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Treatment of CO_2+NH_3 Mixed Waste Gas from Different Sources by Blend Solvents

Kwang-Guk Kim, Chol-Ryong Choe*, Tang-Hyon Yun, Kwang-Myong Rim

Abstract

The waste gas from chemical plants, including urea fertilizer plant, contains a large amount of CO_2 *gas in addition to* NH_3 *gas. New solvents have been studied for use in the absorption of waste gases, but most of them are carried out at specific compositions and flow rates for individual gases. In this paper, a complete conceptual design of the process for separately absorbing* CO_2 *and* NH_3 *gases in a waste gas feedstock stream with a broad range of* CO_2 *contents and flow rates is presented. To absorb this waste gas, a mixed absorbent solvent consisting of 1-butyl imidazolium bis(trifluoromethylsulfonyl)imide ([Bim][NTf*$_2$*]) and monoethanolamine (MEA) was used. The thermodynamic model and kinetic model of the new MEA-*H_2O*-*CO_2*-*NH_3*-ionic liquid (IL) system were constructed and rigorously modeled and simulated for different sources and compared with the conventional* H_2O*-based process. Simulation results showed that the use of mixed solvents compared to conventional processes resulted in less total regeneration energy under all conditions regardless of* CO_2 *content and flow rate and the effect of IL concentration on energy consumption and total regeneration energy with pressure in stripping column were analyzed, with 30% ionic liquid concentration and 180 kPa* CO_2 *stripping pressure and 240 kPa* NH_3 *stripping pressure. In addition, the total regeneration energy was analyzed after the process improvement to optimize the energy consumption of the process, which saved 2.9% of the energy at 40%* CO_2 *content. The [Bim] [NTf*$_2$*] + MEA+*H_2O *blend solvent proposed in this paper is a green mixed solvent that is very effective for the absorption of* CO_2 *and* NH_3 *mixed gases, which can be widely used not only for fertilizer plant waste gas treatment but also for other industries.*

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INTRODUCTION

As industry develops, the emission of greenhouse gases is increasing. The primary ingredient in greenhouse gases is CO_2. In 2019, CO_2 released from fossil fuel burning amounted to 88.6% of the total greenhouse gas [1].

Thus, there has been a lot of interest in CO_2 emissions. Assuming a more than one-third increase in greenhouse gas emissions, a significant solution is required to limit the effects of temperature increases between 2012 and 2040 [2]. Compared to other greenhouse gases like methane or nitrous oxide, CO_2 absorbs less heat per molecule; but it is present in the atmosphere in higher concentrations and has a longer half-life [3]. This will result in an increase in sea level, a rise in global temperature, droughts, wildfires, and other natural calamities.

In addition, in recent years environmental problems caused by NH_3 gas emission have attracted increasing attention. The exhaust gas containing NH_3, an alkaline gas with a strong pungent smell, reacts with sulfur oxides SO_X and nitric oxide NO_X in the atmosphere to form solid particles, which form particulate aerosols in the atmosphere. Such particle substances produce substantial environmental pollution to the air and impact human life and health. This results in actions that tightly restrict the release of gases that contain NH_3.

Most industrial activities directly release NH_3, CO_2, and other gases into the atmosphere, including the manufacture of chemical fertilizers, livestock, and pharmaceuticals [4, 5]. Therefore, the treatment of such exhaust gases plays a significant role in minimizing environmental pollution.

CO_2 capture can be accomplished by a variety of methods, including pre- and post-combustion, oxy-fuel combustion, and others [6]. Without requiring major modifications to currently operating power plants, CO_2 can be extracted from the flue gas released by CO_2 emission sources using post-combustion capture technology. The difficulties in this process are simple to solve compared to the other capture approaches. Liquid absorption-based CO_2 capture is the most developed and extensively utilized technology in commercial applications among CO_2 separation techniques used for post-combustion capture, such as adsorption, membrane, and cryogenic separation. The MEA based post-combustion CO_2 collection also exhibits high CO_2 capture efficiency (>90%) and CO_2 high purity (>99%) [7]. This method is widely used because of its low absorption capacity and selectivity, low energy consumption and high reliability [8].

On the other hand, the most common NH_3-containing tail gas cleaning procedures include traditional solvent absorption method [9–11], biological filtering method [12, 13], catalytic oxidation method [14], adsorption method [15], membrane separation [16], and other purification processes. Now, the primary representative technologies for handling the tail gas are water scrubbing and acid washing [17, 18]. However, there were certain drawbacks to this approach, such as labor-intensive procedures, comparatively high solvent use, high energy consumption during NH3 treatment, and a poor rate of NH3 recovery. To comply with the stricter environmental protection regulations, it is imperative that the current traditional solvent NH3 absorption process be updated simultaneously.

Due to these requirements, more recent methods have been developed for the use of ionic liquids as adsorbents for CO_2 and NH_3 gases.

The ionic liquid is a liquid organic salt that has both positive and negative ions at room temperature. Its highly gas-soluble nature, programmable structure, and exceptionally low vapor pressure have sparked a lot of interest in gas separation. Depending on which cations and anions are chosen, ionic liquids can be used for a variety of purposes. According to the references, some ionic liquids have high absorption selectivity not only for CO_2 gas but also for NH_3 gas.

Basha et al. [19] created an absorption separation procedure to investigate the separation properties of ionic liquids and used the Peng-Robinson (PR) equation to assess the solubility of CO_2 in [HMIm] [Tf2N]. After regressing the CO_2 solubility data in [C4 Mim] [Ac] using the Redlich-Kwong (RK) model, Shiflett et al. [20] were able to derive well-correlated RK model parameters and investigate the CO_2 absorption process by ionic liquids. The process with the lowest energy consumption is identified through the sensitivity analysis of process parameters, and this process yielded a 16% reduction in energy consumption when compared to standard MEA. Using the NRTL model and compounded MEA-IL of CO_2 absorption, Huang et al. [21] developed a gas-liquid equilibrium model appropriate for [Bmim] [BF4], [Bmim] [DCA], and [Bpy] [BF4] IL-CO_2 system.

