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A simulation study on the removal of CO_2 and CH_4 lost from raw biogas in a packed bed absorption column

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Abstract: A simulation study on the removal of CO_2 and CH_4 lost from raw biogas in a packed bed absorption column has been carried out to observe the effect of pressure and water flow rate. Biogas produced by the anaerobic digestion contains mainly CH_4 (55%-65%) and CO_2 (35%-45%). CO_2 is necessary to remove before its use as domestic fuel because it reduces the calorific value of the biogas. Pressure of the absorption column has been changed from 5 to 20 bar and absorption of CO_2 varies from 49.9 to 97.99%. CH_4 lost is also noted at these pressures which vary from .142 to 1.65%. Water flow rate is changed from 40 to 100 kg/hr and CO_2 absorption varies from 49.9 to 84.14%. CO_2 gas in the purified biogas should be less than 3% and CH_4 loss should be less than 1% for its use as replacement of fossil fuel. It is concluded from this research that water flow rate and pressure is directly proportional to the absorption of CO_2 and percentage CH_4 loss. Optimum conditions for the removal of are selected as 15 bar pressure of absorption column and 80 kg/hr water flow rate.

Key Words: Absorption Column, Biogas, Carbon dioxide, Methane, Packed Bed

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1 Introduction

Energy production from renewable sources has strategic importance for environmental production [1]. Biomass energy produced by biogas from the anaerobic digestion and in the presence of microorganisms can not only reduce the discharge kitchen waste and city sludge, it also plays an important role in the remission of greenhouse effect [2]. Biogas is traditionally used for energy production rural areas with low efficiency [3-4]. It is now used widely by value added way in which the raw gas is purified to natural gas quality [5-7]. Biogas produced by anaerobic digestion needs to be treated to become the energy of the future [8]. Carbon dioxide (CO_2) present in the raw biogas does not affect the combustion process but it decreases the energy content of the gas.

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Biogas produced from biomass waste contains mainly methane (CH_4) (55%-65%) and CO_2 (35%-45%) [9]. Raw biogas has a calorific value of 22000-25000 $kJ.m^{-3}$, but this value can be increased up to 39000 $kJ.m^{-3}$ by the removal of CO_2 [10]. Biogas after the removal of CO_2 has methane contents 96%, which are similar to natural gas. This purified biogas can be a replacement of fossil fuels [9]. CO_2 in the purified biogas should be less than 3% [11].

Purified biogas can be produced by absorption in organic amine solution or water, membrane separation, cryogenic distillation and pressure swing adsorption [12-14]. The production of purified biogas by absorption with organic amine solution is an efficient process. But the regeneration of the organic amine solution is highly energy consuming [15]. This method is also known as chemical absorption. Apart from using amine solution for purification, potassium hydroxide (KOH), sodium hydroxide (NaOH) and calcium hydroxide $Ca(OH)_2$ can also be used. Purification through membrane is not feasible because membrane is expansive and can easily be contaminated [16]. Cryogenic distillation is a method for separating CO_2 at low temperature. CO_2 is recovered as liquid product which can be transported easily [12]. Disadvantage of this process are low thermal efficiency and high capital cost [17]. Pressure swing adsorption does not involve equipment corrosion and environmental pollution. But frequent adsorption/desorption cycles, high process cost and involvement of complex equipment limits its application [18]. Another method is the absorption of CO_2 by water washing. It is a physical absorption method. Absorption/desorption of CO_2 in water is done by varying the temperature and pressure of the process [19-20]. Water washing method also has an advantage that selective removal of hydrogen sulfide (H_2S) is also achieved due to more solubility of H_2S in water than CO_2. This method is environmentally friendly and lower in cost as it uses water as absorbent.

The main objective of the research is to remove CO_2 from the raw biogas so that it can be used as a replacement of natural gas. A simulation on water washing system is used in this study to investigate the effect of various parameters on the removal of CO_2 gas. The parameters which are investigated in this study are pressure and water flow rate by keeping temperature and biogas flow rate constant.

