# INVESTIGATIONS ON ABSORPTION TECHNIQUE FOR BIOGAS PURIFICATION

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY

IN

**THERMAL ENGINEERING**


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I, PRATIK KR KHEMKA, 2K21/THE/22, of M. Tech (Thermal Engineering), hereby declare that the project Dissertation titled "Investigations on Absorption Technique for Biogas Purification" which is submitted by me to the Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship, or other similar title or recognition.

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## CERTIFICATE

I hereby certify that the Project Dissertation titled "Investigations on Absorption Technique for Biogas Purification" which is submitted by PRATIK KR KHEMKA, 2K21/THE/22, Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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# ABSTRACT

In this research, a biogas purification system was developed using Sodium Hydroxide and Calcium Hydroxide solution through bubble column absorption tower made from plastic bottle. Biogas from 3 different digesters (D1, D2, and D3) with varying feeds were used, and the experiment was conducted with 5 types of solution- pure water, Sodium hydroxide 0.625 mol, Sodium hydroxide 0.9375 mol, Calcium hydroxide 0.625 mol, and Calcium hydroxide 0.9375 mol, with a constant volume of 400 ml for each run. The biogas flow rate was set at 1.25 l/min and 3.33 l/min, and the biogas composition was measured before and after purification using Gas Analyzer. The research findings demonstrated that the effectiveness of the purification system was affected by the biogas flow rate, the type of solution used, and its concentration. Moreover, the results showed that the higher the absorbent in the bubble column, the higher the percentage of $C0_2$ absorption and $CH_4$ content. The most efficient solution for biogas purification was Sodium Hydroxide 0.9375 mol, which can give a maximum methane ratio of 86.2% at a flow rate of biogas of 1.25 l/min.

This paper gives a software analysis of the interaction of absorbent and gas molecules in the absorption column and its effect on the outlet gas temperature. DWSIM software was used to study the model. The research findings demonstrated that the interaction between the molecules was affected by the gas flow rate, the absorbent flow rate and the absorbent pressure.

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# CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF SYMBOLS AND ABBREVIATIONS

| Abbreviations/Symbols | Descriptions |
|---|---|
| UNFCCC | United Nations Framework Convention on Climate Change |
| $CO_2$ | Carbon Dioxide |
| CHP | Combined heat and power |
| PSA | Pressure Swing Adsorption |
| NMP | N-methyl pyrrolidone |
| PEG | Polyethylene glycol ethers |
| $CH_3OH$ | Methanol |
| MEA | Monoethanolamine |
| DMEA | Di-methylethanolamine |
| PFDs | Process flow diagrams |
| EOS | Equations of state |
| CRD | Completely randomized design |
| NaOH | Sodium Hydroxide |
| $Ca(OH)_2$ | Calcium Hydroxide |
| MCDM | Multi-Criteria Decision Making |
| WSM | Weighted Sum Model |
| AHP | Analytic Hierarchy Process |
| TOPSIS | Technique for Order of Preference by Similarity to Ideal Solution |
| MF | Membership function |
| $r_i$ | Geometric mean value |
| wi | Fuzzy weight |
| COA | Centre of Area |

# CHAPTER 1

# INTRODUCTION

## 1.1 GENERAL

In the twenty-first century, we face two pressing challenges that heavily rely on the energy sector: sustainable economic growth and global climate change. Addressing these issues involves the decarbonization of the current energy system. The consumption of primary energy is increasing by approximately 2% annually, primarily driven by the use of fossil fuels. To minimize the adverse impacts associated with the fossil fuel industry, it is essential to explore low-carbon and renewable energy alternatives. Without significant efforts to mitigate these concerns, emissions are projected to rise by around 30% in the next 20 years, already affecting the climate system through human-induced greenhouse gas emissions. To mitigate the severe consequences of climate change, future energy scenarios envision a wide adoption of low-carbon technologies, including renewable energy sources.[1] Mitigating the imminent risks of global warming necessitates a critical reduction in greenhouse gas emissions. The United Nations Framework Convention on Climate Change (UNFCCC) was established in 1992 with the primary goal of reducing greenhouse gas emissions by at least 5% compared to 1990 levels by 2012. The Kyoto Protocol, adopted in Kyoto in December and implemented in 2005, aimed to encourage governments worldwide to implement measures to combat global pollution and climate change. Additionally, the 2009 Copenhagen summit aimed to prompt national governments to adopt behavioural changes to address climate change effectively. However, if genuine efforts are undertaken to avert global climate change, the development of the modern renewable biomass industry in a sensible and responsible manner could offer significant contributions. Renewable biomass has the potential to serve as a substitute for fossil fuels, enhance food security, and contribute to the reduction of global warming in future energy supplies.[2]

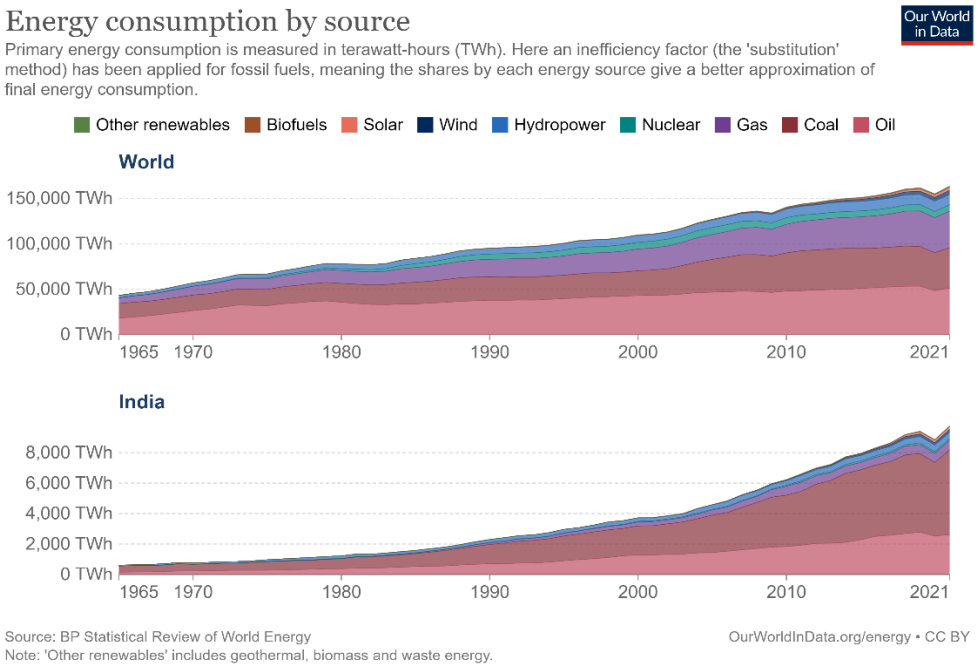


**Fig 1.1 Energy Consumption by source from 1965 to 2021** [3]

Significant carbon dioxide ($CO_2$) emissions from the burning of fossil fuels have sparked worries about the sustainability of energy and environmental protection. More than 1000 kg/s of $CO_2$ are currently being released on a global basis. Only by decreasing the emissions of $CO_2$ from the sources or expanding $CO_2$ usage will the atmospheric $CO_2$ emissions be reduced. Energy resources with little environmental impact should be used to ensure sustainable development.[4]