According to the study, the best energy consumption method (3.17 GJ/t CO_2) is achieved when the mixing ratio of [Bpy] [BF4] is 0.2. This represents an 18% savings over the traditional MEA technique. A cyclic process of ionic liquid-NH_3 absorption-refrigeration was constructed by Ruiz et al. [22] based on the COSMO technique. They also examined the cycle performance of seven different ionic liquids, namely [Choline] [NTf2], [Emim] [Ac], [Emim] [$EtSO_4$], [Emim] [SCN], [Emim] [NTf2], [Hmim] [Cl], and [HOemim] [BF_4]. The cycle performance of the ionic liquids with higher solubility of NH_3 absorption was demonstrated by the results.

The new functional protic IL([Bim][NTf2]) that Zhang et al. [23] and Shang [24] synthesized has a significantly larger NH_3 capacity than traditional ILs; for this work, we have chosen to use this IL as the solvent. Thus, there have been a lot of studies on the absorption of waste gases, such as CO_2 and NH_3 with specific composition and flow rate separately using various solvents, such as ionic liquids, but no research has been carried out to treat CO_2+NH_3 mixed waste gases with a wide range of composition and flow rate range. Therefore, the study of effective solvents for treating CO_2+NH_3 mixed waste gases is of great importance in protecting the environment by treating waste gases from chemical plants, including urea and melamine production plants.

ASPEN Plus, a process simulation software possessing a powerful database, has been widely used in chemical engineering research and has played a great role in simulating many fields, such as oil refinery [25, 26], off-gas and CO_2 absorption from power plant [27, 28], coal chemical industry [29, 30], and biomass power generation systems [31], etc.

Here, a potential sight was brought out whether we could combine the process simulation with experiments together, which reduces the operational cost and time for design.

Therefore, the objective of this paper is to develop a conceptual design of a process for absorbing mixed waste gas consisting of CO_2 and NH_3 from different sources, including chemical plants, and compare the process with the conventional H_2O as an absorber. To achieve this aim, we chose [Bim] [NTf_2] as the solvent to absorb NH_3 gas. Since [Bim][NTf_2] has a low absorption capacity for CO_2 and, the addition of MEA solution, which is currently the industrially widely used absorber [32], increases the absorption capacity for CO_2.

The model of the new MEA-H_2O-CO_2-NH_3-IL ([Bim] [NTf_2]) system using the process simulation software ASPEN Plus V11.0 was simulated and optimized for waste gas raw materials with different flow rates and compositions. The results of total regeneration energy obtained in the simulation were compared with the conventional H_2O-based process to confirm the reasonable process. Then, based on this model, the influence of the ionic liquid concentration and the pressure-dependent energy consumption on the stripping columns was investigated according to the flue gas feedstock composition. An improved scheme to reduce the energy consumption of the IL+MEA+H_2O-based process is proposed to analyze the effect.

Process Description and Modeling Framework

In general, the waste gas from the urea fertilizer plant contains CO_2, NH_3, N_2, H_2O, CO, H_2 and trace components of NOx and SOx. However, in this paper, only waste gases consisting of CO_2, NH_3, N_2 and

H_2O are considered as flue gas feed streams. The flowsheet of the conventional H_2O-based process and novel IL+MEA+H_2O-based process for CO_2 and NH_3 absorption are shown in Figures 1 and 2. Both processes are largely composed of three parts: waste gas absorption section, CO_2 gas stripping section and NH_3 gas stripping section. The objective of both processes is to ensure minimum purity and recovery of CO_2 and NH_3 gases above 90%. The absorption process of CO_2+NH_3 gas was modeled and simulated using the chemical process simulation program Aspen Plus V11.0. The simulation calculated the energy consumption by varying the composition of the flue gas in a wide range (10–40% CO_2, 17.3% N_2, 0.7% H_2O and 70–40% NH_3) with respect to waste gas of different fertilizer plants, and simultaneously simulating four distinct flow rates (0.1, 1, 5 and 10 kmol/s). In the case of the IL+MEA+H_2O-based process, MEA content was fixed at 30% and ionic liquid content was calculated by varying from 0 to 30%.

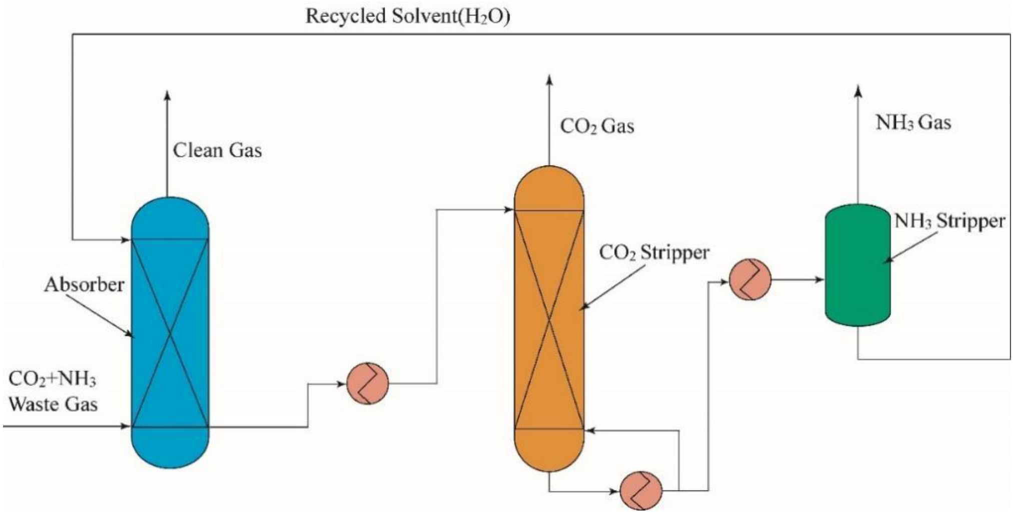

Figure 1. Conventional process flowsheet using H_2O.

