Purification and Upgrading from Biogas to Biomethane

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Biomethane could be upgraded from biogas to increase its heating value, avoid corrosion and eliminate toxicity. The simplest and most common technique for upgrading biogas is absorption process. In this study, two processes between water scrubbing and chemical scrubbing with diethanolamine (DEA) solution integrated with regeneration and recirculation are compared through Aspen Plus simulations. The aim of this study is to find the suitable operational condition in absorption process in order to increase the efficiency of the process in recovery methane and to decrease the energy consumption in the system. Our model was developed by including one additional absorber unit. Results show that the systems, both water scrubbing and chemical scrubbing, can achieve high purity of biomethane of >96 %v/v. In comparison between models for water scrubbing, our proposed system offers higher recovery methane of 4.68 % of and 7,863.07 kW of energy of biomethane. In chemical scrubbing process, our system was able to decrease the pressure of absorber from 55.2 to 10 bar. Consequently, the recovery methane and energy of biomethane were increased while the energy consumption of system was decreased.

Key Words

Biogas purification and upgrading, Diethanolamine (DEA), Biogas to Biomethane

1. Introduction

Bioenergy is one of the promising choices. It is a very attractive renewable energy source 1) 2). Biogas is produced by the process of anaerobic digestion 3). Biogas has properties close to natural gas which can be used as fuel. However, biogas contains some impurities such as hydrogen sulphide (H₂S), water (H₂O) and carbon dioxide (CO₂). Trace components are targeted to while upgrading biogas to biomethane in order to adjust the calorific value and to meet requirements for some gas appliances 4) ~ 6).

There are various biogas purification and upgrading technologies such as absorption (water scrubbing and chemical scrubbing), adsorption (pressure swing adsorption), cryogenic separation, and membrane technology 7). One of the simplest and most common technique is absorption process 8) 9).

In this work we focused on the comparison of two processes between water scrubbing and chemical scrubbing using diethanolamine (DEA) with regeneration of absorbent for purification and upgrading of biogas from swine manure. The absorption processes are modeled in Aspen Plus by considering the quality of biomethane requirement, recovery methane, energy of biomethane, and energy consumption. The systems included with one additional absorber unit were also proposed in order to improve the recovery methane and the energy consumption of the system.
2. Procedures

Water scrubbing and chemical scrubbing models developed in Aspen Plus software were validated with the results reported by Cozma et al. 8) and Niu et al. 9) respectively.

In order to determine a suitable absorbent flow rate required to obtain the desired biomethane according to standard of biomethane quality of E.ON 10) and to calculate the energy consumption needed for the whole process, the process simulations were carried out. The flow diagram for water scrubbing and chemical scrubbing using diethanolamine (DEA) with regeneration and recirculation of absorbent is applied as shown in Fig. 1 to describe physical absorption using NRTL (non-random-two liquid/with ideal gas and Henry’s Law) as the property estimation method. The Radfrac module without a condenser and a reboiler in Aspen was selected to model the absorber and the desorber. To model the absorber and desorber units the equilibrium-stage gas-liquid system was selected. Biogas production from swine farm wastes was used in this work. The compositions of biogas are 68% CH₄, 24% CO₂, 3000 ppm H₂S, 2% N₂, 0.1% O₂, and 5.6% H₂O 11). Biogas is fed from the bottom of absorber 1 while absorbent enters from the top of the column. Both biogas and absorbent are at 30 °C. The number of stages of absorbers 1, 2, and desorber are 7, 5, and 10 respectively. The pressure is reduced from 10 to 1 bar in order to minimize methane loss in the flash column where CO₂-enriched absorbent leaving the absorber 1 is transferred. Water released from this flash column along with the gas containing CO₂, CH₄, H₂S, N₂, and O₂ is fed to absorber 2. The raw biogas is mixed with the gas from the absorber 2. Rich solvent after leaving from the flash column and absorber 2 are sent to a mixer and then fed to the desorption column. Gas such as carbon dioxide and hydrogen sulfide are released from absorbent at a pressure of 3 bar and a temperature of 30 °C. The treated absorbent is recirculated (LIQREG) back to the top of the absorber. Absorbent stream is assumed to recycle continuously in a closed loop.

3. Results and Discussion

The information of pressurized water scrubbing in Cozma et al. 8) and chemical absorption with DEA in Niu et al. 9) were used for validating the absorption models. The results of the gas outlet compositions as shown in Table 1 were found to be in good agreement with those from the studies of Cozma et al. and Niu et al. at their reported conditions, indicating that our models can well represent the physical absorption and chemical absorption.

