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Simulation of pressurized water scrubbing process for biogas purification using Aspen Plus

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Abstract. Biogas produced from anaerobic digestion process has a major amount of biomethane (bioCH_4), carbon dioxide (CO_2), and traces amount of impurities. It must undergo biogas cleaning first to remove the impurities depending on the requirement of the applications. Pressurized water scrubbing is the most applicable method for removing CO_2 because of its simplicity, low cost, and low toxicity. This study aims to develop a pressurized water scrubbing process model for biogas purification using Aspen Plus software. Several process parameters such as absorber column pressure and liquid to gas (L/G) ratios were varied to investigate their effects on bioCH_4 purity and percentage of CO_2 removal. The simulated results show good agreement with previous work and agreed well with the typical standard concentration of bioCH_4 of over 95% to be used as vehicle fuels or in a gas grid.

1. Introduction

Attaining solution to the depleting source of fossil fuel and environmental issues due to the use of fossil fuel requires long term possible actions for sustainable development. Renewable energy is a promising option as an effective and efficient way to solve these issues. Biogas is one of the renewable energy resources that has received attention worldwide as it can accommodate the depleting resources of fossil fuel. This renewable energy has a continuous supply of resources such as municipal solid waste, agricultural waste, industrial waste, and kitchen waste. It definitely seems like a promising option to solve the problem of fossil fuel shortage and environmental issue due to usage of fossil fuel and waste management. In terms of environmental issue, biogas engine emission of CO_2 is less than fuel from fossil fuel sources. The burning of fossil fuels over the past century has dramatically increased the levels of CO_2 that traps heat in our atmosphere. The implications of the increasing levels of these greenhouse gases are a serious matter. Concerns about the depletion of fossil fuels, energy security, and emission of greenhouse gas have initiated renewable energy studies.

Biogas is produced from the biological process of the decomposition of organic material in the absence of oxygen [1]. The breakdown or decomposition of organic material is a process called anaerobic digestion. Anaerobic digestion involves four phases, namely hydrolysis, acidogenesis, acetogenesis, and methanogenesis [2]. Anaerobic digestion process for biogas production has become one of the important sources of renewable energy to generate electricity, heating, and transportation fuel, and the digestate can be used as fertilizer. According to Yang et al. [2], biogas produced from anaerobic digestion process has a high amount of biomethane (bioCH_4), carbon dioxide (CO_2), and significant traces amount of impurities such as hydrogen sulfide, hydrogen, nitrogen, oxygen, and ammonia. These impurities can cause corrosion and toxicity and reduce the heating value of biogas. Biogas purification or upgrading has become an important element in the development of the biogas



industry. Due to the impurities in biogas, raw biogas cannot be used directly. Biogas cleaning method may require the removal of a large amount of impurities depending on the requirement of the applications [3]. For instance, the typical standard concentration of bioCH₄ is over 95% to be used as vehicle fuels or in gas grid [4].

Pressurized water scrubbing is the most applicable method for removing CO₂ because of its simplicity, low cost, and low toxicity [1]. The pressurized water scrubbing unit comprises compressor, absorber, flash, and stripper. An absorber that operates at high pressure between 0.8 and 1.2 MPa is used to increase the partial pressure of CO₂ [5], which increases the absorption rate of CO₂ and the attainment of the high purity of bioCH₄ in gas form, leaving the top of the absorber. Since CO₂ is more soluble in water than bioCH₄, it is an advantage to separate CO₂ and bioCH₄ with high efficiency [2]. Flash vessel, operates at low pressure between 0.11 and 0.2 MPa is used to depressurize water coming from the absorber [5,6], to ensure a major portion of gases is desorbed to be recycled into the absorber. Stripper, which uses air as stripping agent operates under ambient pressure to regenerate water from CO₂-rich stream and desorb CO₂ from the water. According to Petersson and Wellinger [7], pressurized water scrubbing method is mainly applied in Germany and Sweden for biogas purification for transportation fuel and gas grid. Despite the advantages of biogas upgrading to bioCH₄ using pressurized water scrubbing technology mentioned before, this process faces multiple challenges in the real-life process. The percentage of CO₂ removal and the purity of bioCH₄ content produced are determined by several parameters such as temperature, pressure, and the amount of fresh water [8]. The main concern of this process is the high water demand [2]. Although water is assumed to be recycled continuously, the amount of evaporated water needs to be replaced, and it requires high water demand to increase the absorption capacity in the column. The performance of this process can be improved by operating it at optimum process conditions. Experimental work to investigate the optimum process condition will be costly and time-consuming.