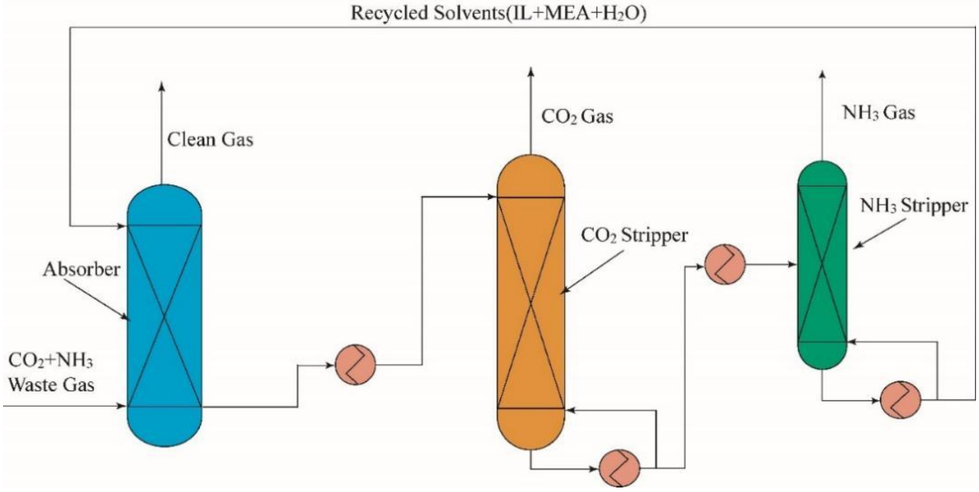

Figure 2. Novel process flowsheet using blend solvent.

IL+MEA+H_2O-based CO_2+NH_3 Capture process

Process Description

In this paper, using a blend solvent of a conventional MEA solution effective for the CO_2 absorption and of IL ([Bim][NTf_2]) with high selectivity for NH_3 absorption is selected. The scheme of the absorption process for treating CO_2+NH_3 mixed waste gas using IL+MEA+H_2O blend solvent is shown in Figure 3. In the absorbing section, a large amount of CO_2 and NH_3 mixed waste gas is absorbed in the absorbing solvent in the absorber, leading to the next step and only a small fraction is released. In the CO_2 gas stripping section, solvent stream absorbed a large amount of waste gas is supplied to the top of the CO_2 stripping column, and in this column only CO_2 gas is removed from column and collected and stored. In the discharged liquid, a large amount of NH_3 gas is absorbed. In the NH_3 gas stripping section, NH_3 stripping column is used to strip NH_3 gas in the absorbent solvent exhaust stream to obtain NH_3 gas product that meets product purity. The solvent flow obtained is recycled and then enters the absorption column again. The detailed operating parameters for the absorption column and stripping columns are listed in Table 1.

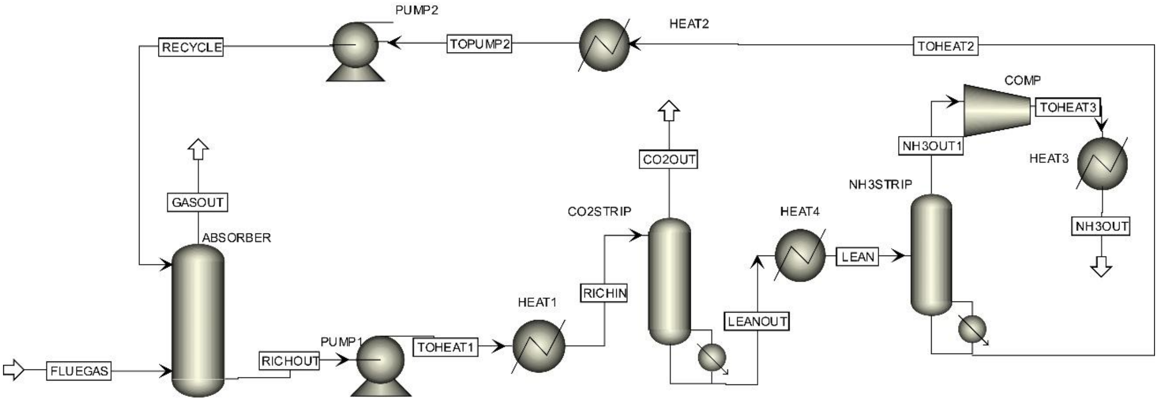

Figure 3. IL+MEA+H_2O-based CO_2 and NH_3 capture process scheme in Aspen Plus.

Table 1. The model setting parameters in IL+MEA+H_2O-based process.

Model Name	**Aspen Plus Model**	**Number of Stages**	**Working Pressure/kPa**
ABSORBER	RadFrac	20	120
CO_2STRIP	RadFrac	22	180
NH_3STRIP	RadFrac	16	240

Calculation Modeling

Tables 2 and 3 display critical properties and Equations of main physical properties of ionic liquid([Bim] [NTf_2]) used to simulate MEA-H_2O-CO_2-NH_3-IL system, respectively. Critical properties were computed using Huang's [21, 22] fragment contribution-corresponding states (FC-CS) approach.

Table 2. Critical properties of [Bim] [NTf_2].

Parameter	**Value**	**Unit**
Molecular weight (*Mw*)	405.34	g/mol
Boiling temperature (*Tb*)	745.07	K
Critical temperature (*Tc*)	1120.17	K
Critical pressure (*Pc*)	2205.00	kPa
Acentric factor (ω)	0.14	–

Table 3. Equation of main physical properties of [Bim] [NTf_2].