2 Materials and Methods

Purified biogas is achieved in a simulated model in which packed column is used for the continuous gas absorption operation. Packed column consists of cylindrical column with the permission of inlet and outlet streams for liquid and gas flow. Proper distribution of liquid and gas is required for proper absorption of CO_2 in water. Permission for the packing is added to increase the contact between liquid and gas. As the liquid flows down the column, gas is absorbed which goes on increasing as the liquid flows downward. Packing is selected as plastic saddles because it has low weight and provides more surface area. After water scrubber, the resulting biogas is saturated with water. This water is necessary to remove before using biogas because it will corrode the lines. This water content can be removed by using a bed of alumina or zeolite.

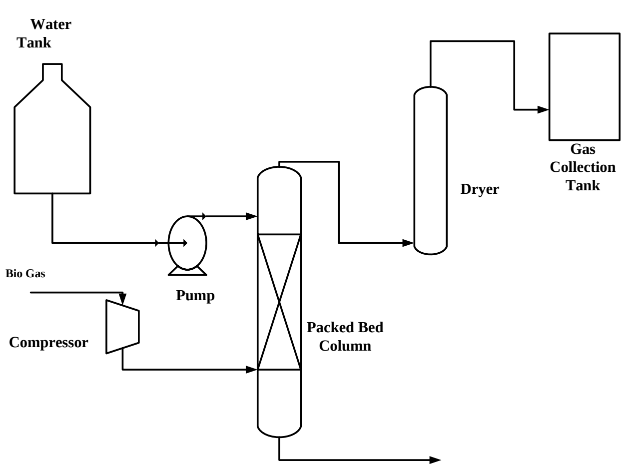


Fig.1. Flow sheet diagram of the process

In the simulated model which is done on ChemCAD software, following parameter are calculated. Gas flow rate of the raw biogas is set at 4.8 kg/hr and this value is kept constant while effect of other parameters is calculated. Diameter of the packed column is calculated as 6 inches. We have used plastic saddles as the packing material in our column whose size is taken as 0.5 inch and surface area calculated from the literature is 480 m^2/m^3. The height of the absorption column is calculated as 1.04 m. these all values are put in the ChemCAD software and the effect of water flow rate and pressure are noted on the absorption of CO_2.

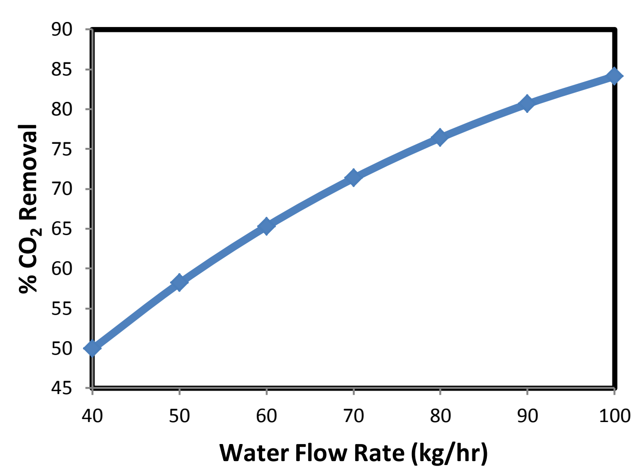
3 Results and discussion

This discussion will help to choose the best feasible condition for purifying biogas. Effect of Pressure and water flow rate is discussed in this section.

Water is selected as solvent in this absorption process because water is cheap and solubility of CO_2 in water is low but at higher pressure adequate absorption takes place. Water enters from the top of the packed column while raw biogas flows from the bottom.The absorption of CO_2 in water is an interphase mass transfer operation during which diffusion of CO_2 occurs from the gas phase to liquid phase. After absorption of CO_2 in water, some CO_2 molecules escape to the gas phase. The point at which the transfer of net molecules to and from the both phase is equal, a dynamic equilibrium exists.