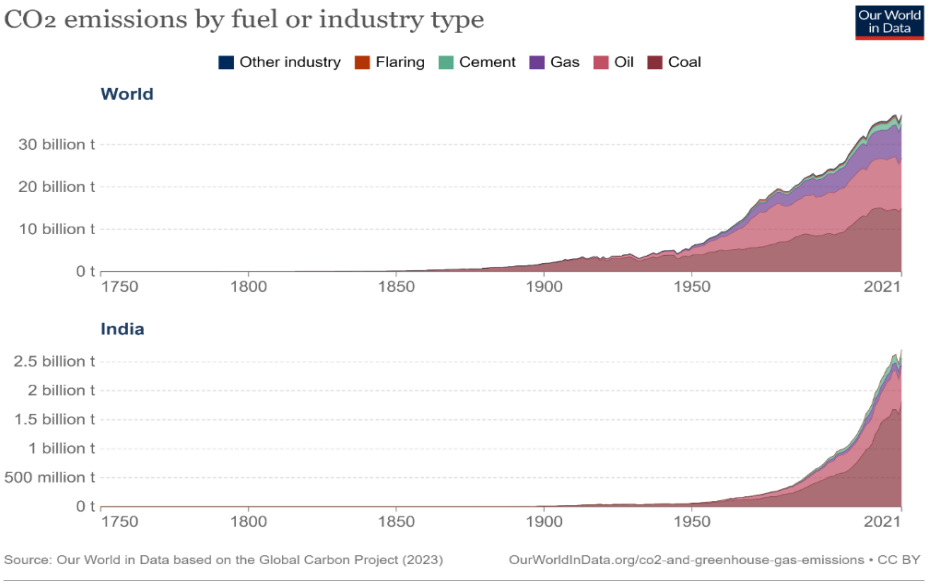


**Fig 1.2 Annual carbon dioxide ($CO_2$) emissions, estimated in tonnes per year, from various fuel types** [5]

### 1.1.1 BENEFITS OF BIOGAS AS A RENEWABLE ENERGY SOURCE

*Renewable and Sustainable***:** Biogas is considered renewable because the organic materials used in its production can be continuously replenished. It is a sustainable energy source that helps reduce reliance on fossil fuels and mitigates greenhouse gas emissions.

*Greenhouse Gas Reduction:* Biogas production plays a crucial role in reducing greenhouse gas emissions. When organic waste decomposes in landfills or other anaerobic conditions, it releases methane, a potent greenhouse gas. By capturing methane through anaerobic digestion, biogas systems prevent its release into the atmosphere, thereby mitigating its impact on climate change.

*Energy Conversion:* Biogas can be used to generate electricity and heat through combined heat and power (CHP) systems or can be upgraded to biomethane for use in natural gas pipelines or as a transportation fuel.

*Versatile Applications:* Biogas can be used in various sectors. In addition to electricity and heat production, it can be used as a fuel for cooking, heating water, and powering vehicles. Biogas can also be utilized in industries such as agriculture, wastewater treatment plants, and food processing facilities.

*Waste Management Solution:* Biogas production provides an effective waste management solution by utilizing organic waste that would otherwise contribute to pollution and environmental degradation. It helps divert waste from landfills and reduces the release of harmful substances into the environment.

## 1.3 BIOGAS IMPURITIES

To improve efficiency and lessen environmental contamination from dangerous gas emissions during biogas generation, certain pollutants must be removed prior to usage [8]. Different applications for heating, cooking, and power generation can directly use biogas. However, if biogas is used directly and there is a significant concentration of $CO_2$, the heating value will decrease, which restricts the direct use's economic viability[9].

**Table 1.1 Effects of biogas impurities** [10]

| Impurity | Negative effect |
|---|---|
| $CO_2$, $N_2$, and $H_2$ | The biogas's calorific value and energy content are being reduced. |
| $H_2O$ and $O_2$ | corrosion is a result of the combustion process' reaction with other substances (such siloxanes) to produce sulfuric acid and hydrochloric acid; While $O_2$ is corrosive and may be explosive at concentrations above 6%, $H_2O$ can build in pipes. |
| $NH_3$ | Corrosive; This may cause the development of hazardous respiratory chemicals such as nitrogen oxides (NOx) and aerosols during the burning of biogas. |
| $H_2S$ and other sulphur compounds | Extremely corrosive to heat and power units; Can be converted to toxic and environmentally hazardous and corrosive forms ($SO_2$, $SO_3$, and $H_2SO_4$); Sulphur compounds poisoning on nickel sites of fuel cells Deposits of elemental sulphur. |
| CO | Toxic to humans and some microorganisms present in the biodigester |

## 1.4 BIOGAS PURIFICATION

The objective of employing different technologies for biogas purification is to minimize the presence of unwanted gases like $CO_2$, $H_2S$ etc, thereby enhancing efficiency by elevating the energy content of the gas. This enables its utilization in various everyday applications after undergoing suitable processing. Moreover, the purified gas serves as an alternative to environmentally detrimental fossil fuels, effectively replacing them.

To enhance the economic feasibility of biogas in power generation, its effectiveness is limited by elevated $CO_2$ levels during production, leading to a decline in heating value and increased expenses for compression and transportation. Furthermore, the presence of additional impurities, such as engine, tube, and chimney corrosion, negatively impacts the integrity of downstream system equipment [11]. The two main steps in treating biogas are cleaning (removal of minor undesirable components) and upgrading (reduction of $CO_2$ content). The end product is biomethane, which is primarily constituted of $CH_4$ (95–99%) and $CO_2$ (1–5%), with no $H_2S$ present. Biogas applications often begin with cleaning, which is an energy-intensive operation. The second method seeks to increase biogas's low calorific value in order to transform it into a fuel with high requirements [4].

## 1.5 BIOGAS PURIFICATION TECHNIQUES

Various purification techniques are used to rid biogas of impurities in order to open the door for the use of a clean and effective energy source in a variety of applications. Since the main application of these approaches is the separation of carbon dioxide ($CO_2$), there are limitations in terms of choosing the best technology, with methane losses and cost being the most important. Each technology has advantages and disadvantages. The methods mentioned in the literature for this purpose include absorption (water scrubbing, organic scrubbing, chemical absorption), adsorption (pressure swing adsorption, or PSA), cryogenic separation, membrane separation, and biological upgrading.