Properties	**Correlated Equation with Parameters**	**Unit**	**Reference**
Viscosity	$\ln \mu = -457.44 + \frac{24536.8}{T} + 65.43 \ln T$	Pa·s	[23, 33]
Heat capacity	$C_p = -106.2 + 2.93T - 0.01T^2$	kJ/K/kmol	[34, 35]
Density	$\frac{M_w}{\rho} = 0.21928 + 0.00019T$	m^3/kmol	[24, 34]
Surface tension	$\sigma = 43.84 \times (1 - (\frac{T}{T_c}))^{(0.43 + 3.89(\frac{T}{T_c}) - 8.02(\frac{T}{T_c})^2 + 6.09(\frac{T}{T_c})^3)}$	Dyne/cm	[34]
Thermo Conductivity	$\lambda = 0.198 - 0.0004T$	W/m/k	[24]

NRTL model is sufficiently reliable for the CO_2+NH_3+IL system to be employed for process modeling [23–25]. However, for MEA–H_2O–CO_2–NH_3–IL system, MEA, NH_3 and H_2O are polar substances that will interact electrically, so the chemical equilibrium, phase equilibrium and reaction heat of the system are calculated using the electrolyte non-random-two-liquid (ELECNRTL) model available in Aspen Plus V11.0 and the gas-phase properties are calculated by the Redlich-Kwong (RK) state equation. The interaction coefficient data of MEA and other components were obtained in Ref. [36] and the interaction coefficients with [Bim] [NTf_2] and other components were obtained in Ref. [23]. Table 4 shows the interaction coefficients between CO_2, NH_3 and ionic liquids.

Table 4. Interaction coefficients with gases and IL([Bim] [NTf$_2$]) [23].

Gas	IL	a_{ij}	a_{ji}	b_{ij}	b_{ji}	c_{ij}	R^2	AARD (%)
NH$_3$	[Bim] [NTf$_2$]	–8	–10.3	476.1	1259.4	0.2	0.995	8.32
CO$_2$	[Bim] [NTf$_2$]	–3	19.7	867.9	–0.03	0.3	0.995	4.79

The blend constituents follow two different paths when absorbing CO$_2$ and NH$_3$: equilibrium and rate-controlled reactions. In MEA-H$_2$O-CO$_2$-NH$_3$-IL system, the equilibrium reactions are defined as:

$2H_2O \leftrightarrow H_3O^+ + OH^-$ (R1)
$MEAH^+ + H_2O \leftrightarrow MEA + H_3O^+$ (R2)
$HCO_3^- + H_2O \leftrightarrow CO_3^{2-} + H_3O^+$ (R3)
$NH_3 + H_2O \leftrightarrow NH_4^+ + OH^-$ (R4)

On the other hand, the rate-controlled reactions are defined as:

$CO_2 + OH^- \rightarrow HCO_3^-$ (R5)
$HCO_3^- \rightarrow CO_2 + OH^-$ (R6)
$NH_3 + CO_2 + H_2O \rightarrow H_2NCOO^- + H_3O^+$ (R7)
$H_2NCOO^- + H_3O^+ \rightarrow NH_3 + CO_2 + H_2O$ (R8)
$MEA + CO_2 + H_2O \rightarrow MEACOO^- + H_3O^+$ (R9)
$MEACOO^- + H_3O^+ \rightarrow MEA + CO_2 + H_2O$ (R10)

In this paper, kinetic model proposed in reference [37–39] were used. Using the expression in the following Equation (1), the equilibrium constant Keq of reactions (1)–(4) was calculated based on molar concentration:

$$\ln(K_{eq}) = A + \frac{B}{T} + C \cdot \ln(T) + D \cdot T \tag{1}$$

The kinetic expression of reactions (5)-(10) is:

$$r = k \exp(-\frac{E}{RT}) \prod_{i=1}^{N} C_i \tag{2}$$

The value of parameters for equilibrium and rate-controlled reactions are shown in Table 5.

Table 5. Parameters for Equations 1 and 2 [37, 39].

Reactions	*A*	*B*	*C*	*D*
R1	132.889	–13455.9	–22.477	0
R2	216.049	–12431.7	–35.482	0
R3	–3.038	–7008.36	0	–0.00313
R4	–1.2566	–3335.7	1.4971	–0.03706

Reactions	***k***	$E/J\cdot kmol^{-1}$
R5	4.32e+13	5.55e+7
R6	2.38e+17	1.23e+8
R7	1.35e+11	4.84e+7
R8	4.75e+20	6.91e+7
R9	9.77e+10	4.13e+7
R10	2.18e+18	4.13e+7

Conventional H_2O-based CO_2+NH_3 Capture process

Process Description

The scheme of the conventional process of absorbing CO_2+NH_3 mixed waste gas with H_2O as absorber is shown in Figure 4. As shown in the Figure, the process of treating mixed waste gas consists of an absorption column, a CO_2 stripping column, and a flash evaporator for NH_3 stripping. The NH_3 + CO_2 + H_2O solution is reached by passing the waste gas through the absorption column. This NH_3 + CO_2 + H_2O solution is released from the absorption column and 90% CO_2 is recovered from the CO_2 stripping column. Then, the remaining solution was stripped with more than 90% NH_3 in an NH_3 flash evaporator, and the solvent flow was recycled back to the first column. The purity of the CO_2 and NH_3 streams obtained with the product is more than 90%, respectively.

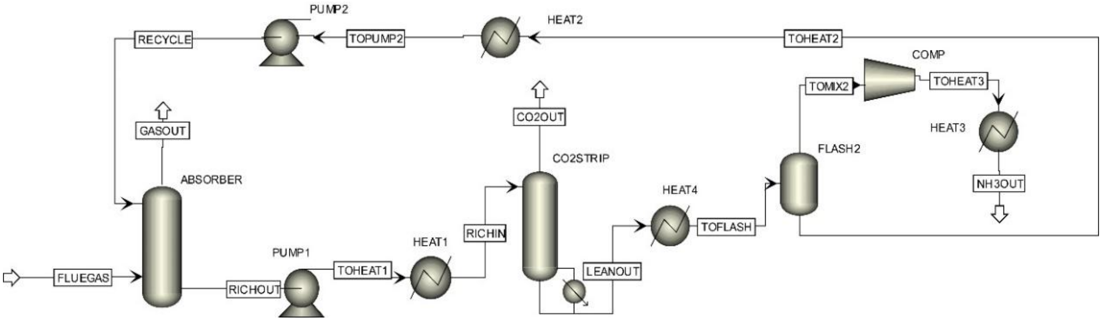

Figure 4. Conventional H_2O-based CO_2 and NH_3 capture process scheme in Aspen Plus.