If operating conditions of water flow rate or pressure is changed, the equilibrium will disturb. And a new equilibrium will form different from the previous one and dynamic equilibrium will establish at a different position than previous one.

3.1 Effect of water flow rate on absorption of CO_2



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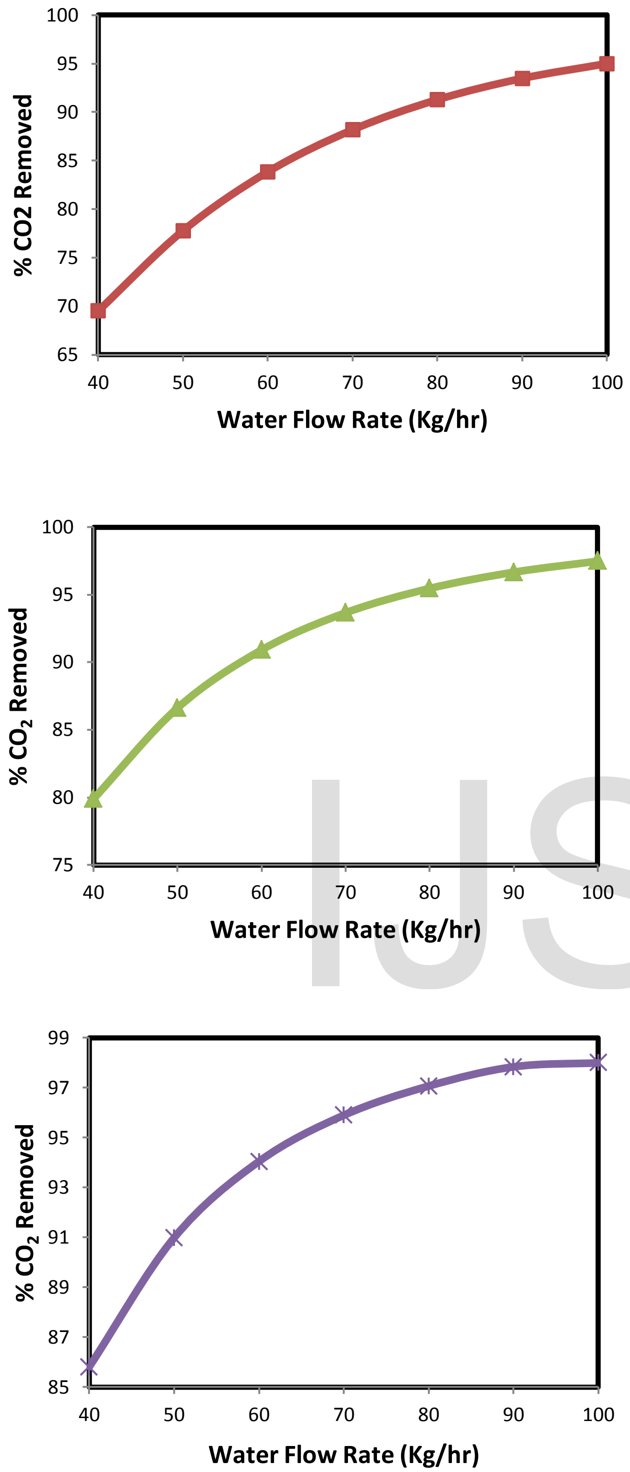

Fig.2: Effect of water flow rate and % CO_2 removal at (a) 5 bar (b) 10 bar (c) 15 bar and (d) 20 bar

Fig. 2 is the graph of water flow rate vs % CO_2 removed in the purification process of raw biogas. Water flow rate is on the horizontal axis while % CO_2 removal on the vertical axis. Water flows from the top of the column absorbs CO_2 from the biogas flowing in the counter current flow. This purification process should be carried out under some pressure because pressure increases the absorption of CO_2 and thus increasing the efficiency of the process. We have done experiments on four (04) different pressures 5, 10, 15 and 20 bars. For each pressure reading several different flow rates are tested to get the maximum efficiency of the process. The flow rates on which readings of CO_2 absorption are taken are 40, 50, 60, 70, 80, 90, and 100 kg/hr.