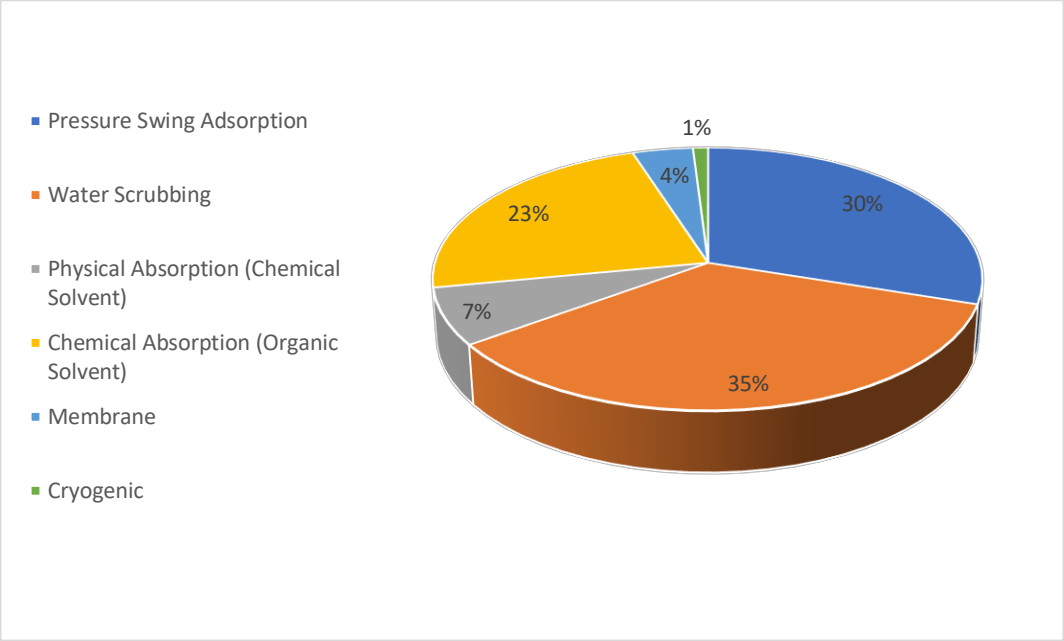


**Fig 1.3 Technologies used biogas enrichment** [12]

### 1.5.1 ABSORPTION TECHNIQUES:

Techniques for absorption can be carried either chemically or physically by scouring with water and organic materials. The underlying principle of this method is that carbon dioxide ($CO_2$) exhibits higher solubility compared to methane. The variations in absorbent techniques rely on the specific type of absorbents employed in the column. Specifically, the biogas column experiences a counterflow of liquid, such as a liquid chemical solution or water. Consequently, upon exiting the column, the liquid will exhibit an increased $CO_2$ concentration, while the enriched gas will contain a higher methane concentration.[13]

#### 1.5.1.1 WATER SCRUBBING:

The water scrubbing method is widely recognized as the most popular technique for biogas purification; it works on the theory that $CO_2$ and $H_2S$ absorb more water than $CH_4$ and can thus be separated from biogas with great efficiency [14]. The solubility of $CH_4$ is 26 times less than that of $CO_2$ at 25 °C. $H_2S$ is more soluble in water than $CO_2$, and because it is so much more corrosive than $CO_2$, it is advised to separate it before removing $CO_2$ [15]. To enhance gas-liquid mass transfer, the absorption column often employs random packing material. Following compression and heating of biogas to a pressure range of 6 to 10 bar and

temperature up to 40 °C, it enters the bottom of the scrubber alongside water containing $CO_2$ and $H_2S$, which is supplied from the top. Biomethane is subsequently released at the scrubber's top. It is then directed from the bottom to a flash vessel, where the pressure is decreased to approximately 2.5 to 3.5 bar. Consequently, dissolved $CH_4$ residues in the water are collected, minimizing biomethane losses in the process [16].

#### 1.5.1.2 ORGANIC SCRUBBING:

Organic scrubbing works on a similar principle to water scrubbing but uses an organic solvent in place of water. A variety of solvents, including N-methyl pyrrolidone (NMP), polyethylene glycol ethers (PEG), and methanol ($CH_3OH$), The amount of solvent and pumping capacity needed will decrease since $CO_2$ is five times more soluble in PEG than it is in water for the same upgrading capacity. Furthermore, apart from carbon dioxide absorption, a solvent has the capacity to assimilate various contaminants such as hydrogen sulphide ($H_2S$), water ($H_2O$), oxygen ($O_2$), nitrogen ($N_2$), and halogenated hydrocarbons. However, it is recommended that $H_2S$ be removed first from this absorption process to minimise energy consumption because of $H_2S$'s high solubility, which necessitates higher temperatures for its separation during solvent regeneration[17].

#### 1.5.1.3 CHEMICAL ABSORPTION:

Monoethanolamine (MEA) and di-methylethanolamine (DMEA) were the most frequently employed amine chemicals, and for alkali solutions that function on the same principles as water scrubbing. The most often used hydroxides are sodium, potassium, and calcium. Based on the concept of a reversible chemical process that incorporates absorbed gases and a chemical solvent, chemical scrubbing operates effectively. The reaction takes place when the amine is provided to the top of the column to create a countercurrent flow contact and the raw biogas is introduced into the absorber from the bottom. After interacting exothermically with the amine solution, $CO_2$ is absorbed, increasing the absorber's temperature from 20 to 40 to 45 to 65 °C. The capacity of the amine solution to absorb $CO_2$ will grow as the temperature of the amine scrubbing process rises. While the liquid from the absorber's bottom is sent to the upper part of the stripper

column, where it joins the steam, and $CO_2$ is released through the heat exchanger, the resultant gas ($CH_4$) is expelled from the upper section of the column.[18].

### 1.5.2 PRESSURE SWING ADSORPTION (PSA):

The Pressure swing adsorption (PSA) technique has been widely employed in the purification of biogas. PSA leverages variations in gas adsorption ratios within the adsorbents to separate the required gases. The adsorbates are subsequently released at low pressure to regenerate the adsorbent for another adsorption cycle. The selection of adsorbents is based on their exceptional thermal stability, significant specific area, substantial pore volume, and cost-effectiveness. Zeolite, silica gel, activated carbon, and carbon molecular sieve rank among the commonly used adsorbents.

Pressure swing adsorption (PSA) operates in four main steps. First, biogas, freed of $H_2S$ and $H_2O$, enters an adsorber vessel at 6–8 bar. Carbon dioxide, oxygen, and nitrogen are selectively absorbed as the gas moves through the vessel, and methane is released. In the second step, saturated adsorbent is regenerated in another vessel. The adsorber vessel undergoes a gradual depressurization process, transitioning from elevated pressure to atmospheric and subsequently to close vacuum conditions. The pressure is lowered from 6–8 bar to 3–4 bar through interaction with column 4. In the third step, the vessel is evacuated to 0.1 bar, primarily removing $CO_2$. Some purified $CH_4$ displaces $CO_2$ in the purge phase. Off-gas is recycled to the biogas intake to reduce $CH_4$ loss. The off-gas containing a high concentration of $CO_2$ can either be directed to off-gas treatment or released into the atmosphere. The exhaust gas from the $CO_2$-saturated column is transferred to the nearby regenerated adsorption column. A combination of $CO_2/CH_4$, which has a high $CH_4$ content, is discharged and recycled back into the input of the PSA system. The saturated column is cleaned using upgraded biogas. The final step involves pressurization to resume the adsorption phase, achieved by gradually re-pressurizing the adsorber vessel with the feed gas after balancing the pressure with an adsorber in adsorption mode.[19].

### 1.5.3 CRYOGENIC SEPARATION:

The main concept behind this method relies on the variation in liquefaction temperatures for biogas compounds caused by a progressive decrease in gas temperature. Liquefaction involves gradually reducing the temperature to remove specific pollutants or groups of pollutants. Initially, the temperature is set at 25 °C to collect products such as $H_2O$, $H_2S$, and siloxanes. In the subsequent step, the temperature is lowered to 55 °C to partially liquefy $CO_2$, and in the final stage, the temperature is further reduced to 85 °C to solidify any remaining $CO_2$. Another operational system employs lower temperatures, ranging from 45 to 55 °C, and involves drying the gas before compressing it in phases up to 80 bar. However, a drawback of multiple-stage compression is the need for cooling. In terms of cryogenic separation, the resulting liquid $CO_2$ can be sold as a by-product to enhance the economic viability of the technology [20].

