Aspen Plus Simulation Model for Biogas CO_2 Reduction with Low Pressure Water Scrubbing

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ABSTRACT

Biogas is an alternative energy that can be obtained from the anaerobic degradation process of organic matter. The high carbon dioxide (CO_2) content in biogas needs to be reduced, even if it can be removed so that the quality and heat value of biogas increases. The water scrubbing method is a method that can be applied to reduce CO_2 biogas. However, to get high-quality biogas using the water scrubbing method it is necessary to add external pressure and a high enough scrubber column. Besides, pressurized water scrubbing also requires a higher electricity cost (0.34 kWh m-3 of raw biogas) compared to water scrubbing at low or near atmospheric pressure (0.24 kWh m-3). In this research, simulation modelling was carried out using Aspen Plus to reduce CO_2 biogas by water scrubbing at low pressure, using a packing sponge. The sensitivity of the system performance was tested against variations in column pressure, the number of scrubber stages, and the liquid-to-gas ratio (L/G ratio). The Aspen Plus simulation results show that that increasing the number of columns can reduce CH_4 losses and optimal operation under low pressure conditions is achieved at a scrubber column pressure of 1.4atm with an L/G ratio of 10.5 in the design of the number of stage scrubber columns of 5 pieces with pure biogas production levels reached 96.7%.

Keywords: *Water Scrubber, Biogas Purification, Low Pressure, Aspen Plus Simulation*

1. INTRODUCTION

Biogas is a bioenergy which is a renewable energy product. In general, the composition of biogas consists of 50-70% methane (CH4), 25-45% carbon dioxide (CO2), the rest is a small amount of gas including H2S [1] [2] [3]. The main component with a relatively high energy content is CH4 which can be used as fuel in the combustion process. However, the percentage of biogas methane is relatively low because there is quite high CO2 gas. This can be a problem especially if it is used as generator fuel or an internal combustion engine, because of the nature of CO2 which can reduce the value of heat, disrupt the combustion process, and is corrosive.

There are several biogas purification methods, including physicochemical absorption, pressure swing adsorption (PSA), membrane separation, cryogenic separation, and the use of biological technology [4]. Since these purification methods have their respective characteristics, a suitable technology should be selected taking into account the purification efficiency, operational conditions, investments and maintenance costs [5]. PSA and wet scrubbing or water scrubbing are very popular. However, the PSA process is more complex than water scrubbing [6], due to the difficulty of operating PSA in controlling high temperature and pressure, limiting the application of this method to a wider scale [7].

In contrast, high pressure water scrubbing is the most commercially viable technology due to its simplicity and reliability of performance [8]. However, there are drawbacks to high pressure water scrubbing in terms of the high specific electricity cost of 0.34 $kWh.m^{-3}$ of raw biogas [9]. Whereas water scrubbing is closer to atmospheric pressure, the specific electricity cost is lower, namely 0.24 $kWh.m^{-3}$ of raw biogas [10]. In addition, the direct biogas output from the bio-digester is at a pressure close to atmospheric pressure. Research using a water scrubber with polyurethane sponge packing results in better performance due to increased hydraulic retention times. The experimental results show that this scrubber model can perform high biogas purification under atmospheric conditions with a column length of only 120 cm. By using artificial biogas with a methane content of 60% can be purified to more than 90% methane without detection of hydrogen sulfide, this quality can be used as city gas [11]. In this study, a simulation model of biogas CO_2 absorption by water scrubbing will be carried out using Aspen Plus software.

2. RESEARCH OBJECTIVES

The purpose of this research is to create a simulation model using Aspen Plus software to reduce CO_2 biogas by using the water scrubbing method, at low pressure biogas conditions (moderate close to atmospheric pressure). The system performance sensitivity was tested against variations in column pressure, number of scrubber stages and L/G ratio to obtain optimal system configuration and operating parameters.

3. SIMULATION METHOD USING ASPEN PLUS

The NRTL Electrolyte activity coefficient model uses binary and paired parameters, which represent the aqueous electrolyte system as well as the mixed solvent electrolyte system over the entire electrolyte concentration range. The NRTL electrolyte model uses infinite dilution solutions to calculate the transformation of the ion reference state, so that water must be present in the electrolyte system. The NRTL electrolyte model was used to calculate the Aspen system physical properties consisting of the activity coefficient, enthalpy, and Gibbs energy for the electrolyte system. The NRTL electrolyte model has adjustable parameters, namely: the dielectric constant coefficient of the pure component of the non-aqueous solvent, the radius of birth of ionic species, and the NRTL parameter for the molecular, molecular-electrolyte, and electrolyte-electrolyte pairs.