Table 6 gives the simulation parameters of the absorption column, CO_2 stripping column and NH_3 stripping column of the conventional H_2O absorption process.

Table 6. The model setting parameters in IL+MEA+H_2O-based process.

Model Name	**Aspen Plus Model**	**Number of Stages**	**Working Pressure/kPa**
ABSORBER	RadFrac	22	120

CO_2STRIP	RadFrac	20	180
FLASH	Flash2	–	200

Calculation Modeling

Aspen Plus developed a thermodynamic model for process modeling in the traditional water scrubbing method for absorbing NH_3 and CO_2]. Since NH_3 and H_2O are polar substances that can interact electrically in this system, electrolyte NRTL method (ELECNRTL) was used [40]. The reaction model also consists of both the equilibrium reactions and the rate-controlled reactions. There are R1, R3 and R4 in the equilibrium reaction and R5–R8 in the rate-controlled reaction. The parameter values for each reaction according to Equations. 1 and 2 are already given in Table 5.

Improvement of Il+Mea+H_2O-Based Process for Energy Consumption Optimization

To optimize the energy consumption of the newly proposed IL+MEA+H_2O-based process, the process should be improved as shown in Figure 5.

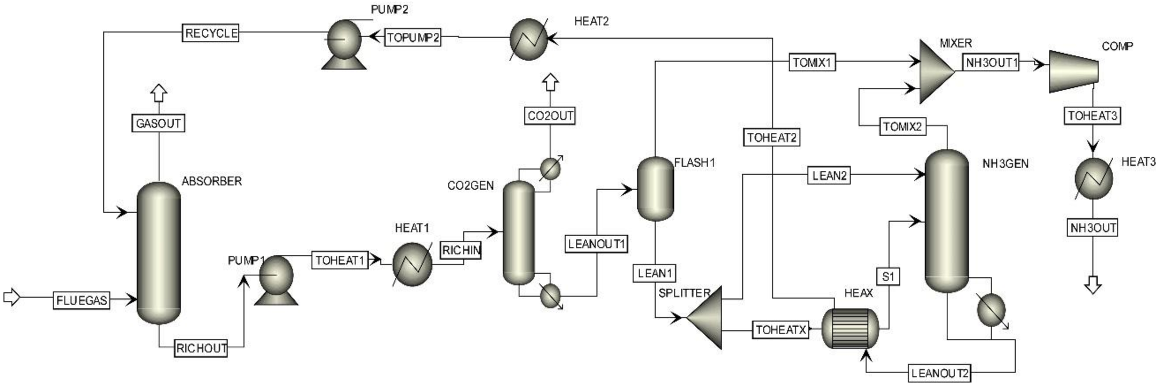

Figure 5. Improved IL+MEA+H_2O-based process for energy consumption optimization.

Before stripping the solvent stream from the bottom of the CO_2 stripping column in the NH_3 stripping column, the appropriate amount of NH_3 gas was first stripped through a flash evaporator. Then, some of the liquid phase is heat exchanged with the lower outlet of the NH_3 stripping column and supplied to the middle of the column under heated conditions. The remaining liquid is supplied directly to the top of the column without heating. The preheated liquid is supplied in the middle of the NH_3 stripping column and heat exchange between the lower hot stream of the stripping column and the cold stream of the flash evaporator, thereby reducing the energy consumption compared to the previous process. In the improved process, simulations were performed by varying the CO_2 contents in the flue gas.

Results and Discussion

Comparison of Conventional H_2O-Based Process with IL+MEA+H_2O-Based Process

The conventional process using H_2O and the process using blend solvents were simulated and compared using waste gas feed streams with different CO_2 contents (10–40% CO_2) and flow rates (0.1, 1, 5 and 10 kmol/s). Blend solvent composition was 30% IL, 30% MEA and 40% H_2O. Figure 6 shows the total regeneration energy with CO_2 contents and flow rates of flue gas. The total regeneration energy is expressed as the energy used for solvent regeneration (reboiler duty) for unit mass of CO_2+NH_3 mixed gas stripped from solvent. In the conventional H_2O process, instead of the reboiler duty in the NH_3 stripping column, the heat duty in the flash evaporator is used.