Therefore, this study aims to apply a simulation approach to elucidate the effect of different operating parameters on the purification of biogas to remove impurities. Simulation approach can greatly reduce the cost of the process before real-life operation by optimizing the operating parameters involved. Aspen Plus software was applied in this study to develop a biogas purification using pressurized water scrubbing method. The model was compared against data reported by Cozma et al. [8].

2. Process simulation model

The process simulation model for high-pressure water scrubbing process was developed using Aspen Plus software. The steps to build a simulation using Aspen Plus cover the selection of the property method, the list of component setup, and the creation of a process flowsheet in the simulation environment. The thermodynamic properties package used in this simulation is the nonrandom-two-liquid (NRTL) method because most of the components used in this process simulation are polar mixtures and suitable for pressure up to 10 bar.

The composition of raw biogas in FEED stream is tabulated in Table 1. The process flow sheet of the pressurized water scrubbing process for biogas purification is depicted in Figure 1. The process conditions and input data applied in this study were obtained from Cozma et al. [8].

Table 1. Biogas input specifications [8]

Components	Mole composition (%)
Methane	60
Carbon dioxide	38.9
Hydrogen sulphide	300 ppm
Nitrogen	0.5
Oxygen	0.5

The biogas enters the bottom of the absorber after being pressurized to 10 bar in compressors (COMP1, COMP2) while pressurized water is fed from the top of the absorber. The PRODUCT gas, which contains a high amount of bioCH₄, leaves through the top of the absorber and the CO₂-enriched

water leaving the absorber is sent to the flash column. The flash column pressure is set at 3 bar to minimize bioCH₄ losses. The gas released from the flash column containing CO₂, bioCH₄, hydrogen sulfide, nitrogen, oxygen, and water is mixed with raw biogas in the mixer and recycled through the inlet of the compressor, COMP2. The liquid solution leaving the flash column is transferred to the desorption column (STRIPPER) where it meets a counter-current flow of hot air. CO₂ and hydrogen sulfide are separated from water at atmospheric pressure and temperature of 1 atm and 20°C, respectively. Water is recycled back to the top of the absorber.

