INVESTIGATION OF EMISSION CHARACTERISTICS OF PURIFIED BIOGAS IN SI ENGINE

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Abstract— *Biogas typically refers to a mixture of gasses produced during the breakdown of biodegradable organic matter in the absence of oxygen. It is primarily comprises 45-75% (v/v) of methane (CH4), 25-55% (v/v) of carbon dioxide (CO2), 2000 ppm of trace element hydrogen sulfide (H2S), and ammonia (NH3). The presence of CO2 and H2S may affect the performance of biogas. Hence, its removal before its use is crucial to improve the quality of biogas. In this work, a method to purify both gasses, CO2 and H2S were employed by using a sodium hydroxide solutions (NaOH). CH4 composition after treatment was also studied as removal of impurities is interrelated to CH4 enhancement. The concentrations of sodium hydroxide were varied as well as the biogas flow rate. Experiments that revealed the highest removal efficiency had been achieved at 14% concentration of sodium hydroxide solution used and the maximum absorption capacity was achieved when CH4 increment is about 54.9% from its original value. In the continuous flow, the composition of CH4 increased up to 26% of H2S removal, however, was unable to achieve the target due to its low concentration (ppm) in biogas mixtures. Hence, there are no significant changes in its concentration that are worth to be analyzed.*

1. INTRODUCTION

The rapid growth of world population combined with drastic economic development can cause drastic increase energy in demand. Currently, the main energy supply is from carbon-containing fossil fuel sources like oil and natural gas. However, these sources produced the non-renewable type of energy and are said to be depleted soon. Finding of fossil fuel now involves deep sea exploration (as most oil shores are already depleted) which cause an increase in drilling cost. Eventually, the scarcity of the raw sources has led to an increase in the price of fossil fuels in the market over the years. Apart from that, the fossil fuels need to be combusted to obtain the energy needed. The combustion of the fossil fuels contributes to the emission of the largest greenhouse gasses like carbon dioxide into the atmosphere which could cause global warming. Concerning over global warming issues and because of too many negative impacts, many countries have now moved towards the generation of cleaner and greener energy as an alternative energy source. One example of the green energy that could be used is biogas. Biogas is preferred sources as it is much cheaper and environment friendly. The sources for biogas production could be from readily available raw materials like animal manure, fruit, and vegetable waste, food processing industries waste as well as municipal solid waste (MSW). Utilization of these sources is said to serve two functions, which are converting waste to energy and fertilizer application purposes [1, 2].

After its production, biogas has to be further processed into biomethane using purification. The transformation of biogas into biomethane generally involves two major steps; (1) a cleaning process to remove the trace components, H_2S, water vapor, NH_3, particles, etc. and (2) an upgrading process to adjust the calorific value and relative density in order to meet the specifications of the Wobbe Index [3]. Upgrading biogas to natural gas quality is a multiple step procedure. Various technologies are available to remove contaminants or trace elements from biogas being produced, leaving more methane per unit volume of gas. Separation of H_2S from the gas stream can be achieved through chemical absorption in aqueous solutions, physical absorption on solid adsorbents and conversion to base Sulfur or low solubility metal sulfide. There are also some techniques to remove CO_2 gas. For example absorption by chemical solvents, physical absorption by water scrubbing, cryogenic separation, membrane separation and CO_2 fixation by biological or chemical methods [4].

Chemical absorption involves the formation of reversible chemical bonds between the solute and the solvent. Regeneration of the solvent, therefore, involves breaking of these bonds and correspondingly, a relatively high energy input. It has reported by the previous researcher [5] that the advantages of chemical absorption for biogas purification including complete H_2S removal, the ability to operate at low pressure and high efficiency and reaction rates compared to water scrubbing. Several works have also been developed to model mass transfer in the gas-liquid absorbing system, just like absorption of CO_2 and H_2S in sodium hydroxide solution [6]. In that study on amine that H_2S and CO_2 absorption in packed columns, it has been concluded that amine mass transfer is not limited by a chemical reaction but the mechanical diffusion or mixing of the gas with the liquid and by the absorbing capacity of amine.

The focus of this study is to study the efficiency of sodium hydroxide (NaOH) for removal of CO_2 by absorption of biogas into three different concentrations and to study the absorption of biogas in a continuous system.

2. MATERIALS AND METHODS

Preparation of sodium hydroxide solution

400 g, 900 g and 1400 g of solid sodium hydroxide (NaOH) were added into a container containing 10 liters volume of water. This container was then stirred for well mixing to produce a homogenous aqueous solution of sodium hydroxide. Three different concentrations (4%, 9% and 14% w/v) of sodium hydroxide were then produced. The pH also had taken before beginning the experiment. The pH of sodium hydroxide indicated that in the range between 11.3 and 11.6.

