Removal of CO₂ from Raw Biogas using Water Scrubbing based Up-Gradation Method

Dhruv Singh[1], Anjani K Dwivedi[2]

[1]M.Tech Student, Department of Chemical Engineering, Ujjain Engineering College, Ujjain (M.P.)
[2]Professor, Department of Chemical Engineering, Ujjain Engineering College, Ujjain (M.P.)

---***---

Abstract - *Biogas is arguably a more versatile renewable energy source due to its determinate energy value and abundant biomass availability. The main hurdle for implementing the technology for vehicular application and power generation is that biogas contains certain concentration of impurities of CO₂ majorly and some Trace components that are often present in biogas are water vapor, hydrogen sulfide, siloxanes, , ammonia, oxygen , and nitrogen. Considering the biogas is a clean and renewable form of energy that could well substitute the conventional source of energy (fossil fuels), the optimization of this type of energy becomes substantial. Water scrubbing technology is being widely and increasingly implemented around the world. This method takes the benefit of higher water solubility of H₂S and CO₂ compared to sparingly soluble CH₄.*

Thus, the present study is aimed to evaluate the operation and design parameters such as gas and water flow rates, pressure inside the column, packing material, diameter and height of the packed bed column of the water scrubbing column. These factors are linked to each other, therefore an optimum combination of these factors was experimentally studied to maximize the CO₂ removal. Since, CO₂ removal from water scrubbing based biogas up-gradation plants is an important area and a detailed experimental analysis had been carried out.

Key Words: Biogas up-gradation, Water scrubbing, Bio-methane, CO₂, CH₄, Biogas

1. Introduction

Biogas is a renewable source of energy derived from anaerobic digestion of biomass, mainly comprising of dairy waste which is widely available in form of cattle dung in the Indian villages[1]. Its main constituents comprise of CH4, CO2, H2S with traces of nitrogen, water vapors, hydrogen, oxygen, organic silicon compounds and ammonia, their composition depending on the source[8]. In order to obtain methane rich gas, the biogas must pass through two major processes, a cleaning process and an upgrading process[2,3]. The available upgrading technologies include Amine scrubbing, Membrane separation, Water scrubbing, Organic physical scrubbing, Pressure swing adsorption, Cryogenic separation and liquefaction. Among all up-gradation technologies, Water scrubbing is the most simplest, feasible and cost effective method with high CO2 separation efficiency among all the technologies[6]. Water scrubbing technology is being widely and increasingly implemented around the world. This method takes the benefit of higher water solubility of H2S and CO2 compared to sparingly soluble CH4[4].

The present study aims to optimize various operation and design parameters such as gas and water flow rates, pressure inside the column, packing material, diameter and height of the packed bed column of the water scrubbing column. These factors are linked to each other, therefore an optimum combination of these factors was experimentally studied to maximize the CO2 removal. Since, CO2 removal from water scrubbing based biogas up-gradation plants is an important area and a detailed experimental analysis had been carried out. Therefore, an optimal combination of the above factors is essential for maximum separation of CO2 as well as biogas up-gradation profile via water scrubbing reveals that these novel purification processes are effective and affordable[4,5].

2. Materials and Methods

2.1 Biogas Plant:

Raw biogas for the experiment of bio methane production has been taken from the biogas plant of capacity 9000 m³. The biogas plant is operated by Spectrum Renewable Energy Private Limited located at village Waranagar, District Kolhapur, Maharashtra. Press mud from sugar industry is used as a major feed stock for the biogas plant.

2.2 Water Scrubbing System

2.2.1. Raw Biogas compressor: As the water scrubbing system is based on the pressure for which the biogas is compressed at 7.4 bar pressure which has a maximum capacity of 900 m³/hr. The above compressor is water cooled with inter cooler and after cooler which helps in increasing the efficiency as well as reducing the temperature of the raw biogas which increases the process efficiency. The flow diagram for Raw biogas compression system is shown in the figure....