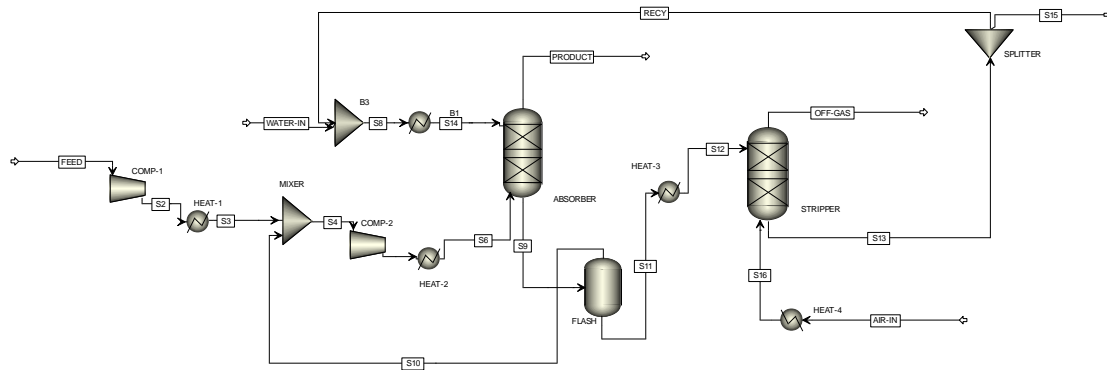


Figure 1. Flow sheet of pressurized water scrubbing process in Aspen Plus

3. Results and discussion

The FEED stream had a total of 604.6 kg/h biogas and 5000 kg/h water [8]. The process condition and column specification are presented in Table 2. The amount of bioCH₄ purified in the PRODUCT stream and the percentage of CO₂ removal in the OFF-GAS stream are considered as the main outputs from this simulation. Table 1 displays the comparison between the results obtained by Cozma et al. [8] and the present study. The percentage of CO₂ removal and bioCH₄ purity in this study was slightly higher than those in Cozma et al. [8]. This is due to the absorber column pressure and the number of theoretical stages chosen were slightly higher than those reported in Cozma et al [8], to minimize the differences of bioCH₄ purity and percentage of CO₂ removal between this study and Cozma et al. [8]. The product gas leaving the absorber mainly contained bioCH₄ with 97.6 mole % and traces amount of CO₂, hydrogen sulfide (H₂S), oxygen (O₂), and nitrogen (N₂). The purity of bioCH₄ in the PRODUCT stream is suitable for gas grid and vehicle fuel which require more than 95 mole % bioCH₄ purity. The percentage of CO₂ removal obtained from this study was slightly higher than that from Cozma et al. [8] which is 99.9 mole %. This model shall further be used for sensitivity analysis to study the effect of absorber pressure and liquid-to-gas ratio (L/G) on bioCH₄ purity and percentage of CO₂ removal.

Table 2. Comparison base-case simulated results

Parameters	Cozma et al. (2014)	This study
P _{absorber} (bar)	8	10
T _{absorber} (°C)	20	20
T _{stripper} (°C)	20	20
P _{flash} (bar)	3	3
P _{stripper} (bar)	1	1
Number of theoretical stages (absorber)	11	18
CO ₂ removal (%)	99.12	99.93
Product gas (mole fraction)		
CO ₂	0.00397	0.000338
bioCH ₄	0.965	0.976
H ₂ S	0.000094 ppm	0.000088 ppm
N ₂	0.0209	0.0106
O ₂	0.00563	0.0092

Parameters	Cozma et al. (2014)	This study
H ₂	0.000902	-
H ₂ O	0.00319	0.00348
Off gas (mole fraction)		
CO ₂	0.171	0.1065
bioCH ₄	0.000677	0.01151
H ₂ S	38 ppm	82 ppm
N ₂	0.635	0.688
O ₂	0.168	0.160
H ₂	0.193 ppm	-
H ₂ S	0.0234	0.03381

3.1. The effect of absorber pressure

The absorber column provides intimate contact of the biogas with water so that the CO₂ molecules can be transferred from the gas phase into the liquid phase. The analysis of various pressures setting for absorber was conducted to investigate its effect on bioCH₄ purity and CO₂ removal efficiency. Figure 2 depicts the bioCH₄ composition and percentage of CO₂ removal for pressure setting between 5 and 20 bar. The purity of bioCH₄ and CO₂ removal efficiency is increasing along with the pressure of absorber. Pressurized water scrubbing is a physical absorption process that requires high pressure to increase the solubility of CO₂ in water [9,10]. At 10 bar, the bioCH₄ purity and CO₂ removal efficiency remained constant and did not affect the performance of CO₂ absorption. Higher pressure up to 10 bar gives better performance of CO₂ absorption. However, increasing the pressure absorber will result in higher power consumption and cost. Hence, the optimum pressure for absorber for this process is 10 bar.