Initially the NRTL electrolyte model was initiated by Chen et al. [12] [15], for aqueous electrolyte systems. This model was later extended to a mixed solvent electrolyte system by Mock et al. [13] [14]. The model is based on two basic assumptions: First, the similar-ion repulsion assumption which states that the local composition of the cations around the cations is zero (and so it is for the anions around the anions). Second, the local electroneutrality assumption which states that the distribution of cations and anions around the central molecular species is such that the net local ionic charge is zero.

Chen then proposes the Gibbs energy excess equation consisting of two contributions: one contribution to the long-distance ion-ion interaction that exists outside the immediate environment of the central ionic species represented by the asymmetric Pitzer-Debye-Hückel model and the Born equation, and the other is related to local (short-range) interactions in the immediate environment of any major species represented by the Non-Random Two Liquid (NRTL) theory.

The Electrolyte NRTL method equation of state are used to compute liquid and vapor properties respectively in this equilibrium model. The accuracy of estimating the molecular and ionic component molecular fractions considered in the reaction process equation model is based on the accuracy of the kinetic data and their equilibrium constants. Aspen Plus uses several reactions for ionization of acidic components. In this case, the equilibrium and stoichiometry of the acid gas reaction that occurs are presented.

Reaction 1: $H_2O + HCO_3^- \leftrightarrow CO_3^{-2} + H_3O^+$
Reaction 2: $2\ H_2O + CO_2 \leftrightarrow HCO_3^- + H_3O^+$
Reaction 3: $H_2O + HS^- \leftrightarrow H_3O^+ + S^{-2}$
Reaction 4: $H_2O + H_2S \leftrightarrow H_3O^+ + HS^-$

CO_2 is a weak electrolyte that can dissolve into ions in water as shown in reaction number 2. The equilibrium of this reaction can cause partial dissociation of CO_3^{-2} as shown in reaction number 1.

The initial simulation system configuration is shown in Figure 1 with raw biogas input and scrubber water output at the bottom of the scrubber column, while at the top of the scrubber column there is raw water input and pure biogas output. The scrubber column used RadFrac block without using condenser and re-boiler. The packing used was sponge packing with a size of 384 m2/m3. In this initial simulation, the size of the column diameter used is 12 inches with a total of 6 stages, with a height of each stage of 60 cm. The raw biogas composition data used in this simulation are shown in Table 1 with a volume fraction of CH4 60%, CO2 38.97%, H2S 0.03% and N2 and H2 0.05%. In the initial simulation used a column pressure of 1.3atm with a raw biogas flow rate of 320 kg/h and the water flow rate is 3,500 kg/h so the initial L/G ratio is 10.9375.

Table 1. Initial raw biogas composition for simulation

Components	Mass Flow (kg/h)	Mass Fraction	Mole Flow (kmol/h)	Mole Fraction
CH_4	113.7173	0.355366	7.088386	0.6
CO_2	202.617	0.633178	4.603907	0.3897
H_2S	0.120793	0.000377	0.003544	0.0003
N_2	1.654753	0.005171	0.05907	0.005
O_2	1.890165	0.005907	0.05907	0.005
Total	320	1	11.81398	1

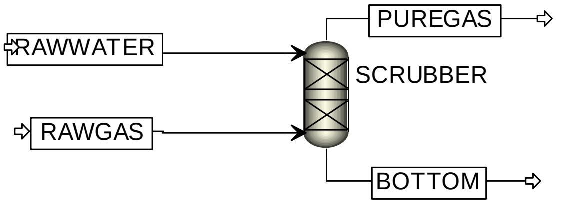

Figure 1. Simulation design of a water scrubbing system with Aspen Plus

4. RESULTS AND ANALYSIS

The first step is conducting a sensitivity analysis to see the behavior of this LPWS system / technology against the number of stage to meet the proper operation. The simulation results can be seen in Figure 2, the absorption of N_2 and O_2 shows a very small average value, respectively 0.786% and 1.409% with a relatively constant rate pattern. While the CH_4 content of pure biogas increases rapidly at the beginning of the process then slows down, it can be said that the rate of change is getting smaller and the asymptotic graph pattern is seen at the number of stages of 5 and above which indicates the rate of addition is near zero. This also means that CO_2 absorption decreases with the increase in the number of column stages. Interestingly, the larger the number of stages it turns out that the CH_4 losses are getting smaller and it looks closer to constant at the number of stages of 5. So on this basis the sensitivity analysis on the L/G ratio and the pressure of the scrubber column was applied to the number of stages 5 pieces.