2.2.2. Scrubbing tower: The scrubbing tower is a cylindrical shape column with height 5meters and diameter 0.5m which is used to remove CO2 from the biogas to produce Bio-CNG:

a)   **Packing material:** The circular shape rings are randomly filled inside the tower as shown in the figure known as packing bed. The main function of the packing bed provides a larger area of contact between the liquid and gas and to encourages intimate contact between the phase which increase the efficiency of scrubbing process.

b)   **Water level Indicator**: The Water level indicator is a cylindrical shape glass rod connected to the scrubbing column. This is used to physically observe the water level at the bottom of the scrubber after every hour. The water level is maintained at 0.5m height from to bottom which act as a water seal which protects the escape of biogas from the water outlet pipe line.

c)   **Biogas piping**: The biogas is introduced from the pipe at bottom above than water level maintained at bottom which comes out from the pipe at the top as shown in the flow diagram.

d)   **Water Piping:** The water is poured from the pipe at the top the column in the form of spray which comes out after absorbing CO2 from the Biogas from the pipe at the bottom as shown in the figure.

e)   **Water pump:** The maximum capacity of the pump is 150m^3 per hour which supplies the recycled water to the scrubbing process from the top at required flow rate.

f)   **Stripping column**: The tower is a cylindrical shape column with height 5 meters and diameter 0.5m which is used to recycle the water used for the water scrubbing process so that it can be used again and again.

g)   **Damper blower**: The damper blower is a king of air blower of very high capacity which forces air into the stripping Colum which enhances the water recycling process.

h)   **Water level and pressure sensor:** It is a diaphragm based pressure and level sensor which send the output signal to PLC program. As the operator enters the set point for the water level inside the scrubbing tower the system compares the set point value to the output from the sensor. By comparing both system controls the opening and closing of the pneumatic valve over the water scrubbing line as shown in the figure. With the help of the sensor reading the system also controls the water flow rate entering to scrubbing column.

2.2.3. Chiller unit: The chiller maintains the temperature of scrubbing water between 15°C - 18°C which is required for the efficient scrubbing process.

a)   **PHE (Plate heat exchanger):** It absorbs the heat from the water coming from the stripping column and provides Colling from water from the chiller. The PHE contains no of plates through which heat transfer between stripping column water and the water from chiller units takes place without any physical mixing.

b)   **Pump:** The pump circulates the water from PHE to chiller.

2.3. High Pressure Compressor:

After removing the CO+ from the biogas the upgraded biogas is compressed up to 200 bar pressure and stored in the Bio-CNG cylinder cascade. The capacity of the compressor is maximum 350m^3/hr. The compressor is facilitated with variable frequency drive to run the system at required flow rate.
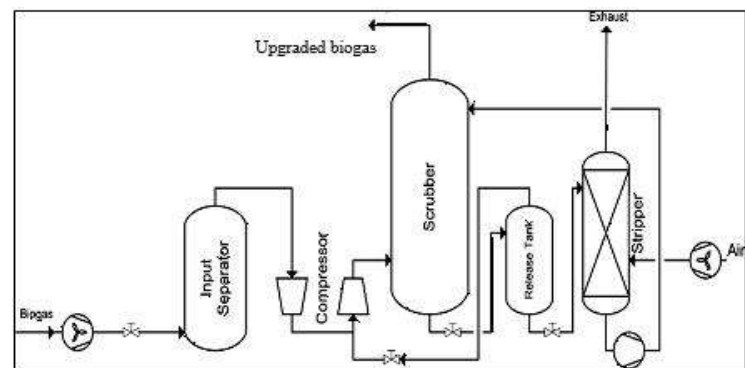

Fig. 1.1: Schematic diagram of Water Scrubbing System

3. Result and Discussions

The result and discussion pertaining to physical absorption of gases in water via water scrubbing based biogas upgradation method and optimization of the system was done on variable water to gas flow rates to obtain maximum methane purity and minimal methane losses from the system. All the results of experiments were shown below with their analysis and detailed discussions and at the end conclusion of whole results was discussed followed by recommendation of future research was done.
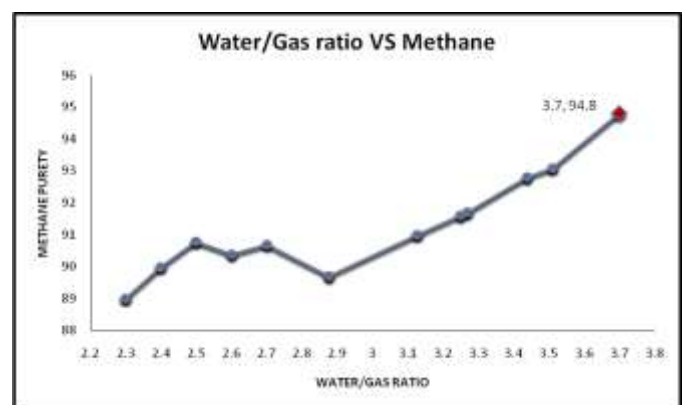

Figure 3.1: Water/ Gas ratio VS Methane (W/G from2.6-3.4)

