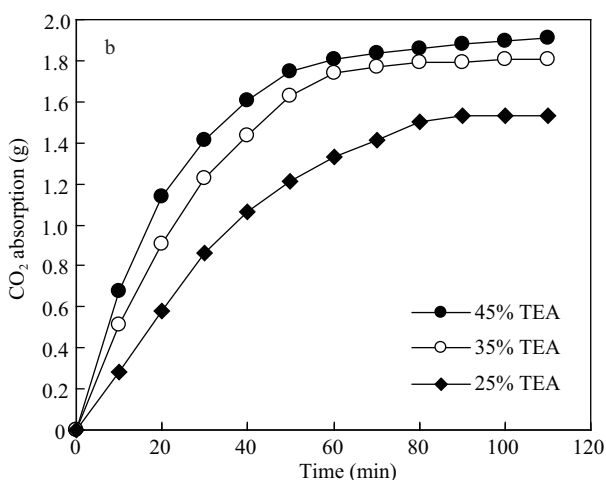
### 2.2 Aqueous ionic liquids as the absorbents

Ionic liquids synthesized in this work were used in the absorptive experiments of  $\text{CO}_2$  at normal temperature ( $25^\circ\text{C}$ ). Parts of experimental results of aqueous solutions of ionic liquids are showed in Fig. 3.

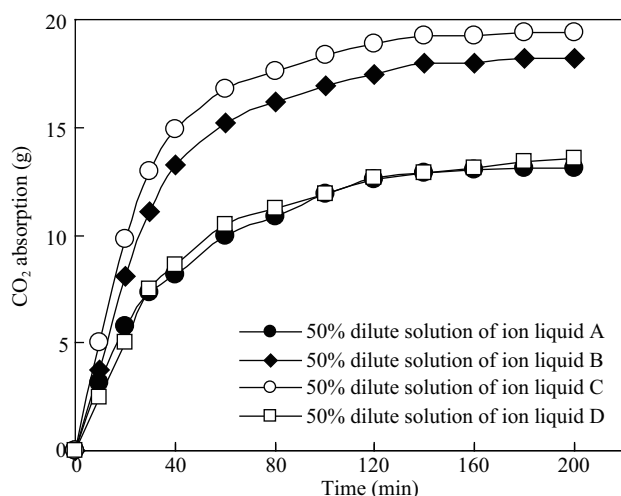
## 3 Discussion

### 3.1 Possibility PSA cycle

PSA is a kind of adsorption cycle process, in which at certain temperature, the same component can be adsorbed by the adsorbent under a higher partial pressure, and the rest components are expelled from the tower, then at a lower partial pressure even in vacuum, the adsorbed component is desorbed, meanwhile the adsorbent will be regenerated (Fukunaga et al., 1968; Gomes and Yee, 2002; Takamura et al., 2001). In addition to pressurization, feed, countercurrent depressurization and purge four original steps, new operation steps such as repressurization, equal-

**Fig. 2**  $\text{CO}_2$  absorptive abilities by use of DEA aqueous liquids (a) and TEA aqueous liquids (b) at  $25^\circ\text{C}$  on 100 g absorbent.





**Fig. 3** CO<sub>2</sub> absorption curves by use of dilute aqueous solutions of ion liquids synthesized at 25°C over 100 g absorbent.

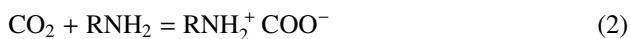
ization, co-current depressurization and reflux were also put forward (Anderson and Newell, 2004; Park et al., 2002).

According to the principle of PSA cycle, a minimum pressure differential of 100 k Pa is required for the cycle working, but small parts of blast furnaces with high pressure operation can meet the requirement nearby 2000. BF gas is produced largely in quantity, it needs large scale equipment of PSA cycle to process, and the waste gas emission will cause secondary contamination (Zhang et al., 2000). Nevertheless, PSA cycle is good alternatives for CO capture in BF gas even though there still are some other obstacles.

### 3.2 Possibility of alkanolamines aqueous liquids as the absorbents

With advantages of good stability and low energy consumption, alkanolamines aqueous liquids as conventional absorbents have successfully been used in absorption SO<sub>2</sub> and CO<sub>2</sub> from natural gas, coke oven gas and other fuel gases in chemical industry (Huang et al., 2008; Abdelbaki, 2007; Li et al., 2009). Since piperazine was adopted as the activator of N-methyldiethanolamine for absorbing CO<sub>2</sub> (Wang, 2008), many activated alkanolamines aqueous liquids have been developed and hydroxyl ammonium ionic liquids have been synthesized (He et al., 2009; Yuan et al., 2007; Kurnia et al., 2009).