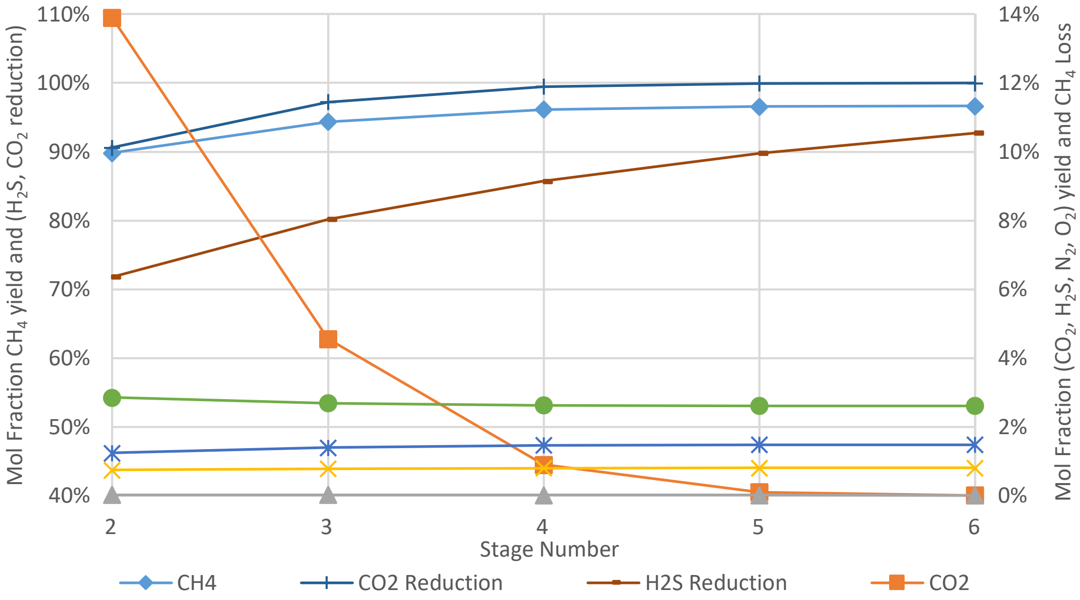

Figure 2. Effect of stage number on composition of pure Biogas yield, CH4 loss, CO2 and H2S reduction at initial state (scrubber pressure= 1.3 atm and L/G ratio= 10.9375)

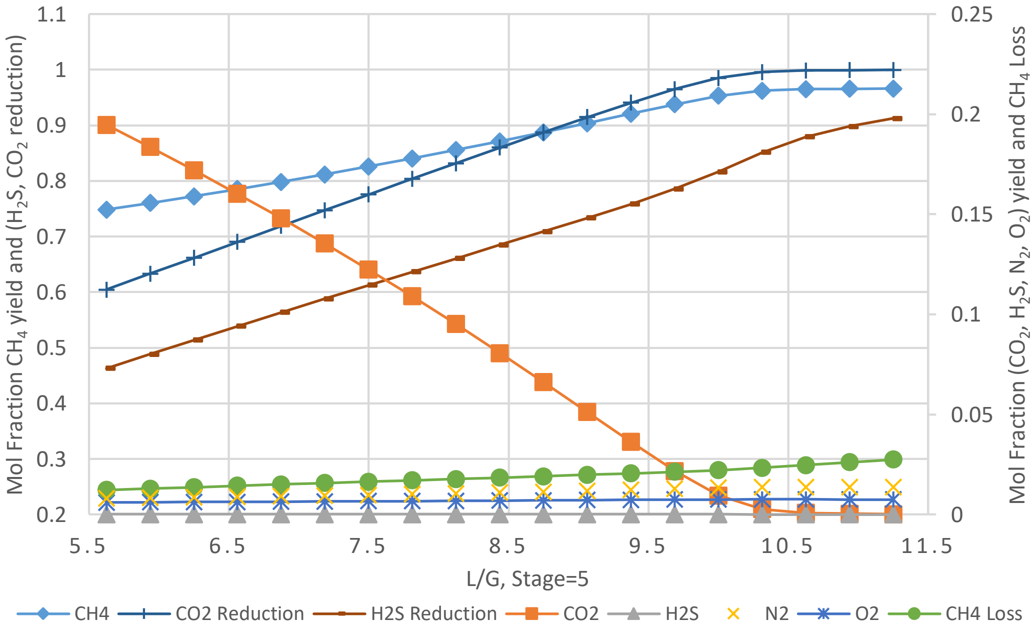

Figure 3. Effect of L/G ratio on composition of pure Biogas yield, CH4 loss, CO2 and H2S reduction at stage number=5

Figure 3 shows the results of the second sensitivity analysis carried out on the L/G ratio on the number of stage scrubber columns of 5 pieces. The results of the sensitivity analysis showed that an increase in the L/G ratio could increase the level of biogas purity up to 96.6%, although the amount of CH4 losses increased with the increase in the L/G ratio. In order to save raw water usage and reduce CH4 losses and from the graph pattern of CO2 levels in pure biogas it looks flat at an L/G ratio of 10.5, an L/G value of 10.5 is chosen for the sensitivity analysis to the pressure of the scrubber column.