Figure 3.1 shows the expected behavior of increase in Methane purity with increase in water to gas ratio which happens generally. This is due to the reason that for every m^3 of biogas flowing through the water scrubbing column there is more water available in which Carbon Dioxide will get absorbed and more amount of Carbon Dioxide will be

removed from the biogas as compared to low water to gas ratio. As the Carbon Dioxide absorption in the water scrubbing tower increases at higher water to gas flow rate which due to this condition there is better distribution of the gas in the water scrubbing column because at higher water to gas ration less amount of gas is flowing through the column per unit time[4]. The highest purity was achieved at 3.7 water to gas ratio of 94.8% of methane.
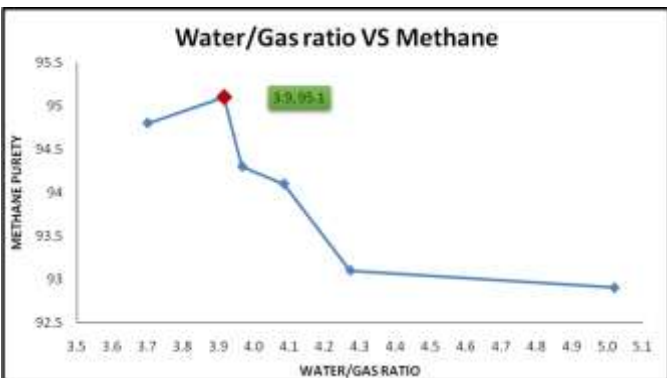

Figure 3.2: Water/Gas Ratio VS Methane (W/G from 3.7-5)

Figure 3.2 shows the same behavior that with increase in water to gas ratio the methane purity increases and the highest purity is achieved at 3.9 water to gas ratio of 95.1 %. But it is observed when the water to gas ratio was further increased beyond 3.9 the methane purity somewhat decreases to93-94% this could be happing because of the saturation of absorption of CO_2 in the water. This also indicates that excess water in the water scrubbing column could cause flooding condition in which lot of moisture will get mix in to the purified gas[3].
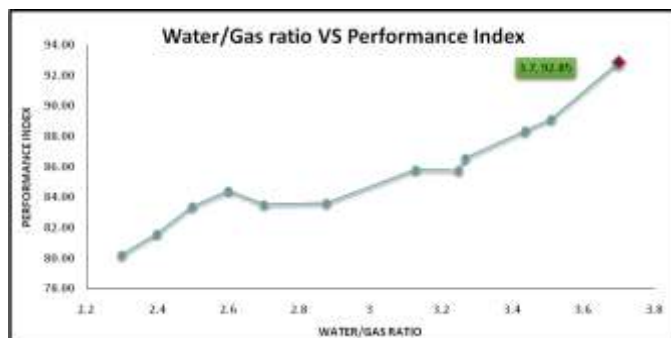

Figure 3.3: Water/Gas Ratio VS Performance Index(W/G from2.6-3.4)

Figure 3.3 shows the computation of performance index was based on the percentage of CO_2 in raw and enriched biogas. The performance index is given by:

$$\sigma = \frac{x}{y_r} \times 100$$

Equation can further be written as:

$$\sigma = \frac{(1 - \frac{y_e}{y_r})}{(1 - \frac{y_e}{100})} \times 100$$

where, σ = Performance index of scrubbing column, %x = Quantity of CO_2 absorbed in water, y_r= Percentage of CO_2 in raw biogas, y_e= Percentage of CO_2 in enriched biogas

The performance index is calculated on the above formulation which indicates the percentage of CO_2 removed from the biogas as comped to its value in raw gas. The superlative performance index is achieved at 3.7 water to gas ratio of 92.85 %. This indicates that 92.85 % of CO_2 is removed from the CO_2 percentage in raw biogas[4].
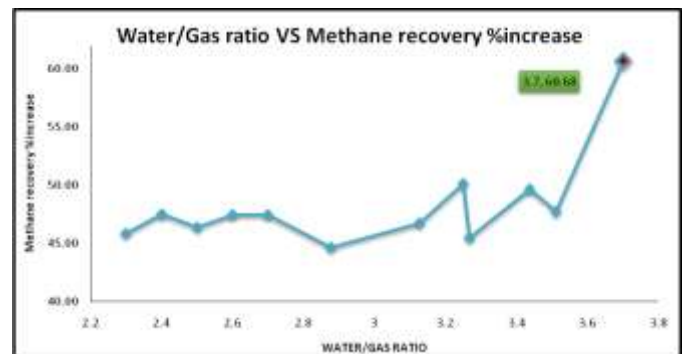

Figure 3.4: Water/Gas Ratio VS Methane Recovery Increased Percentage(W/G from2.6-3.4)

Figure 3.4 shows the Methane recovery percentage increase in percentage which is amount of CH_4 in upgraded gas as percentage of CH_4 in raw gas. The highest methane recovery percentage increase was observed at 3.7 water to gas ratio which is 60.68.