For the first set of experiments as shown in the fig. 2 (a), 5 bar pressure is selected as operating pressure and flow rate is changed from 40 kg/hr to 100 kg/hr. The absorption of CO_2 in water at 40 kg/hr is 49.9% while at maximum flow rate of 100 kg/hr, absorption is 84.14%. For the second set of experiments as shown in fig. 2 (b), pressure is set at 10 bar and absorption of CO_2 at various flow rates is observed. Here at 40 kg/hr of water flow rate, the absorption of CO_2 in water is observed as 69.51% which goes on increasing with the increase in flow rate and at the flow rate of 100 kg/hr it reaches the value 95%.

For the third set of experiments as shown in fig. 2 (c), 15 bar pressure is selected and flow rate is changed from 40 kg/hr to 100 kg/hr. the absorption of CO_2 in water at 40 kg/hr is 79.9% while at maximum flow rate of 100 kg/hr, absorption is 97.49%. For the fourth set of experiments as shown in fig. 2 (d), pressure is set at 20 bar and absorption of CO_2 at various flow rates is observed. Here at 40 kg/hr of water flow rate, the absorption of CO_2 in water is observed as 85.81% which goes on increasing with the increase in flow rate and at the flow rate of 100 kg/hr it reaches the value 97.99%.

Fig. 2 shows that water flow rate and %CO_2 removed have directly relationship with each other. At lower value of water flow rate the amount of absorbed CO_2 is less which increases with the increase in flow rate until it reaches its maximum value. Pressure has also the same effect on the absorption of CO_2 as flow rate. With the increase in pressure, absorption increases because the solubility of CO_2 in water is more at higher pressure. At low values of pressure the absorption is low while at higher values of pressure, considerable change is observed and maximum absorption is noted at 20 bar pressure.

3.2 Effect of water flow rate on % CH_4 loss

Fig. 3 is the graph of water flow rate and % CH_4 loss. CH_4 is the desired component in the purification of biogas during this process. Some quantity of CH_4 is absorbed in water due to its miner solubility in water and being wasted. This loss should be kept to a minimum if possible. Fig.3 (a) shows that at 40 kg/hr water flow rate and 5 bar operating pressure, amount of CH_4 is absorbed in water is 0.142% while at 100 kg/hr Ch_4 is absorbed in