The model of CO<sub>2</sub> absorbed by alkanolamines aqueous liquids can be expressed as:



here B is the amine molecules in the liquid mainly.

The regeneration process and desorption can be realized by thermal decomposition as follows:



Regeneration is an important factor to the use of the alkanolamines aqueous liquids widely, from which it can be seen the order of regeneration: AMP > MDEA > DETA > DEA > MEA (Cai, 2009).

To a continuous production process like steel making, pipe line corrosion is a fatal weakness. It is uncertain whether the pipes and other BF gas equipment will be corroded in the weak alkaline medium of alkanolamines aqueous liquids, but there is possibility of steel corrosion.

Form results of this work, the absorptive loads are not higher than 5 g/100 g absorbents) when alkanolamines aqueous liquids were used as the absorbents. In real operation in blast furnace, consumption of energy of cycles caused by relatively small absorptive load for CO<sub>2</sub> is another weakness.

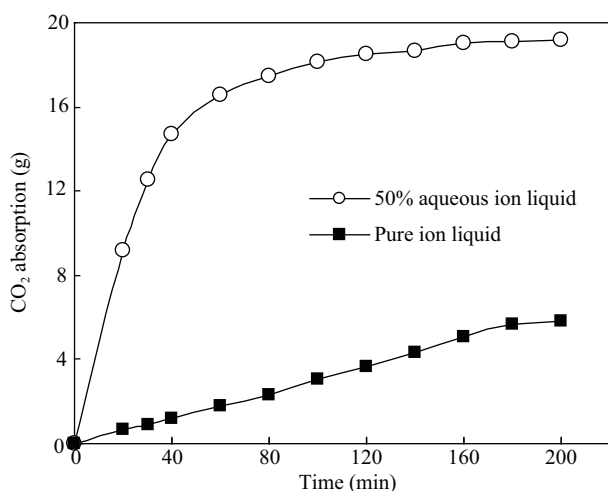
### 3.3 Possibility of aqueous ionic liquids as the absorbents

As to CO<sub>2</sub>, Bates et al. (2002), who had synthesized the functionalization ionic liquid with functional groups -NH<sub>2</sub> (TSILS), found that the ionic liquid containing functional groups -NH<sub>2</sub> is much better than that ionic liquid without this functional group in the aspect of adsorbing CO<sub>2</sub>. At normal temperature and pressure, this CO<sub>2</sub> adsorption rate of ionic liquid with functional groups -NH<sub>2</sub> can reach 7.4% (mass fraction). The study results show that the functionalization ionic liquid is expected to replace the current industry and some organic solvents using for separation and removal of CO<sub>2</sub>.

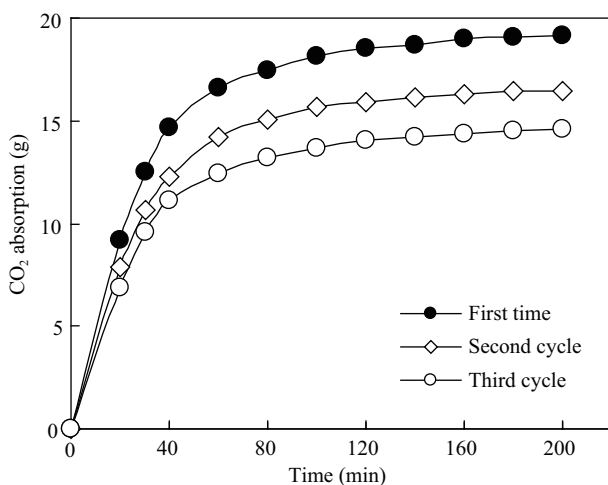
It has been proved that CO<sub>2</sub> in [APBIM] [BF<sub>4</sub>] is a kind of chemical absorption, [APBIM] [BF<sub>4</sub>]-NH<sub>2</sub> and CO<sub>2</sub> reacted to form the carbonate of ammonium by FT-IR and CNMR spectra (Tang et al., 2005).