Both water scrubbing and chemical scrubbing were further simulated in order to find the absorbent flow rate needed for obtaining a 96% v/v biomethane according to standard of biomethane quality of E.ON. The biogas compositions used in the simulations were 68% CH₄, 24% CO₂, 3000 ppm H₂S, 2% N₂, 0.1% O₂, and 5.6% H₂O 11). Moreover, the corresponding values of biomethane purity,

| Parameters         | Cozma et al. 8) | Our simulation | Niu et al. 9) | Our simulation |
|--------------------|-----------------|----------------|---------------|----------------|
| Product gas (mole fraction) |                 |                |               |                |
| CH₄                | 0.967           | 0.956          | 0.837         | 0.842          |
| CO₂                | 0.009           | 0.006          | 0.001         | 0.003          |
| H₂S (ppm)          | 0.006           | 0.000          | <4            | 0.000          |
| N₂                 | 0.011           | 0.023          | -             | -              |
| O₂                 | 0.010           | 0.013          | -             | -              |
| H₂O                | 0.002           | 0.002          | 0.001         | 0.001          |
| DEA                | -               | -              | 0.000         | 0.000          |

Fig. 1 DEA absorption process flowsheet
recovery methane, energy of biomethane, and energy consumption in the system were determined.

Table 2 shows the simulation results of the pressurized water scrubbing system by comparing between the system of Cozma et al. and our system shown in Fig 1. The operational conditions, such as biogas compositions, biogas flow rate, total water flow rate, and pressure of absorber and desorber, were set the same. However, the model of Cozma et al. could not achieve 96% v/v biomethane, the purity according to the quality standard of E.ON. Furthermore, the results of our system showed 4.68% higher in the recovery methane and energy of biomethane was 7,863.07 kW higher than Cozma et al. model. However, the energy consumption of our system was 1,714.41 kW higher than Cozma et al. model. In our proposed system, the numbers of absorber were 2 which offered the increased absorption capacity but demanded higher energy consumption.

Table 2 also shows the simulation results of the DEA scrubbing system by comparing between the system of Niu et al. and our system shown in Fig 1. Mass concentration of DEA solution was set at 30 wt%. Model of Niu et al. used DEA solution flow rate and water flow rate equal to 2,500 and 65.885 kmol/hr respectively and the pressure of absorber as 55.16 bar which was quite high in order to obtain 96% v/v biomethane which resulted in higher overall energy consumption. However, the system of Niu et al. used the quantity of absorbent less than our system while the pressure of absorber was higher than our system which was only 10 bar. In consideration of recovery methane, energy of biomethane, and energy consumption our model was better than Niu et al. model by increase of 12.9%, 21,695.85 kW, and 4,232.23 kW respectively. The solubility increased with increasing pressure which resulted in higher power consumption.

4. Conclusion

In this work the comparison between the previous and our proposed systems for water scrubbing and chemical scrubbing using diethanolamine (DEA) with regeneration of absorbent for purification and upgrading of biogas coming from swine manure were investigated. In the process of water scrubbing and chemical scrubbing in our system could obtain the quality of biomethane requirement according to standard of E.ON. Furthermore, the efficiency of the process in recovery methane and energy of biomethane was higher. In consideration of chemical scrubbing process our system was able to decrease the pressure of absorber from 55.16 to 10 bar. The decreased pressure of absorber increased the flow rate of the absorbent. Consequently, the recovery methane and energy of biomethane were increased while the energy consumption of system was decreased.

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| Parameters | Water scrubbing | DEA scrubbing |
|------------|-----------------|---------------|
| Biogas flow rate (kmol/hr) | 1,000 | 1,000 | 1,000 | 1,000 |
| Total water flow rate (kmol/hr) | 16,000 | 16,000 | 65,885 | - |
| Total DEA solution flow rate (kmol/hr) | - | - | 2,500 | 16,000 |
| Absorbent to biogas ratio | 16 | 16 | 2.5 | 16 |
| P_{absorber} (bar) | 10 | 10 | 55.16 | 10 |
| P_{desorber} (bar) | 3 | 3 | 1.827 | 3 |

Product gas (%)

- CH₄: 93.544, 96.005, 96.076, 96.026
- CO₂: 0.124, 0.320, 0.341, 0.330
- H₂S: 0.000, 0.000, 0.000, 0.000
- N₂: 5.313, 3.098, 3.320, 3.114
- O₂: 0.892, 0.154, 0.163, 0.155
- H₂O: 0.156, 0.424, 0.100, 0.395
- Recovery methane (%) | 85.28, 89.96, 76.57, 89.47
- Energy of biomethane (kW) | 143,532.68, 151,395.75, 128,873.25, 150,569.10
- Energy consumption (kW) | 9,395.52, 11,309.93, 15,563.27, 11,331.04

a Fresh water flow rate: 500 kmol/hr, recirculated water flow rate: 15,500 kmol/hr.
b Fresh water flow rate to absorber 1: 375 kmol/hr, recirculated water flow rate to absorber 1: 11,625 kmol/hr, fresh water flow rate to absorber 2: 125 kmol/hr, recirculated water flow rate to absorber 2: 3,875 kmol/hr.
c Fresh DEA solution flow rate to absorber 1: 375 kmol/hr, recirculated DEA solution flow rate to absorber 1: 11,625 kmol/hr, fresh DEA flow rate to absorber 2: 125 kmol/hr, recirculated DEA flow rate to absorber 2: 3,875 kmol/hr.
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