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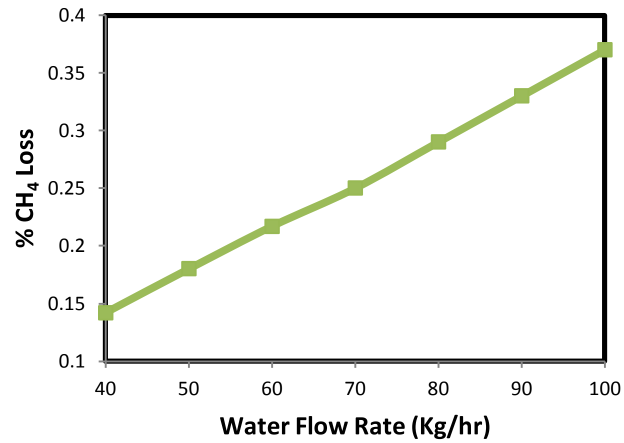
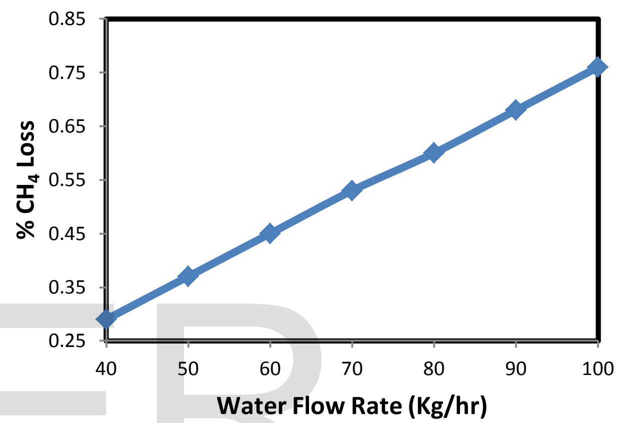
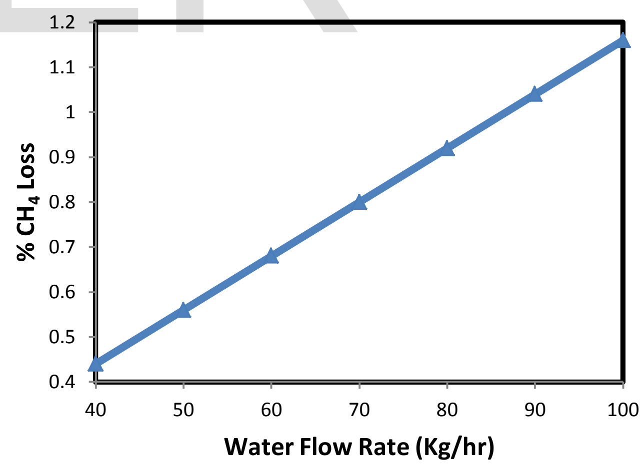
water is 0.37%.Fig.3 (b) shows the effect of % CH_4 loss with water flow rate at operating pressure of 10 bar. At 40 kg/hr water flow rate the % CH_4 loss is 0.29% which goes on increasing with the increase in water flow rate. At 100 kg/hr the % CH_4 loss is 0.76.Fig.3 (c) shows that operating pressure is fixed at 15 bar. At 40 kg/hr water flow rate amount of CH_4 is absorbed in water is 0.44% while at 100 kg/hr Ch_4 is absorbed in water is 1.16%.Fig.3 (d) shows the effect of % CH_4 loss with water flow rate at operating pressure of 10 bar. At 40 kg/hr water flow rate the % CH_4 loss is 0.6 which goes on increasing with the increase in water flow rate. At 100 kg/hr the % CH_4 loss is 1.65.







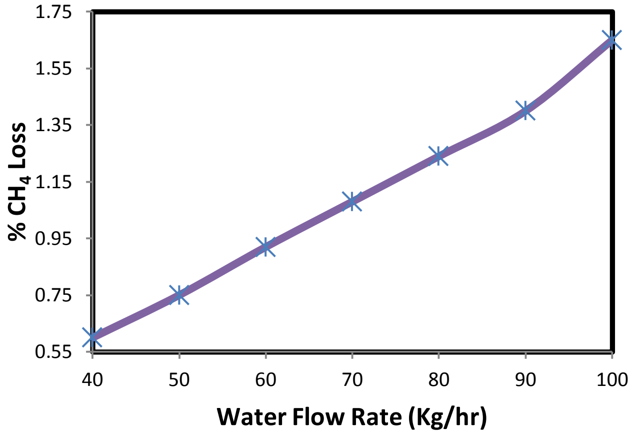
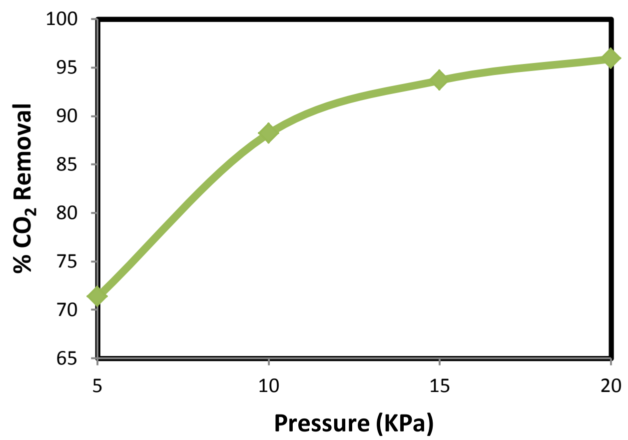


Fig.3: Effect of water flow rate and % CH_4 loss at (a) 5 bar (b) 10 bar (c) 15 bar and (d) 20 bar

Fig. 3 shows that water flow rate and % CH_4 loss is directly proportional to each other. As the water flow rate increase the amount of CH_4 loss also increases because as the water flow rate increases more CH_4 is absorbed in water.