### 1.5.4 MEMBRANE SEPARATION:

The concept of membrane separation involved retaining certain components of raw biogas while transporting others across a membrane. Working pressures typically ranged from 25 to 40 bars. Hollow fibre and spiral wound modules were commonly employed due to their high packing density. The process involved two phases. Prior to entering the hollow fibres, a filter was used to remove water, oil droplets, and aerosols from the gas, thus preventing them from affecting the membrane's performance. Two methods were utilized for membrane separation: gas/gas (high-pressure gas separation) and gas/liquid adsorption. Although multiple phases might be necessary for these processes, they could result in methane losses. Initially, gas-gas separation used pressurized gas ranging from 20 to 36 bar to eliminate $H_2S$ and oil vapours [21].

## 1.6 COMPARISON BETWEEN DIFFERENT PURIFICATION TECHNIQUES

Each biogas purifying method has advantages and disadvantages. When assessing the effectiveness of these technologies, it is crucial to consider the percentage of contaminants removed, the energy consumption during the process, and the necessity of chemicals or other consumables.

**Table 1.2 Examining various methods employed for biogas purification (**[22]–[24]**)**

| Technique | Advantages | Disadvantages |
|---|---|---|
| Water scrubbing | • it is not a difficult procedure; it is easy to utilize and can be adapted for different pressures and temperatures. $CH_4$ purity can reach up to 97%.<br>• Minimize the presence of carbon dioxide ($CO_2$), ammonia ($NH_3$), and particles.<br>• Remove $H_2S$ When $H_2S < 300$ $cm^3/m^3$<br>• No chemicals are required.<br>• Opportunity for regeneration.<br>• The loss of $CH_4$ is less than 2%. | • Even in regenerative processes, a substantial quantity of water is necessary for the processing.<br>• Bacterial growth leads to the occurrence of clogging.<br>• Foaming possibility<br>• The occurrence of sulphur dioxide results in corrosion.<br>• The flexibility of input gas is restricted<br>• The pace is hindered by the physical solubility.<br>• The removability of $H_2S$ is low in certain instances |
| Organic scrubbing | • $CO_2$ exhibits greater solubility compared to water<br>• The $CH_4$ purity is greater than 96% for organic solvent and ranges from 93 to 98% for polyethylene glycol.<br>• $CH_4$ losses are low | • In the context of the regenerative process, there will be a rise in energy consumption.<br>• The complexity of solvent regeneration arises when $H_2S$ removal does not take place. |

| | | |
|---|---|---|
| | | • Operating is difficult |
| Chemical absorption | • The $CH_4$ purity achieves a level of 96-99% efficiency.<br>• The losses of CH4 are less than 0.1%.<br>• This process eliminates $H_2S$, HCN, $NH_3$, and $H_2O$.<br>• The operation is faster than water scrubbing, and the column size is smaller compared to water scrubbing.<br>• The process of regenerating the chemical solvent is simple. | • difficult to operate<br>• The regenerative process necessitates heat for the production of steam.<br>• At elevated temperatures, corrosion can occur.<br>• Expanding potential<br>• The chemicals employed are costly.<br>• Water with chemical properties is generated. |
| Pressure swing adsorption (PSA) | • Highly efficient ($CH_4$ 96% – 98%)<br>• No heat or chemicals are employed.<br>• $CO_2$, $N_2$, and $O_2$ are eliminated.<br>• Streamlined and readily expandable.<br>• The installation and start-up processes are relatively fast. | • $CH_4$ is lost when a valve fails<br>• The elimination of $H_2S$ and water is necessary prior to processing<br>• Ensuring process control is crucial. |
| Cryogenic separation | • The $CH_4$ purity ranges from 90 to 98 percent with high efficiency<br>• $CO_2$ is generated as a by-product and can be sold.<br>• The gas volume decreases because $CH_4$ is in a liquid state, making distribution easier.<br>• Methane losses are low | • Numerous pieces of equipment and processes are utilized<br>• Pre-treatment procedures are necessary.<br>• High energy is needed for cooling.<br>• The $CH_4$ molecule can temporarily house $CO_2$. |
| Membrane separation | • The purity of $CH_4$ exceeds 96%. | • To attain a substantial purity |

| | | |
|---|---|---|
| | • Chemicals are not used<br>• Simple, compact, and high reliability<br>• Easily operable and requires low maintenance<br>• The purest form of $CO_2$ can be generated.<br>• The removal of $H_2O$ and $H_2S$ takes place. | ratio, multiple procedures need to be conducted<br>• Methane losses vary from moderate to high ($CH_4$ losses <10%), making it unsuitable for high purity requirements.<br>• Membrane obstruction and fouling<br>• The membrane replacement is required every 1-5 years. |

## 1.7 DWSIM SOFTWARE

DWSIM is an open-source process simulation software used for modelling and simulating chemical processes. It stands for "Distillation, Water and Solvent properties, and Industrial Modelling." DWSIM provides a comprehensive set of tools for designing, analyzing, and optimizing various types of chemical processes.

### 1.7.1 KEY FEATURES OF DWSIM INCLUDE:

*Process Modelling:* DWSIM allows you to create process flow diagrams (PFDs) by connecting unit operation blocks such as reactors, separators, heat exchangers, pumps, and distillation columns. It supports a wide range of chemical components and thermodynamic models.

*Thermodynamic Models:* DWSIM offers a vast selection of thermodynamic models, including equations of state (EOS), activity coefficient models, and property prediction methods. These models help simulate the behavior of chemicals under different process conditions.

*Unit Operations:* DWSIM provides a library of pre-built unit operations, which can be customized and interconnected to create complex process flows. It supports

various types of reactors, distillation columns, heat exchangers, pumps, compressors, and more.

*Sensitivity and Optimization:* DWSIM enables sensitivity analysis and optimization of process parameters. It allows you to perform parameter sweeps, design optimizations, and analyze the impact of different variables on process performance.

*Reporting and Analysis:* DWSIM offers extensive reporting capabilities, allowing you to generate detailed reports and analyze simulation results. It provides features like data plotting, tables, and summary statistics to aid in the interpretation of simulation data.

*Integration and Extensions:* DWSIM supports the integration of external tools and databases, facilitating the import and export of data. It also provides an API for creating custom modules and extensions to enhance its functionality.

## 1.8 MULTI-CRITERIA DECISION MAKING (MCDM) TECHNIQUES:

The MCDM (Multi-Criteria Decision Making) technique is a systematic approach used to evaluate and select the best alternative among multiple options or choices.

The MCDM technique aims to incorporate both quantitative and qualitative factors into the decision-making process. It provides a structured framework for assessing alternatives based on their performance across multiple criteria and synthesizing these assessments into an overall ranking or preference order.

There are several different MCDM methods available, each with its own approach and mathematical models. Some of the commonly used MCDM techniques include:

*Weighted Sum Model (WSM):* This method involves assigning weights to each criterion and calculating a weighted score for each alternative based on its performance on each criterion. The alternative with the highest overall score is considered the best choice.

*Analytic Hierarchy Process (AHP):* AHP breaks down complex decisions into a hierarchy of criteria and alternatives. Decision-makers assign pairwise comparisons to determine the relative importance of criteria and alternatives, and then calculate a priority score for each alternative based on the consistency of these comparisons.

*Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS):* TOPSIS compares alternatives to an ideal and anti-ideal solution based on their performance on each criterion. The method calculates a proximity score for each alternative, and the alternative with the highest proximity score to the ideal solution is chosen.