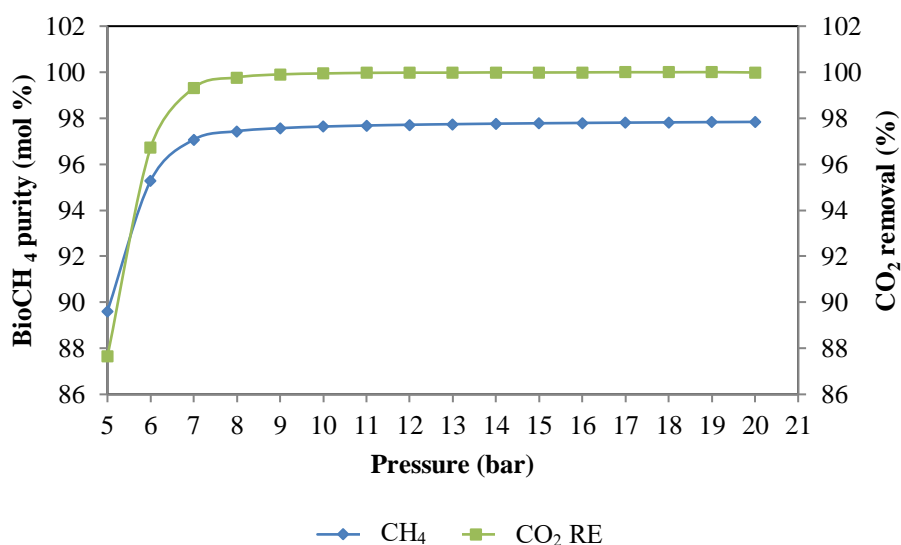


Figure 2. Effect of absorber pressure on bioCH₄ purity and CO₂ removal

3.2. Effect of L/G ratio

The flow rate of feed biogas was kept constant at 604.6 kg/h, and only the flow rate of water was varied. The effect of L/G (water flow into the absorber with biogas inlet flow) ratio on bioCH₄ purity and CO₂ removal is illustrated in Figure 3. The CO₂ removal efficiency increases along with the ratio of L/G. A higher flow rate of water increases the area for mass transfer process between gas and liquid, which increases the mass transfer coefficient since more water molecules are available to dissolve CO₂ [10]. Hence, a higher amount of solvent used increases the rate of gas absorption in the solvent. At the ratio of 10, the CO₂ removal is nearly complete at 99.9%. The L/G ratio of 10 shows a slight decrease in bioCH₄ purity in the product gas. It might be due to some of bioCH₄ dissolved in water as the ratio is high. Hence, at the ratio of 10, the bioCH₄ purity slightly decreases to 97.5% from 97.6% at the ratio of 9.

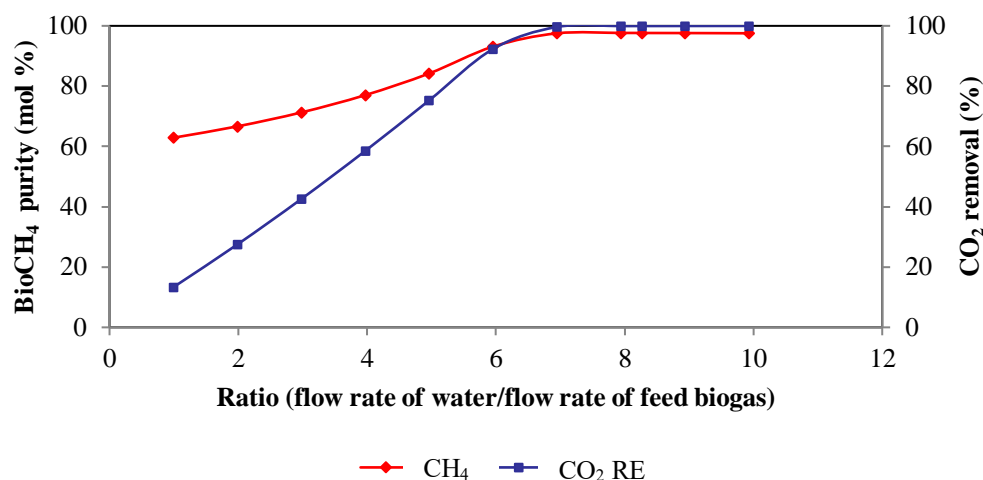


Figure 3. The effect of L/G ratio on bioCH₄ purity and CO₂ removal

4. Conclusions

A simulation of biogas purification to produce bioCH₄ was carried out using Aspen Plus software. The simulation to purify biogas gave a result of 97.6 mole % bioCH₄ purity and 99.9 mole % CO₂ removal. It was pointed out that the influence of absorber column pressure and liquid to gas (L/G) ratio significantly affected bioCH₄ purity and percentage of carbon dioxide removal. Increasing the absorber column pressure up to 10 bar increased the solubility of CO₂ in water and purification of bioCH₄. As the flow rate of fresh water was increased, more CO₂ dissolved in water, and it increased the bioCH₄ purity and CO₂ removal efficiency. It shows that more carbon dioxide can be removed in a high amount of fresh water.

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