3.3 Effect of pressure on absorption of CO_2 and %CH_4 loss

Fig.4 (a) is the graph between pressure and absorption of CO_2 while fig. 4 (b) is the pressure and % CH_4 loss. Water flow rate is kept constant at 70 kg/hr. simulation is done on four different pressures i.e.; 5, 10, 15 and 20 bar. Absorption of CO_2 and % CH_4 loss is noted at these pressures. At 5 bar pressure the absorption of CO_2 and % CH_4 loss is noted as 71.33% and 0.25% respectively. In the same way at 10 bar pressure, absorption of CO_2 and % CH_4 loss is calculated as 88.18% and 0.53%. at 15 and 20 bar pressure, absorption of CO_2 and % CH_4 loss is 93.67%, 0.8% and 95.89%, 1.08% respectively. It is observed that absorption of CO_2 and % CH_4 loss increases with the increase in pressure.



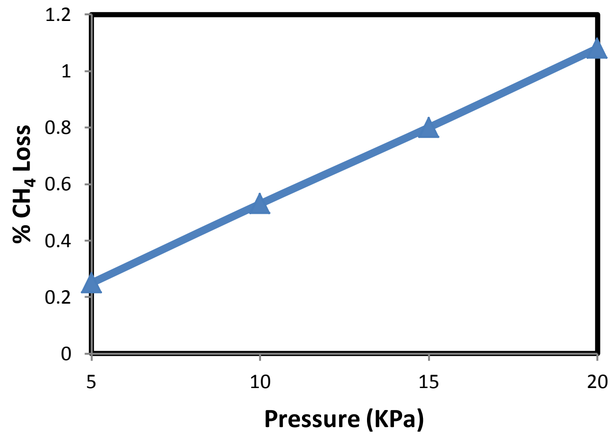


Fig.4: Effect of pressure at constant water flow rate of 70 kg/hr on (a) % CO_2 removal (b) % CH_4 loss

The absorption of CH_4 in water increases as the pressure increases because increase in pressure increases the solubility of CH_4 in water. Selection of optimum conditions becomes more important as the absorption of CH_4 increases both with water flow rate and pressure.

Conclusion

The aim of this paper is to find the effect of pressure and water flow rate on the absorption of CO_2 and to find the optimum condition at which raw biogas gives best result of CO_2 removal. The optimum conditions should be selected in such a way that the CO_2 removal should be maximum and the CH_4 lose is kept to a minimum.

It is concluded from the above experiments that CO_2 absorption increases with the increase in water flow rate. The relationship of water flow rate vs absorption of CO_2 is non-linear. At low values of water flow rate, less absorption of CO_2 is observed which goes on increasing as the flow rate increases and reaches maximum value at highest flow rate i.e. 100 kg/hr.

It is concluded form the above simulation model that absorption of CO_2 and CH_4 in a packed column is directly proportion to both pressure and water flow rate. Since we required CO_2 removal in the purified biogas more than 97% and CH_4 lose 1%. Biogas can be used as a replacement of the fossil fuel when it contains CO_2 contents not more than 3%. Results show that this can be achieved at higher water flow rate with lower pressure or at lower flow rate with higher pressure. So optimum conditions selected from this study is 15 bar pressure and 80 kg/hr water flow rate.

H_2S is also present in the raw biogas, which if not removed severe problems to the pipelines. Presence of H_2S is an environmental problem because it reacts with water vapors to form H_2SO_3 and cause acid rain. Solubility of H_2S is three times more than CO_2. So H_2S is easily removed from the raw biogas by the action of water.

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