## 1.9 OVERVIEW OF THESIS

This section outlines the comprehensive design for this thesis in the following manner:

**Chapter 1 (Introduction):** introduces the topic with additional information about different techniques and the objective of the study.

**Chapter 2 (Literature Review):** discusses the previous works done by the researchers in the form of a literature review.

**Chapter 3 (Methodology):** The research approach taken for this thesis will be covered in this chapter.

**Chapter 4 (Results):** discusses the results obtained from the above work.

**Chapter 5 (Conclusion):** discusses the conclusions drawn from the above study and also discusses some recommendations.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 GENERAL

This chapter involves the previous studies done by researchers to understand the effect of chemical absorption technique on reducing the amount of $CO_2$ in biogas purification process. And also, to investigate on the interaction of absorbent and gas molecules so that at different parameters the purification process can be understood.

**Shah et al.** [25] conducted the analysis of the factors influencing the purification of biogas through pressure swing adsorption (PSA) technologies. It examines variables such as adsorption technologies, adsorbent types, bed configuration, biogas source and composition, time cycle, and operating conditions. Additionally, it highlights creative engineering approaches that enhance process performance and explains the fundamental principles of the PSA process.

**Srichat et al.**[26] developed a biogas purification system using calcium oxide and amine solution. Various solutions, including pure water, 0.1 mol and 0.2 mol calcium hydroxide, and 0.1 mol and 0.2 mol mono ethanol amine (MEA), were tested. Different solution flow rates (10, 20, and 30 l/min) and biogas flow rates (5, 10, and 15 l/min) were examined for 30 minutes. The composition of biogas was analyzed before and after purification, showing methane and carbon dioxide ratios of 51.00% and 39.36% respectively. The most effective solution was 0.2 mol calcium hydroxide, achieving a maximum methane ratio of 89.30% at a solution flow rate of 30 l/min and a biogas flow rate of 5 l/min. These findings emphasize the impact of flow rates, solution types, concentrations, and biogas flow rates on the purification process.

**Tira et al.** [27] explores variations in water absorption (V) and biogas input flow rate (Q). The analysis is based on the volumes of raw biogas pumped into the absorbent. The purification process enhances the biogas composition by significantly reducing CO2 and H2S levels within minutes. Simultaneously, CH4 quantity increases, improving the quality of the raw biogas. After purification, the composition of raw and purified biogas becomes nearly identical, mainly due to an absorbent pH increase. Comparing different water volumes and biogas flow rates, it is clear that higher water volume and slower biogas flow rate produce better results in reducing CO2 and H2S while increasing CH4. This cost-effective and user-friendly purification process has significant potential in improving raw biogas quality.

**Kasikamphaiboon et al**.[28] conducted research on the concurrent absorption of CO2 and H2S by MEA solution in a packed column. The effects of gas flow rate, L/G ratio, and absorbent content were studied using biogas from an anaerobic digestion facility and simulated biogas with 40% CO2 and 60% N2. The system's efficiency varied based on these process parameters. Increasing the gas flow rate decreased system efficiency, while increasing the L/G ratio and MEA concentration improved it. The study found a removal rate of over 99.5% for CO2 and H2S from biogas under specific working conditions: L/G ratio of 83.3 ml/L, gas flow rate of 3 L/min, and MEA concentration of 3 mol/L. The volumetric overall mass-transfer coefficient (KGav) for CO2 removal initially increased with higher gas flow rates but eventually reached a constant value. Within the measured range of the study, the KGav also increased with higher L/G ratios.

**Purba et al.** [29] investigated using $Ca(OH)_2$ and NaOH solutions in a bubble column to decrease $CO_2$ levels and enhance the heating value of the biogas. The influence of the column height, sparger hole diameter, and column diameter on the purification process is examined. The bubble column, made of acrylic, has three different diameters (2.5, 3.0, and 4.0 in) and a height of 100 cm. The sparger is located at the base of the column and consists of holes ranging from 1 to 2 mm in diameter. The solvent height varies based on the column diameter, with heights of 63, 44, and 25 cm for the solutions. The biogas is introduced at the bottom of the column at a flow rate of 1 liter/min. Gas chromatography is used to analyze

the samples taken from the column's output and intake. The results indicate that the proportion of $CO_2$ absorption and $CH_4$ containment increases with the amount of absorbent used. $Ca(OH)_2$ and NaOH are employed to enhance $CO_2$ absorption, with absorption rates of 70.18% and 90.66%, respectively. The use of $Ca(OH)_2$ and NaOH also leads to higher $CH_4$ content, with values of 66.84% and 87.755%, respectively

**Tira et al.**[31] investigated on the effects of adding different concentrations of sodium hydroxide to raw biogas were studied to remove contaminants. Results indicate that 5% NaOH led to the highest methane ($CH_4$) concentration compared to 0% and 15% NaOH. This was due to the superior zeolite micropores, which improved the selectivity and adsorption process of the membrane. The structure of the membrane also showed smaller crystal size, supporting this finding. The 5% NaOH solution created larger caves or pores, allowing for increased trapping of $CO_2$ and $H_2S$ and consequently raising the $CH_4$ concentration in purified biogas. The purified biogas with 5% NaOH maintained a $CH_4$ concentration of 95% for a longer duration, surpassing the levels achieved with 0% and 15% NaOH.

**Mel et al**.[32] investigated on using sodium hydroxide solutions (NaOH) to purify $CO_2$ and $H_2S$ gases. The effect of contaminant removal on $CH_4$ composition was also investigated by altering the biogas flow rate and sodium hydroxide concentrations. Experiments revealed that the maximum absorption capacity was achieved with a roughly 54.9% increase in $CH_4$ from its initial value, while the highest elimination efficiency occurred at a sodium hydroxide concentration of 14%. However, the low concentration (ppm) of $H_2S$ in the biogas mixture led to only a 26% removal in the continuous flow, which was insufficient to meet the desired objective. Consequently, the $CH_4$ concentration did not change significantly enough to warrant further analysis.

**Pertiwiningrum et al.**[33] studied on the attempts to look into how well purified biogas burns after being exposed to sodium hydroxide. The absorption method has been used to remove carbon dioxide. The four types of sodium hydroxide

(NaOH) concentrations employed in this investigation are 5, 15, 25, and 35. Methane content of biogas rose after carbon dioxide absorption utilising 5, 15, 25, and 35%. The increase in calorific value was impacted by the rise in methane. After being absorbed with 5, 15, 25, and 35% sodium hydroxide, purified biogas increased in energy by 187.91, 225.42, 227.91, and 243.82 kJ, respectively.

**Maile et al.** [34] studied on amines because they are frequently used to purify biogas globally. In a continuous system, biogas was produced in a 1L digester and bubbled through an absorbent in a 500mL gas washing container. Gas chromatography was used to evaluate the gas that was leaving the absorption column. MEA is an excellent absorbent, which contributed to the greater methane output found in this study. It was discovered that the biomethane potential was 0.40 m3 $CH_4$/kg VS (volatile solids). The capacity and rate of $CO_2$ absorption increased as concentration increased; at the corresponding concentrations, averages of 76%, 78%, and 84% vol were attained from initial concentrations of 52% vol. With rising temperature, the purified biogas's $CH_4$ content increased. Carbon dioxide removal effectiveness rose from 66% at ambient temperature to 77% at 40 °C. The solvent's temperature boosted the process's capacity for absorption and carbon dioxide removal effectiveness.