A series of amino acid ionic liquids have been synthesized in Zhang's work. Because of the high viscosity of the ionic liquid he synthesized, it was coated on the surface of porous silica gel, forming a film on the surface and the experiment was cycled for 4 times. Comparing with the absorption that CO<sub>2</sub> is directly put into ionic liquids, more rapid absorption, stability as well as reversible absorption - desorption process and recycled absorbent were found in this experimental method of surface coated (Zhang et al., 2006).

It was also found in this experiment that the viscosities of most ionic liquids synthesized in this work are too high to be used as absorbents alone. In order to realize the adsorption of CO<sub>2</sub> with synthesized ionic liquids, aqueous solutions of ionic liquids were made. The experimental results showed that aqueous solutions of ionic liquids are much better than pure ionic liquids on absorptive loads of CO<sub>2</sub>. A comparison on absorptive loads between



**Fig. 4** Comparison of CO<sub>2</sub> absorption by use of pure ionic liquid and its aqueous dilute solution at 25°C over 100 g adsorbent.



**Fig. 5** CO<sub>2</sub> absorptive capacities in different regeneration cycles of ionic liquid A synthesized at 25°C over 100 g adsorbent.

pure ionic liquid and its aqueous solution is shown in **Fig. 4**. Moreover, In contrast to less than 5 g CO<sub>2</sub>/100 g adsorbents in alkanolamines aqueous liquids absorption, the absorptive loads of aqueous solutions of ionic liquids are over 10 g CO<sub>2</sub>/100 g adsorbents, the best result is about 19 g CO<sub>2</sub>/100 g adsorbent.

Regeneration is vital to putting ionic liquids into steel making process for capturing CO<sub>2</sub>. A group of experiments for regeneration of ionic liquids were done. It was found that the CO<sub>2</sub> absorptive abilities of each ionic liquid decrease while using the recovery ionic liquids in their second and third cycle. The results in this condition indicate that regeneration rates are 90% in the second cycle and 88% in the third cycle. The CO<sub>2</sub> absorptive abilities of aqueous ionic liquid A in different cycling absorption are showed in **Fig. 5**.

Comparing the above methods for separating CO<sub>2</sub> in steel making process, chemical absorption with ionic liquid is the most promising. In spite of advantages in ionic liquid absorption, there are difficulties to be overcome with

the aim that ideal ionic liquid can be easily synthesized with high efficiency and low price. It is expected the ionic liquids can absorb CO<sub>2</sub> steadily and recycle with high regeneration ratio at an average temperature of BF gas (about 350 K), and should not cause second contamination to the surroundings.

## 4 Conclusions

BF gas is large in quantity, according to the feature of PSA process, it needs large scale equipment, and the waste gas in the PSA process should be treated well.

Alkanolamines aqueous liquids and with their advantages of low price and easy to synthesize are good in absorption to CO<sub>2</sub> and have been used in chemical fields, the experiment results showed that the absorptive loads are not higher than 5 g/100 g adsorbents, so it needs large quantities of liquids for circulation and energy consumption in the operation if used them in blast furnace. Moreover, the weaknesses of alkalinity-bearing and corrosion to the steel reactor in alkanolamines aqueous liquid should not be underestimated.

The experiments of ionic liquid absorption showed that pure ionic liquids absorptive abilities are limited due to their high viscosities. In this work, it is found that the absorptive abilities of aqueous ionic liquids can reach 19 g CO<sub>2</sub>/100 g adsorbent which is much higher than that in the absorption of alkanolamines aqueous liquids. The regeneration ratios in the aqueous solutions are about 90% in the second cycle and 88% in the third cycle.

Analyses indicate that the three ways of separating CO<sub>2</sub> from BF gas, there are advantages and weaknesses for each method. Comparatively, absorption of ionic liquids is more promising.

## Acknowledgments

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## References

- Abdelbaki B, Mohamed K A, 2007. An experimental investigation on the rate of CO<sub>2</sub> absorption into aqueous methyldiethanolamine solutions. *Korean Journal of Chemical Engineering*, 24(1): 16–23.
- Anderson S, Newell R, 2004. Prospects for carbon capture and storage technology. *Annual Review of Environment and Resources*, (29): 109–142.
- Bates E D, Mayton R D, Ntai I, Davis H, 2002. CO<sub>2</sub> capture by a task-specific ionic liquid. *Journal of the American Chemical Society*, 124(6): 926–92.
- Birat J P, Hanrot F, 2006. ULCOS: The European Steel Industry's Effort to Find Breakthrough Technologies to Cut its CO<sub>2</sub> Significantly[C], *Proceedings of EU/Asia Workshop on Clean Production and Nanotechnologies*, 25–26 October 2006, Seoul: 1–5.