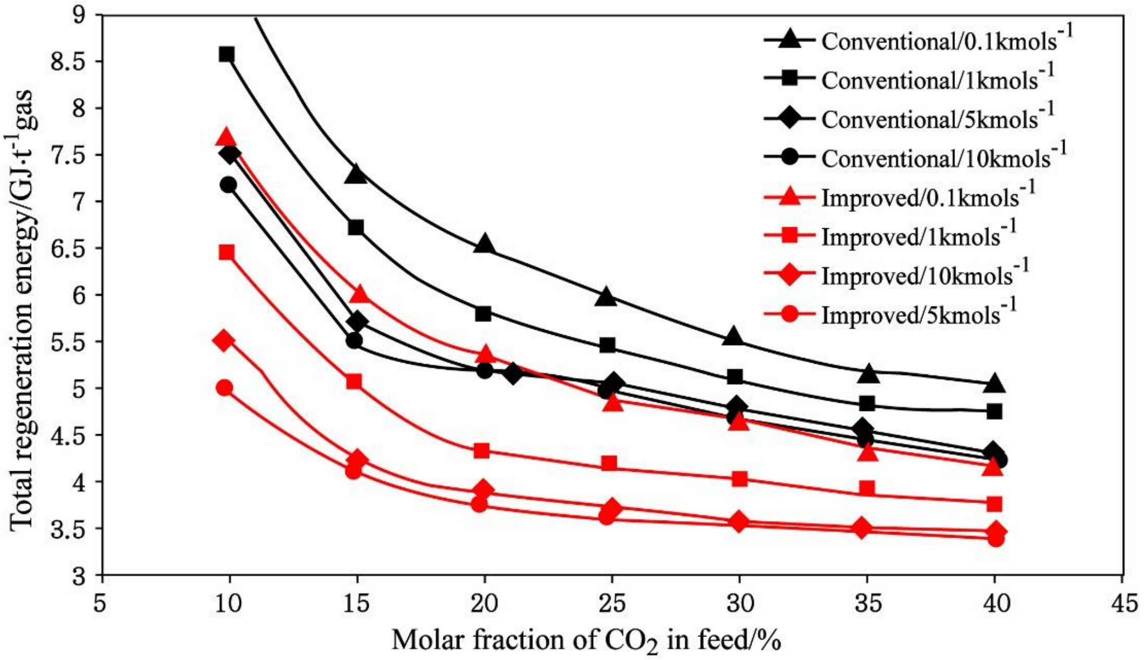

Figure 6. Total regeneration energy between the processes using H_2O and IL+MEA+H_2O.

As shown in the Figure, the total regeneration energy of the H_2O-based process has a direct relationship with CO_2 contents and total feed gas flow rates in all cases. Like the conventional H_2O process, the total regeneration energy in the IL+MEA+H_2O process also varies with the total feed gas flow rate and the waste gas feedstock CO_2 contents. As the feed gas flow rate increases, the total energy regeneration tends to decrease, but at 5 kmol/s there is difference (less than 15%), but at higher CO_2 content (more than 30%), there is no change. In addition, the higher the CO_2 content in the flue gas, the total regeneration energy, regardless of the absorbing solvent, also decreases, and the reduction rate also varies with the feed flow rate. At high flow rates (5 and 10 kmol/s), the total regeneration energy is less variable with the content of CO_2 if the content of CO_2 in the waste gas feedstock is more than 30%. This is because the consumption of H_2O in the conventional process increases with increasing CO_2 content, and the absorption efficiency of IL in the process using blend solvents increases, reducing the energy consumption used to recover the solvents. As a result, regardless of the total feed gas flow rate and CO_2 content of flue gas, the process using the newly proposed blend solvent has less regeneration energy than the conventional H_2O process. In particular, the IL+MEA+H_2O process is reasonable compared to the H_2O process because more energy is saved in the case of high CO_2 content.

Effect of Il Concentration in Blend Solvent-Based Process

The concentration of ionic liquid is an important operating factor affecting the reboiler duty of stripping columns and absorption properties of gas. In general, absorption increases with increasing ionic liquid content. However, ionic liquids must limit their amount because of their high manufacturing cost and high energy consumption. Therefore, considering the economics in the process using blend solvents, simulations were carried out using feed flue gases with wide CO_2 contents and different flow rates, varying the concentration of ionic liquid in blend solvents from 0 to 30%. Since [Bim] [NTf_2] is effective for the NH_3 absorption, it is possible that the uptake of CO_2 can be reduced, whereas the MEA content was kept constant at 30% to prevent this. The variation of total regeneration energy with the content of ionic liquid in the IL+MEA+H_2O-based process is shown in Figure 7.

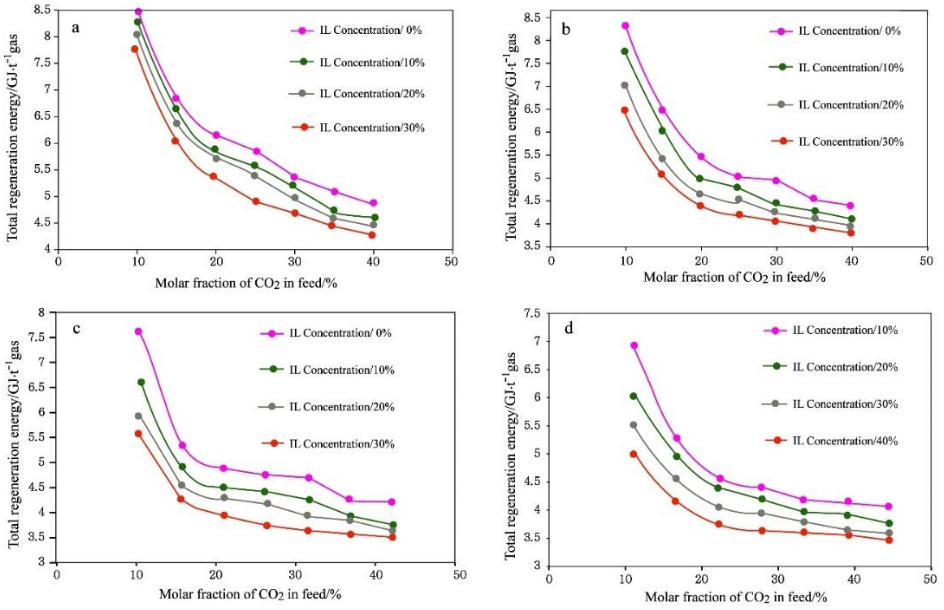

Figure 7. Effect of ionic liquid concentration: total gas flow rates (a) 0.1kmol/s, (b) 1kmol/s, (c) 5kmol/s, and (d) 10 kmol/s.

As shown in the Figure, the low content of CO_2 in the flue gas, regardless of the content of ionic liquid, increases the amount of ionic liquid and increases the total regeneration energy. However, the high CO_2 content decreases the amount of ionic liquid, while the amount of water increases, so the total regeneration energy decreases. When the content of ionic liquid is low, NH_3 must be absorbed by H_2O, so the amount of total absorbing solvent increases, and when the amount of absorbing solvent decreases, the total regeneration energy decreases. In addition, the lower the IL content is, the higher the total renewable energy consumed in the process is. This is because the amount of MEA is fixed at 30% and the concentration of ionic liquid is low, which increases the amount of water and increases the energy consumption of the process. The increase in ionic liquid content results in a decrease in the energy consumption of the process, leading to an increase in the absorption efficiency of NH_3 by ionic liquids. Therefore, the cost of preparing ionic liquids is expensive, and considering the economics, the optimal ionic liquid concentration is 30%.