**Tippayawong et al**.[35] conducted experimental research on the absorption of $CO_2$ and $H_2S$ in biogas using aqueous solutions (MEA, calcium hydroxide, and sodium hydroxide) in a packed column. The liquid solvents were pumped through the column in countercurrent flow, effectively reacting with the biogas. The results indicated high efficiency in removing $CO_2$ (approximately 90%) and reducing $H_2S$ to undetectable levels. The absorption process was temporary, with saturation achieved in around 50 minutes for calcium hydroxide and 100 minutes for sodium hydroxide and MEA. Regular replacement or regeneration of the solutions can maintain upgraded biogas quality. This method holds promise for enhancing biogas quality.

**Gantina et al.** [36] investigated on using the water scrubber technique to separate $CO_2$ from biogas. Biogas pressures (2, 3, and 4 bar) and water flow rates (0.1 and 0.15 L/s) were varied. Results showed that a biogas pressure of 4 bar and a water

flow rate of 0.15 L/s achieved the highest $CO_2$ removal (99.5%) and $CH_4$ increase (38.18%). Higher biogas pressures and water flow rates yielded better CO2 removal in biogas.

**Kulkarni et al.** [37] investigated on packed column reactors and low-cost chemical absorption technology for hydrogen sulphide removal. Industrial-grade chemicals like monoethanolamine, sodium hydroxide, calcium hydroxide, activated carbon, and steel wool were used in 1.2-liter packed column reactors to purify biogas. With a single purification column, hydrogen sulphide removal efficiency reached 92.41%, which increased to 96.84% with multiple purification columns. The study evaluated hydrogen sulphide removal efficiency under various experimental modifications such as dedicated purification column usage, multiple columns, flow fluctuations, and pressure variations of raw biogas. Additionally, the study established data on chemical replacement frequency. These techniques provide end users of biogas technology with cost-effective methods to reduce health risks and corrosion issues.

**Ghatak et al.** [38]used sodalime to build a biogas purification system that will use chemical reactions to extract carbon dioxide from biogas. The simplicity and use of this technology make it particularly advantageous for rural locations. By using this technology, it is anticipated that biogas will be purified to a level comparable to that of the most popular chemical processes, enhancing cost-efficiency.

**Soehartanta et al.** [39]studied on proposing a new method to purify biogas using water absorption columns integrated with an ultrasonic nebulizer. $CO_2$ and $H_2S$ dissolve in water while $CH_4$ is released from the water's surface through an ultrasonic diffuser. By adjusting the water's pH between 6.0 and 7.3, the optimal water absorption capacity was achieved. The biogas purification is influenced by the water's pH, with an ideal setting of 6.78 resulting in significant improvements: 11% enrichment of $CH_4$, 29% increase in $O_2$, 32% reduction in $CO_2$, and 99.8% reduction in $H_2S$.

**Seman et al.**[40] utilized Aspen Plus software to develop a pressurized water scrubbing model for biogas purification. Various process parameters, such as liquid to gas (L/G) ratios and absorber column pressure, were altered to assess their impact on CO2 removal percentage and bioCH4 purity. The simulation findings align well with prior research and the typical bioCH4 concentration of over 95%, suitable for vehicle fuel or the petrol grid.

**Fahmayanti et al.** [41]studied to generate high-quality biogas through NaOH and KOH purification, reducing $CO_2$ and $H_2S$ levels. Different absorbent concentrations (0,05M, 0,1M, and 0,15M NaOH and KOH solutions) were used for biogas purification. Gas chromatography, with a TCD detector, characterized the biogas by representing concentration areas as percentages (%). The control biogas contained 2.14% $CO_2$ and 0% H2S. NaOH additions of 0.05, 1, and 15 mM resulted in $CO_2$ production rates of 1,57%, 1,56%, and 2,98%, respectively. Additionally, KOH additions of 0.05 M, 0,1 M, and 0,15 M produced 0.81%, 0,30%, and 1,03% $CO_2$, respectively. The highest calorie burn came from 0,15M NaOH at 66,528 kcal, while the lowest was from 0,1M KOH at 38,976 kcal.

## 2.2 RESEARCH GAP

From the literature survey, the following research gaps were identified:

- Despite of enormous study on the absorption technique, limited research has been done in the software part to study the purification process.
- Limited research on the temperature variation to understand the interaction of gas molecules with the absorbent molecules in the purification process has been done.
- Limited research work has been done on MCDM technique to identify the best possible parameters in the biogas purification process.

## 2.3 OBJECTIVES OF THE STUDY

- The objective of this dissertation is to investigate on absorption technique for biogas purification. The system's performance was then examined by varying several factors, such as biogas flow rates, absorbent types, absorbent concentrations, absorbent flow rates, etc.

- The goal of the study was to determine the optimal solution type that could effectively lowering carbon dioxide during biogas treatment, and to contrast the variations among each sort of solution.

# CHAPTER 3

# METHODOLOGY

## 3.1 GENERAL

An overview of biogas purification technique has been discussed in the previous chapters. The basic objective of the present study is to design an experimental model, so that the process of absorption technique can be studied at different input parameters. To achieve the stated objective the following flow chart will be followed.

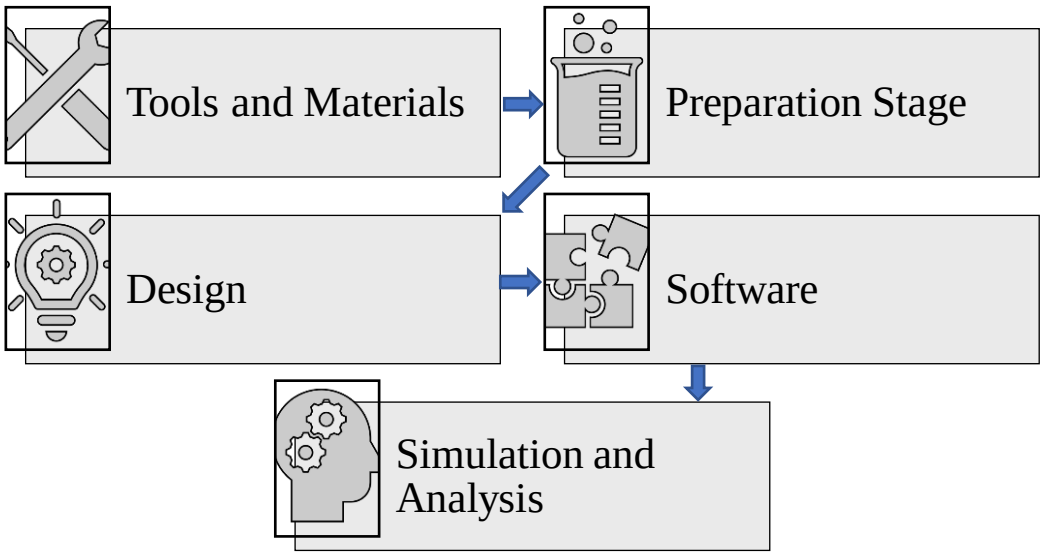


**Fig 3.1 Flow chart of the methodology**

## 3.2 TOOLS AND MATERIALS

The tools used are digester units (drums, pipes, plastic biogas containers, plastic bubble column), scales, gas analyzer, flow meters. The material used are cow dung, water, jaggery, vegetable waste, Sodium Hydroxide, Calcium Hydroxide, Potassium Hydroxide and pipe glue.