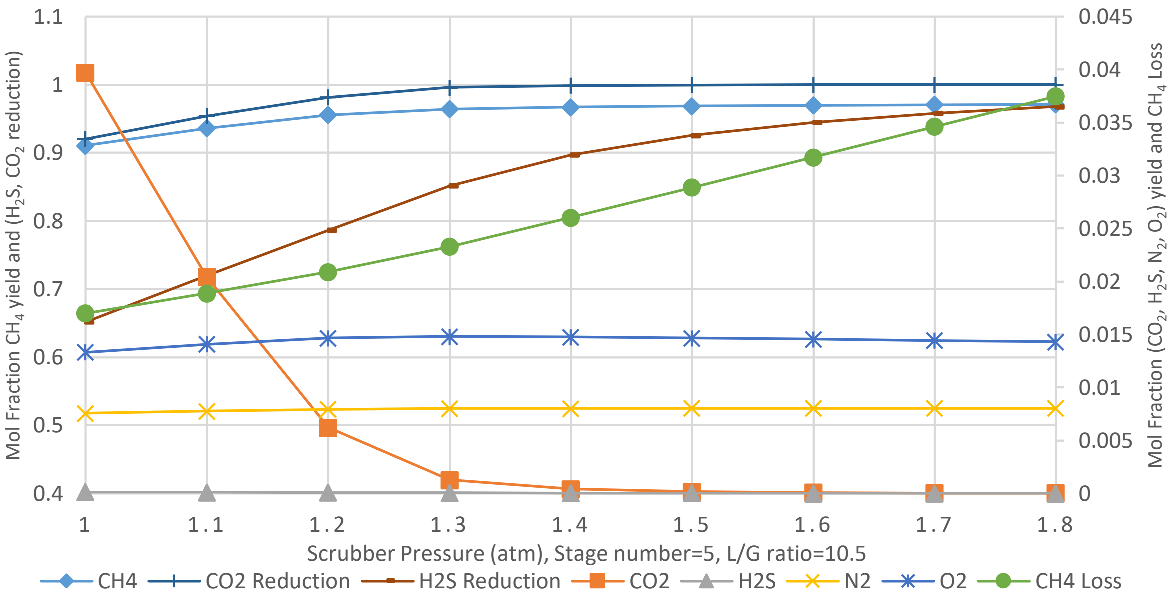

Figure 4. Effect of scrubber pressure on composition of pure Biogas yield, CH4 loss, CO2 and H2S reduction at stage number=5 and L/G ratio=10.5

Finally, the last sensitivity analysis to the column scrubber pressure was applied with the results shown in Figure 4. Increasing the column pressure can reduce CO_2 but increase CH_4 losses. In the graph pattern of CO_2 reduction at the pressure value column 1.4atm and above shows an asymptotic pattern. So that the configuration and operation of the best LPWS technology with the number of column stages is 5 pieces, the value of the L/G ratio is 10.5 and the scrubber column pressure is 1.4 atm. In this option, the operating characteristics of the LPWS system had a CO_2 reduction rate of 99.89%, an H_2S reduction of 89.7%, a CH_4 loss rate of 2.6% and a volume fraction of CH_4, H_2S, CO_2, N_2 and O_2 in pure biogas is 96.7%, 46 ppm, 407 ppm, 0.803% and 1.48%.

5. CONCLUSIONS

The contribution of this work is to produce a sensitivity analysis of the low pressure water scrubber column to the number of column stages, the L/G ratio, and the scrubber column pressure. From the correlation of the data and graphic patterns obtained, in order to maximize biogas purity and minimize raw water use, it can be concluded that:

1. The larger the number of stage column scrubbers, the smaller the proportion of CH_4 losses

2. The best number of stage scrubber columns is designed as many as 5 with optimal operation at a scrubber column pressure of 1.4atm with an L/G ratio of 10.5 with pure biogas production reaching 96.7% by volume of CH_4.

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