Effect of Stripping Pressure

The stripping pressure in the stripping tower not only affects the absorption characteristics but also affects the process devices and other operating conditions. Generally, the higher the stripping pressure is, the easier the gases escape from the absorbing solvent is, and the total regeneration energy of the process is reduced. Figures 8 and 9 show the effect of CO_2 stripping pressure and NH_3 stripping pressure on total regeneration energy. The simulation was performed by varying the content of CO_2 (1–40%) and CO_2 stripping (100–200 kPa) and NH_3 stripping pressure (160–260 kPa) under the conditions of 30% ionic liquid and 10 kmol/s feed gas flow rate.

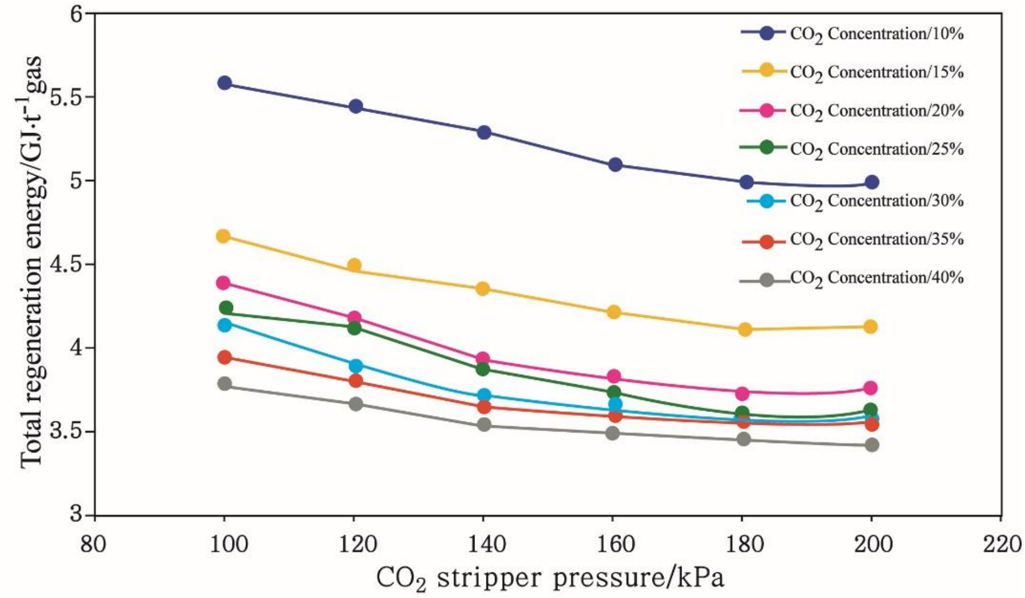

Figure 8. Effect of CO_2 stripping pressure (NH_3 stripping pressure: 240 kPa).

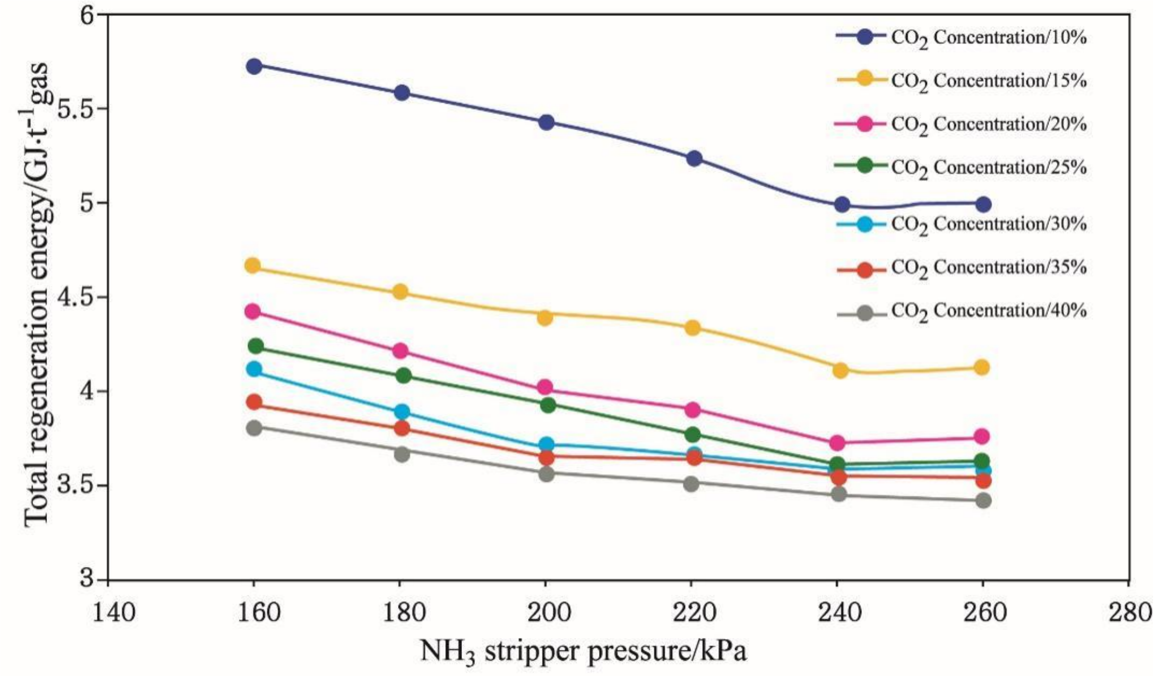

Figure 9. Effect of NH_3 stripping pressure (CO_2 stripping pressure:180 kPa).