## 3.3 PREPARATION STAGE

The biogas for the study was produced at Delhi Technological University laboratory. For the study three different digesters, namely digester (D1), digester (D2) and digester (D3) each with a different feed content was taken. The capacity of the digester used in the experiment was 10 liters, and it was fed with a mixture of cow dung solution, jaggery, and water in a ratio of 1:1.15. The feed content in D1 was solely cow dung, while D2 contained a mixture of cow dung and vegetable waste, and D3 contained cow dung mixed with 10g of KOH.

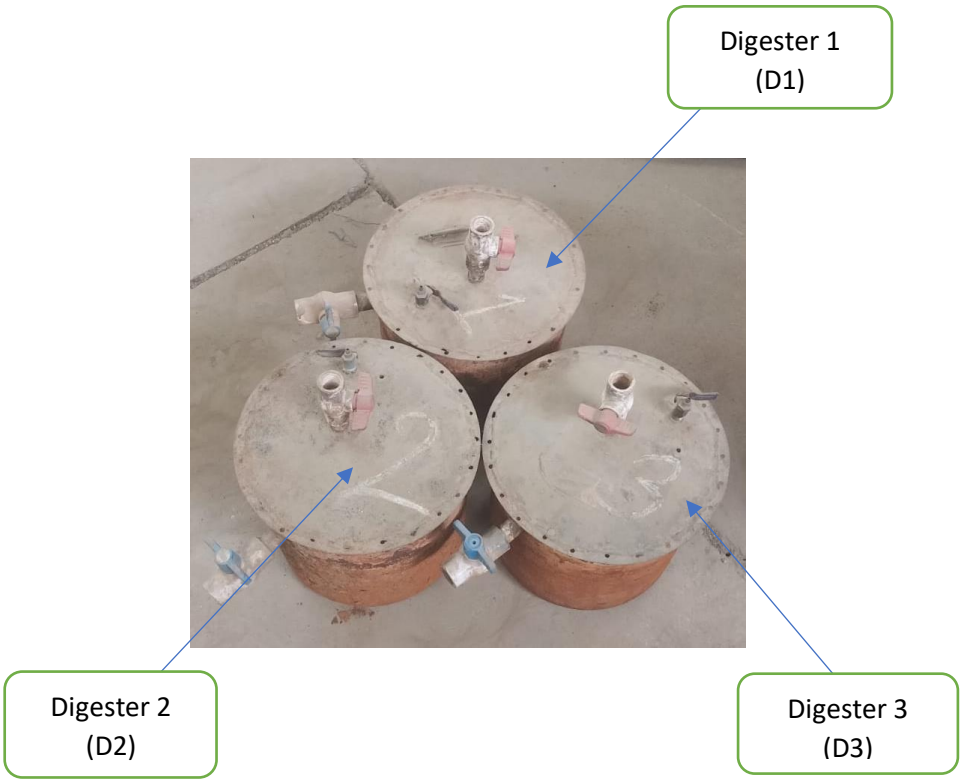


**Fig. 3.2 Production of biogas with different feed in digester D1, D2, D3**

For the study 60 days biogas composition reading for $CH_4$, $CO_2$ and $O_2$ is considered. figure 3.3 shows $CH_4$ concentration (%) reading obtained from each digester.

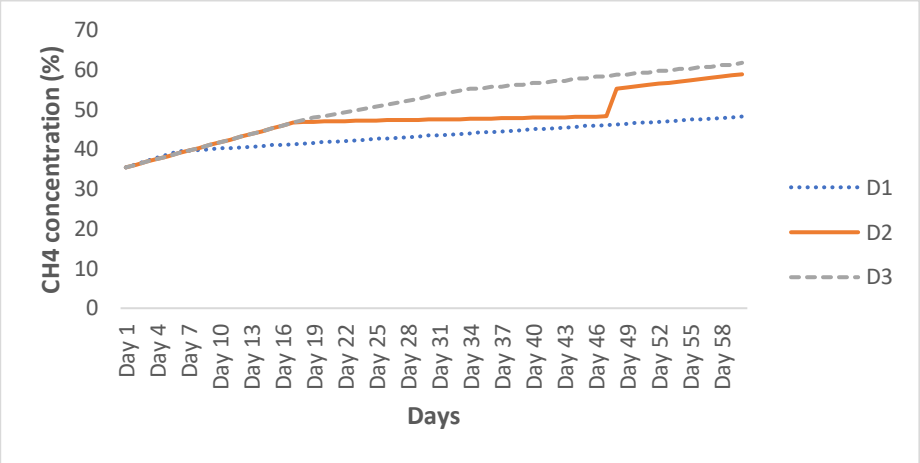


**Fig. 3.3 Per day reading of $CH_4$ concentration (%)**

## 3.4 EXPERIMENTAL DESIGN

For this study, the primary tool employed was a plastic bubble column that had a diameter of 2.36 inches and a height of 17.7 cm. The column contained a fixed volume of 400 ml of absorbent solution and was fitted with a 5mm-diameter pipe. Other equipment used included sample bags for collecting biogas input and output, a gas flowmeter, and a gas analyzer for analyzing the gas.

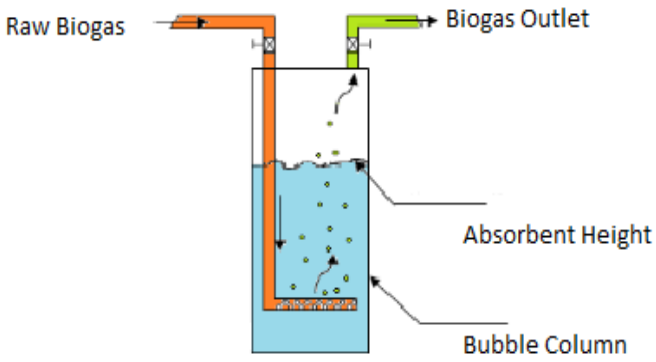


**Fig. 3.4 (a) Schematic diagram of water scrubbing unit**

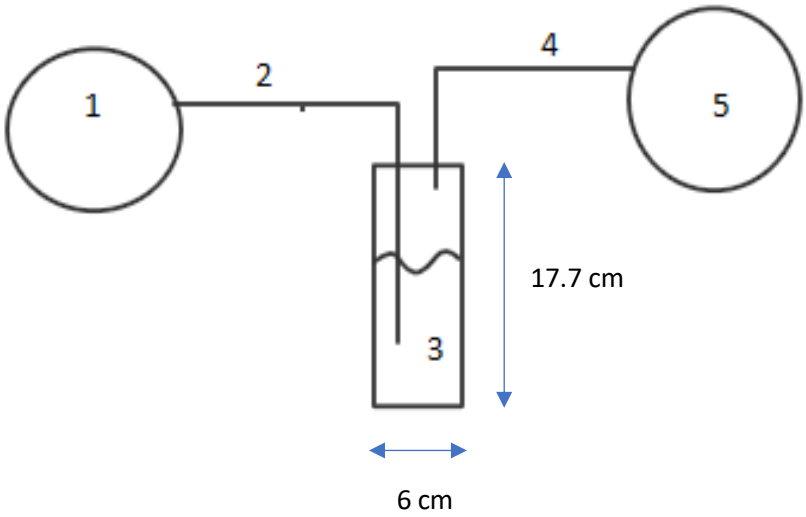


**Fig. 3.4 (b) The schematic diagram. 1 – Biogas input, 2 – inlet pipe, 3 – Absorbent solution, 4 – outlet pipe,5 – Biogas outlet**