Experimental set-up

An experimental approach was used to investigate the suitability of sodium hydroxide solution for removal of CO_2 from biogas. The biogas mixture was contacted with the solvent which preferentially absorbs the desired impurities from the biogas stream. The concentration of solvent was the variables that had been set in this separation process. An absorber column was designed and constructed with a diameter of 10 cm and length of 250 cm and contained a packing media like bioball. The experiment was conducted using actual biogas from biogas compressor tank at Biogas Pilot Plant, Salak Tinggi, Nilai Selangor Malaysia. Flow scheme of the biogas purification system is presented in Fig 1.

The actual volume of the column is 0.02 m3 (20 liters). For safety margin, a working volume of 0.01 m3 was chosen to prevent the sodium hydroxide solution from overflowing in the case of high pressure when the biogas is introduced from the bottom column. Fig. 2 shows the equipment set up for biogas purification.

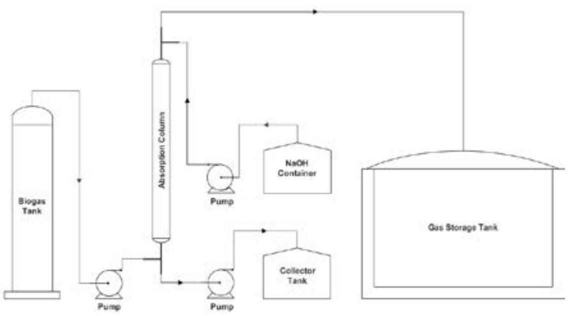

Figure 1. Scheme of the biogas purification system

Figure 2. Absorber Column Set-up

Biogas measurement and analysis

Firstly, biogas composition in the gas compressor before purification was analyzed and recorded. A hose then attached to the bottom column connecting to biogas compressor and a valve attached to the gas compressor was opened to let the gas flow through and injected into the column tank. The flow rate of biogas entering the column was controlled by adjusting the flow meter located at the neck of a gas compressor. After five minutes, the gas analyzer was attached to the tip of the top column, and reading of biogas compositions was taken and recorded for every five minute for about 50 minutes of operation. Within the 50 minutes period, the end of each run was determined as the point at which liquid solvent became completely saturated, or the reading of CO_2 analyzer is increasing after a period of reduction in its value. This procedure was repeated using the three different sodium hydroxide concentrations in batch flow (4%, 9%, and 14%). The optimum of the three concentrations then tested in a continuous flow. The flow rate of the biogas of batch flow is 0.2 l/min. In this experiments, reading of O_2 and NH_3 were neglected as both gasses do not react with sodium hydroxide solution. Plus purification reaction in this project only concern about the removal of CO_2 and H_2S and enrichment of CH_4.

3. RESULTS AND DISCUSSION

CO_2 Removal Efficiency

Biogas concentration before and after treatment with sodium hydroxide solution, NaOH aqueous were determined using a biogas analyzer (Binder-Germany). Reading of the gas compositions in the column after being bubbled up with different concentrations of sodium hydroxide solution (4%, 9%, and 14%) show the significant results. Different percentages of the composition after purification were obtained. CO_2 especially was seen to be absorbed into the sodium hydroxide solution to a great value for each concentration. Fig. 3 shows the CO_2 reading after purification under different concentrations of sodium hydroxide solution. The flow rate of biogas injected into the bottom column had the same value of 1 l/min.

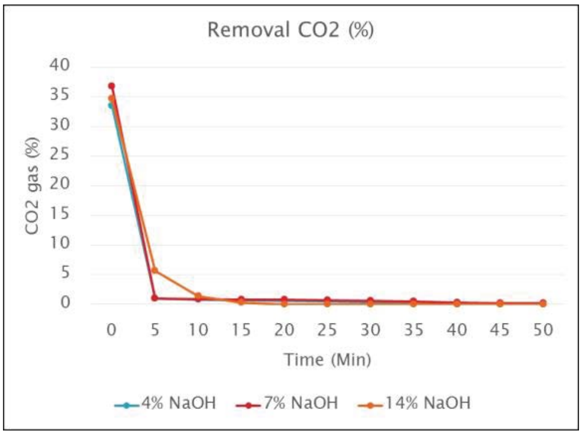

Figure 3. CO_2 composition after treatments at three different sodium hydroxide concentrations with the concentrations of sodium hydroxide solution increasing,

the CO_2 reading dropped drastically to a significant value indicating CO_2 absorption into the sodium hydroxide solution.