4. Conclusion

The water scrubbing system for carbon dioxide removal depends upon the various factors such Temperature, Pressure, water to gas ratio, biogas retention time in water scrubber. The solubility of the CO2 in water increase in water scrubbing system for which we need to maintain the water temperature with the help of chiller into the system[4]. The solubility of the CO2 in water also increases with increase in pressure in the water scrubbing system. Generally, the water scrubbing system works from the range of 7-10 bar pressure because further increase in pressure tends to increase the methane slip from the water scrubber. But in the system on which the experiments were performed was fixed at 7.4 bar pressure so there was a limitation of performing at this pressure only. The study was performed on the industrial scale biogas plant of capacity of 9000m^3/day.

5. Future aspects

Currently there are lot of technologies are available in the market for removal of CO_2 removal from the biogas such as Pressure swing adsorption system, Water scrubbing system, Amines scrubbing, Membrane technology out of which water scrubbing system is the cheapest and simplest in operation but more R&D is required on the designing of scrubbing tower to optimize the volume of the scrubber because retention time plays the major role in the water scrubbing system for CO_2 removal[7].

Currently there are studies done on the lab scale models but at industrial scale water scrubbing system should be designed in such a way that it can be operated on some range of flow rate of biogas. Because in lab scale model you always gets constant flow rate but at industrial scale sometime system runs at 60-70 % of the designed capacity.

6. References

[1]   Sahota, Shivali, Goldy Shah, Pooja Ghosh, Rimika Kapoor, Subhanjan Sengupta, Priyanka Singh, Vandit Vijay, Arunaditya Sahay, Virendra Kumar Vijay, and Indu Shekhar Thakur. "Review of trends in biogas upgradation technologies and future perspectives." *Bioresource Technology Reports* 1 (2018): 79-88.

[2]   Andriani, Dian, Arini Wresta, Tinton Dwi Atmaja, and Aep Saepudin. "A review on optimization production and upgrading biogas through CO 2 removal using various techniques." *Applied biochemistry and biotechnology* 172, no. 4 (2014): 1909-1928.

[3]   Zhao, Q., E. Leonhardt, C. MacConnell, C. Frear, and S. Chen. "Purification technologies for biogas generated by anaerobic digestion." *Compressed Biomethane, CSANR, Ed* (2010).

[4]   Nock, William J., Mark Walker, Rimika Kapoor, and Sonia Heaven. "Modeling the water scrubbing process and energy requirements for CO2 capture to upgrade biogas to biomethane." *Industrial & Engineering Chemistry Research* 53, no. 32 (2014): 12783-12792.

[5]   Yentekakis, Ioannis V., and Grammatiki Goula. "Biogas management: advanced utilization for production of renewable energy and added-value chemicals." *Frontiers in Environmental Science* 5 (2017): 7.

[6]   Ryckebosch, Eline, Margriet Drouillon, and Han Vervaeren. "Techniques for transformation of biogas to biomethane." *Biomass and bioenergy* 35, no. 5 (2011): 1633-1645.

[7]   Wu, Ya-Min, Jing Yang, Xiao-Lei Fan, Shan-Fei Fu, Meng-Ting Sun, and Rong-Bo Guo. "Elimination of methane in exhaust gas from biogas upgrading process by immobilized methane-oxidizing bacteria." *Bioresource technology* 231 (2017): 124-128.

[8]   Sahota, Shivali, Virendra Kumar Vijay, P. M. V. Subbarao, Ram Chandra, Pooja Ghosh, Goldy Shah, Rimika Kapoor, Vandit Vijay, Vaibhav Koutu, and Indu Shekhar Thakur. "Characterization of leaf waste based biochar for cost effective hydrogen sulphide removal from biogas." *Bioresource technology* 250 (2018): 635-641.

BIOGRAPHIES

Dhruv
Dhruv is M.tech student (Environment Management) at Department of Chemical Engineering, Govt Engineering College, Ujjain(M.P.).

Prof. Anjani Kumar Dwivedi
Dr Anjani Kumar Dwivedi is Professor and Head at Department of Chemical Engineering, Govt Engineering College, Ujjain(M.P.). He has more than 30 years experience of research and teaching in chemical engineering.