- Cai P, Wang S L, Zhao S H, 2009. Decarburization amine liquid properties of alcohols. *Membrane Science and Technology*, 12(2): 72–73.
- Douglas A, Costas T, 2005. Separation CO<sub>2</sub> from fuel gas: a review. *Separation Science and Technology*, 40: 321–348.
- Fukunaga P, Hwang K C, Davis S H, Winnick J, 1968. Mixed Gas Adsorption and Vacuum Desorption of Carbon Dioxide on Molecular Sieve. *I&EC Process Design and Development*, 7(2):269–275.
- Gomes V G, Yee K, 2002. Pressure swing adsorption for carbon dioxide separation from exhaust gases. *Separation and Purification Technology*, (28): 161–171.
- He C, Zhong Q, Du H C, Zhai L z, 2009. Microwave synthesis of hydroxyl ammonium ionic liquids and SO<sub>2</sub> absorption. *Chemical Engineering (China)*, 37(2): 8–11.
- Huang J, Riisager A, Berg R W, Fehrmann R, 2008. Turning ionic liquid for high gas solubility and reversible gas sorption. *Journal of Molecular Catalysis A: Chemical*, 279(2): 170–176.
- Kurnia K A, Harris F, Wilfred C D, Mutalib A M I, Murugesan T, 2009. Thermodynamic properties of CO<sub>2</sub> absorption in hydroxyl ammonium ionic liquids at pressures of (100–1600) kPa. *Journal of Chemical Thermodynamics*, 41(10): 1069–1073.
- Li W, Chen J, 2009. Kinetics of absorption of CO<sub>2</sub> into aqueous MEA solutions. *Science Paper Online*, 4(12): 849–854.
- Meisen A, Shuai X, 1997. Research and development issues in CO<sub>2</sub> capture. *Energy Conversion and Management*, 38: 37–42.
- Park J H, Beum H T, Kim J N, 2002. Numerical analysis on the power consumption of the PSA process for concentrating CO<sub>2</sub> from fuel gas. *Industrial and Engineering Chemical research*, 41: 4122–4130.
- Rege S U, Ralph T Y, Kangyi Q, Mark A B, 2001. Air-prepurification by pressure swing adsorption using single/layered beds. *Chemical Engineering Science*, 56: 2745–2759.
- Shi Y J, Wu H, Wang L J, Song H, 2006. Fixation and utilization on research of CO<sub>2</sub>. *China Environmental Industry*, (1): 40–43.
- Takamura Y, Narita S, Aoki J, Uchida S, 2001. Application of high pressure swing adsorption process for improvement of CO<sub>2</sub> recovery system from fuel gas. *Canadian Journal of Chemical Engineering*, (79): 812–816.
- Tang J B, Sun W L, Tang H D, Radosz M, Shen Y Q, 2005. Enhanced CO<sub>2</sub> adsorption of poly (ionic liquid). *Macromolecules*, (38): 2037–2039.
- Choi W K, Kwon T I, Yeo Y K, Lee H, Song H K, Na B K, 2003. Optimal operation pressure swing adsorption (PSA) process for CO<sub>2</sub> recovery. *Korean Journal of Chemical Engineering*, 20(4): 617–625.
- Wang Q Q, 2008. CO<sub>2</sub> Absorption of organic amine liquid research review. *Journal of Shandong Normal University*, 23(1): 81–83.
- Yuan X L, Zhang S J, Lu X M, 2007. Hydroxyl ammonium ionic liquids: Synthesis, properties, and solubility of SO<sub>2</sub>. *Journal of Chemical & Engineering Data*, 52(2): 596–599.
- Zhang C M, Yan G, Liu Q X, 1999. Comprehensive utilization of blast furnace gas. Proceedings of Iron-making process in Liaoning Province: Anshan, 53–58.
- Zhang C M, Yan G, Li A N, Tao X, Chen X J, Su W et al., 2000. Increasing theoretical hot stove burning temperature by PSA technology of enriching blast furnace gas. *Angang Technology*, (4): 7–10.
- Zhang J M, Zhang S J, Dong K, Zhang Y Q, Shen Y Q, Lv X M, 2006. Supported absorption of CO<sub>2</sub> by tetrabutylphosphonium amino acid ionic liquids. *Chemistry-A European Journal*, (12): 4021–4026.



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