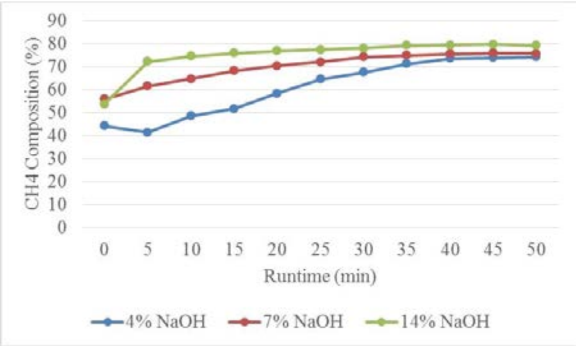

Figure 4. CH_4 composition after treatments at three different sodium hydroxide concentrations

Using data obtained (by taking the CO_2 reading before it is saturated and its CH_4 reading) from the gas analyzer after 50 minutes of contact, CO_2 removal efficiency and CH_4 enrichment were calculated. The calculation for removal efficiency was done by dividing the difference in the initial with the final composition of biogas by the initial composition.

It was found that the concentration of sodium hydroxide plays an important role in the CO_2 removal efficiency.

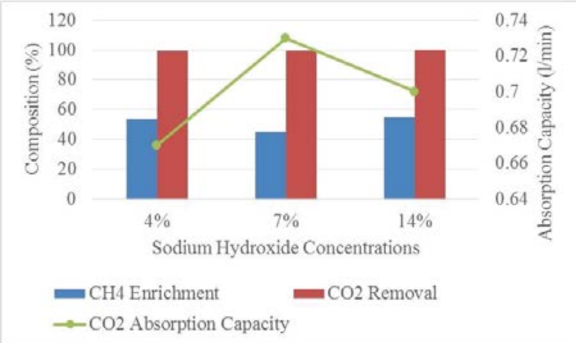

Figure 5. Effect of different concentrations of sodium hydroxide on CO_2 removal and CH_4 enrichment

The result showed that for 14% concentration of sodium hydroxide solution, the 100% removal efficiency could be achieved which result in CH_4 enriched gas about 54.9% purity. This could be due to increasing concentration yields a higher amount of active hydroxide ions available to diffuse toward the gas-liquid interface and react with CO_2. This eventually results in an enhancement of the absorption rate, which leads to a higher CO_2 removal efficiency.

CO_2 Absorption Capacity

According to above figure, the absorption rate shows the highest value when sodium hydroxide concentration used was 7%, followed by 14% concentration and 4% concentration. However, the absorption rate for the lowest concentration which is 7% could be neglected as the solution became concentrated only after five minutes of reaction which indicate the solution is easily saturated, showing instability to be used as a parameter. Hence, it is decided that the 14% sodium hydroxide concentration could be used as a parameter to indicate the absorption rate of CO_2 into the sodium hydroxide which is 0.7 l/min. The superior absorption behavior of sodium hydroxide is attributed to its sodium increasing hydroxide ionization capacity with increasing concentration. With 14% sodium hydroxide concentration, it was found that the CO_2 removal efficiency was 100% which there was no carbon dioxide at the outlet of biogas. However, the CH_4 enrichment was not very high because the concentration of CH_4 in biogas was quickly saturated. The CH_4 at the first 40 minutes were increased until reaching to 60.2%. After 40 minutes, the CH_4 composition is slightly dropping which shows the sodium hydroxide already saturated. The reason for the high removal efficiency is maybe due to at low biogas flow rate; the liquid-gas interaction was sufficient for absorption to occur.

Based on the calculation, for 23.1 kg of NaOH solution, about 3.41 x 10 -4 kg of CO_2 was absorbed into its solution. Hence, the total amounts of CO_2 absorbed were in the range of 1.47 x 10 -4 kg/ per kg NaOH used. This value is lower than the one obtained by another researcher [4] in which they found that the total amounts of CO_2 absorbed were in the range between 0.18 and 0.22 kg/kg per kg chemicals used. This large variation could be due to the packing bioball that was used in absorption column were not cleaned enough and did not wash away the previous sodium hydroxide from previous test for this experiment, and which limit its surface area and contact between gasses and liquid at the interface. This study meanwhile used the packed column to increase the absorption rate of gasses in solution which explains its high absorption of CO_2.