The Figure generally shows that as the stripping pressure increases, the total regeneration energy tends to decrease. When the CO_2 content is low, the stripping pressure should be low to reduce the total regeneration energy, and the stripping pressure should be low even when the CO_2 content is high. This is because low stripping pressure makes the stripping of gases easier, so less energy is consumed in the striping tower. This phenomenon also occurs in the NH_3 stripping column shown in Figure 9. As a result, the CO_2 stripping pressure has almost no change in total regeneration energy above 180 kPa, and the NH_3 stripping pressure remains almost unchanged above 240 kPa.

Effect of IL+MEA+H_2O-based process improvements

To reduce energy consumption, the improved process was simulated using waste gas feed streams with different contents (10–40% CO_2) and flow rates of 10 kmol/s. The composition of the blend solvent was 30 wt% IL, 30 wt% MEA and 40 wt% H_2O, and the pressure of the CO_2 stripping column was 180 kPa, and the pressure of the NH_3 stripping column was 240 kPa to compare the total regeneration energy before and after energy optimization.

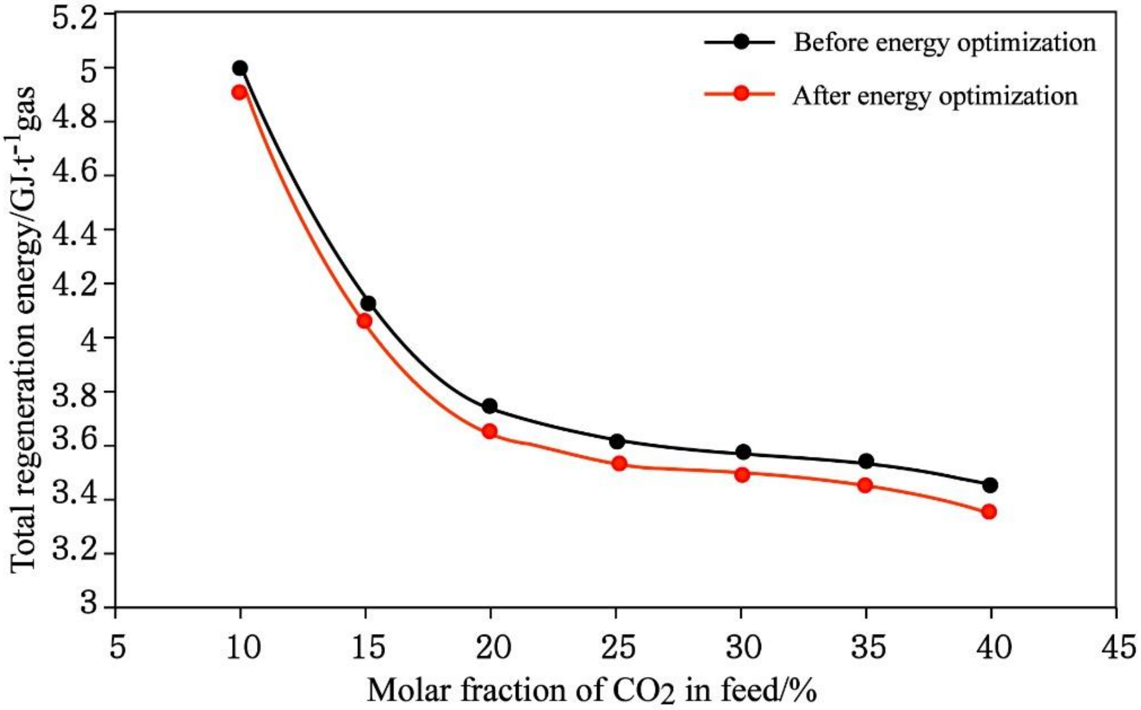

Figure 10. Total regeneration energy before and after improving process.

As shown in Figure 10, after optimization, the energy was saved in the range of 1.6% to 2.9%, compared to before optimization. When the CO_2 content in the waste gas feedstock is 40%, the NH_3 gas content is the least, so that the solvent flow from the CO_2 stripping tower is supplied to the top of the NH_3 stripping tower will consume much energy. However, if only a reasonable amount is supplied to the top of the tower and the rest is preheated through the heat exchanger, the middle part of the process is supplied, which saves the most energy by 2.9%.

CONCLUSIONS

In this paper, an ionic liquid [Bim] [NTf_2] and MEA blend solvent effective for the absorption of NH3 gas were used for the absorption of CO_2 and NH_3 mixed gases. The waste gas obtained from the urea fertilizer plant contains a large amount of CO_2 gas as well as NH_3 gas. To absorb this waste gas, a blend solvent was constructed using an efficient MEA solution for CO_2 absorption and [Bim] [NTf_2] for NH_3 absorption.

The thermodynamic model and kinetic model of MEA-H_2O-CO_2-NH_3-IL system were constructed. And then Aspen Plus simulation data of the blend solvent process and the simulation data of the conventional H_2O-based process were compared using different waste gas sources with a wide CO_2 contents range and flow rate. Regardless of composition and flow rate, the use of blend solvents in all conditions has less total regeneration energy compared to conventional processes. In the IL+MEA+H_2O process, steady-state simulations based on the model were performed to investigate the effects of some conditions. Energy usage decreases with increasing ionic liquid concentration. But the optimum composition is 30% by taking the cost of ionic liquid into account. As the stripping pressure increases, the total energy regeneration also decreases, but there is no change above a certain value. The CO_2 stripping pressure is 180 kPa, and the NH_3 stripping pressure is the lowest energy consumption at 240 kPa. In addition, thermal integration was performed to reduce energy consumption, and the process improvement resulted in a reduction in energy consumption for all waste gas feedstocks, especially at 40% CO_2 content, which saved 2.9%.

The [Bim] [NTf_2] + MEA+H_2O blend solvent proposed in this paper is a green mixed solvent that is very effective for the absorption of CO_2 and NH_3 mixed gases, which can be widely used not only for urea fertilizer plant waste gas treatment but also for other chemical fertilizer plants, livestock production, and pharmaceutical industries.

DECLARATION OF COMPETING INTEREST

The authors state that they have no known competing financial interests or personal ties that could have seemed to affect the work reported in this study.

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