4. EMISSSION CHARACTERISTICS CARBON MONOXIDE (CO)

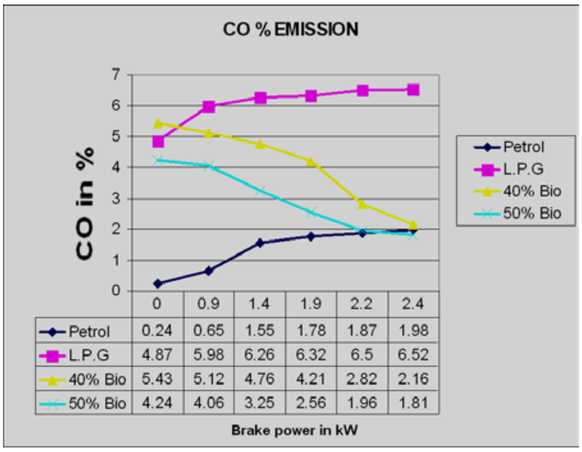

Figure 6.CO vs Brakepower

The CO values with break power for different fuels are shown in above figure - 4, it is observed that the CO decreases with increasing load for all the blends. For different blends of biogas, CO is reducing. It can be observed that blending 50% of biogas with L.P.G results high reduction in CO emissions when compared to that of petrol, L.P.G, 40% blending.

NITROGEN OXIDES (NOx)

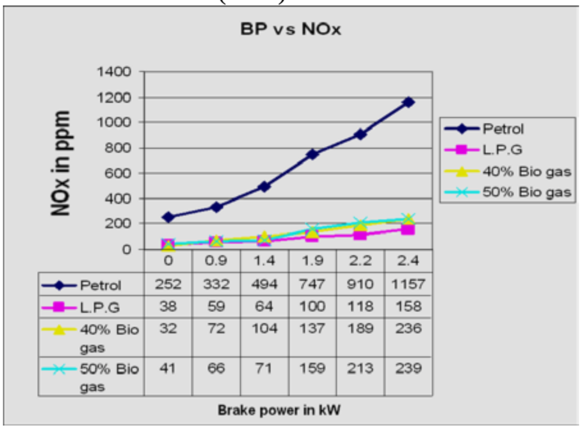

Figure 7.NOx vs Brakepower

The comparison of NOx emissions compared with brake power for petrol, L.P.G and the blend with biogas are shown in Fig 5, it is observed that NOx increases with increasing load for all fuels. If the percentage of Biogas increases, NOx will increased because of biogas contains CO_2. From the figure it is observed that the emission value of NOx are minimum for the biogas blend with compared to the petrol. Because it is a low calorific value fuel and it is a homogenous mixture. That's why, there is no formation of NOx.

HYDRO CARBONS (HC)

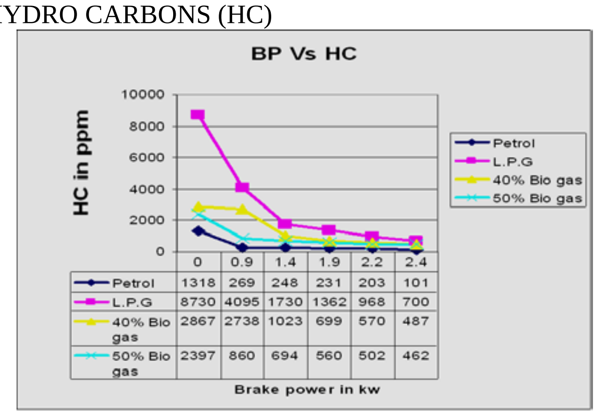

Figure 8.HC vs Brakepower

It is observed that HC decreases with increasing load for all fuels. The comparison of HC emissions for petrol, L.P.G and the blend with biogas are shown in Fig. It can be seen that the HC emissions decrease with increase in percentage of biogas in the L.P.G-Biogas fuel blend. The HC decrease for Biogas may be associated with there is proper combustion is takes place. Above fig. shows HC are less for the 50% Biogas with compare to the L.P.G, 40% Blend and more when compare to the petrol why because petrol is a gaseous fuel.

5. CONCLUSION

The experimental study shows that the concentration of solution plays an important role in the CO_2 removal efficiency. When the concentration of absorbent increased, the CO_2 removal would be increased to a high efficiency. The results also indicated that the highest performance of sodium hydroxide solution as an absorbent is when the concentration of the solution used is at 14% (w/v). In a continuous flow experiment, it also shows that the 14% sodium hydroxide concentrations gave 100% CO_2 removal.

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