- Bubble Column material: Plastic
- Column height: 17.7 cm
- Column diameter: 6 cm

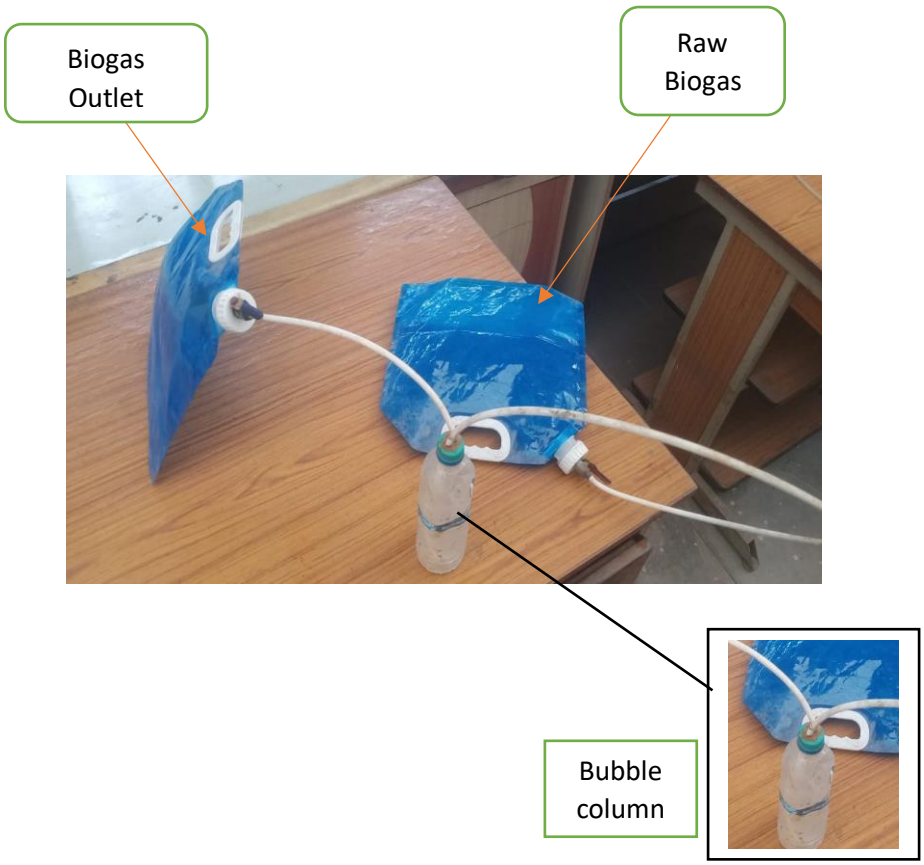


**Fig. 3.5 Experimental setup of bubble column biogas purification process**


**Fig. 3.6 Gas Analyzer**

Fig. 3.6 shows a biogas analyzer used to measure and analyze the composition of biogas, which is a renewable energy source produced through the anaerobic digestion of organic matter.

During the experiment, biogas generated by a system that used cow manure was used. The amount of biogas produced fluctuated on a daily basis, depending on the time of day. To provide a basis for comparison, Tables 1, 2, and 3 were created to show the average values of the different components present in the untreated biogas that came from Digester D1, Digester D2, and Digester D3, respectively. Throughout the 2-month experiment, the mean component values were utilized.

**Table 3.1 The mean values of the biogas composition generated by digester D1**

| Component of Biogas | Mean value |
|---|---|
| (%) $CH_4$ | 48.2 |
| (%) $CO_2$ | 43.4 |
| (%) other gases | 8.4 |

**Table 3.2 The mean values of the biogas composition generated by digester D2**

| Component of Biogas | Mean value |
|---|---|
| (%) $CH_4$ | 56.8 |
| (%) $CO_2$ | 35.6 |
| (%) other gases | 7.6 |

**Table 3.3 The mean values of the biogas composition generated by digester D3**

| Component of Biogas | Mean value |
|---|---|
| (%) $CH_4$ | 62.3 |
| (%) $CO_2$ | 33.4 |
| (%) other gases | 4.3 |

The absorption process utilized a solution of NaOH and $Ca(OH)_2$ with a concentration of 0.625 mol and 0.9375 mol, respectively, and a volume of 400 ml. Gas analysis was performed using a gas analyzer to determine the initial biogas content and the product after the absorption process. The biogas was flown through the sparger in the absorption column at flow rates of 1.25 l/min and 3.33 l/min for the absorption process, and the biogas output was also analyzed by a gas analyzer. The experiment aimed to investigate the impact of altering the flow rates of biogas, types of solutions, and solution concentrations on the system's performance.

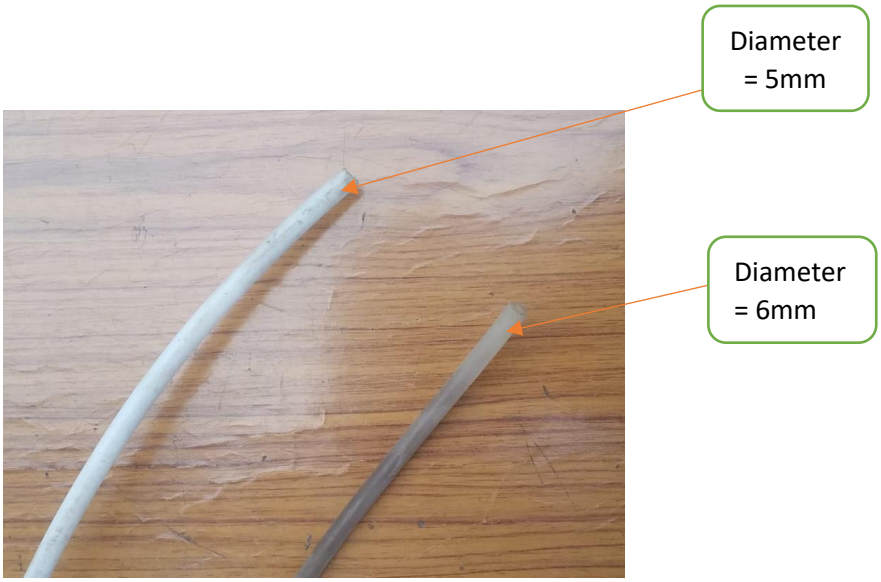


**Fig. 3.7 Pipe with different diameter**

## 3.5 SOFTWARE

### 3.5.1 DWSIM

DWSIM is a comprehensive open-source chemical process simulator that can be used for various applications, including biogas purification. Biogas, which is typically produced from organic waste materials through anaerobic digestion, contains impurities such as carbon dioxide ($CO_2$), hydrogen sulphide ($H_2S$), and moisture. Purifying biogas involves removing these impurities to enhance its quality and make it suitable for various applications, including energy production.

DWSIM provides a range of modelling and simulation capabilities that can be utilized for biogas purification processes. Here are some of the features and functionalities of DWSIM that can be employed in this context.

#### 3.5.1.1 THERMODYNAMIC MODELS

DWSIM supports numerous thermodynamic models, such as Peng-Robinson, Soave-Redlich-Kwong, and others, which are essential for accurately simulating the behaviour of gas mixtures. These models can be used to define the properties and behaviour of biogas components and impurities.

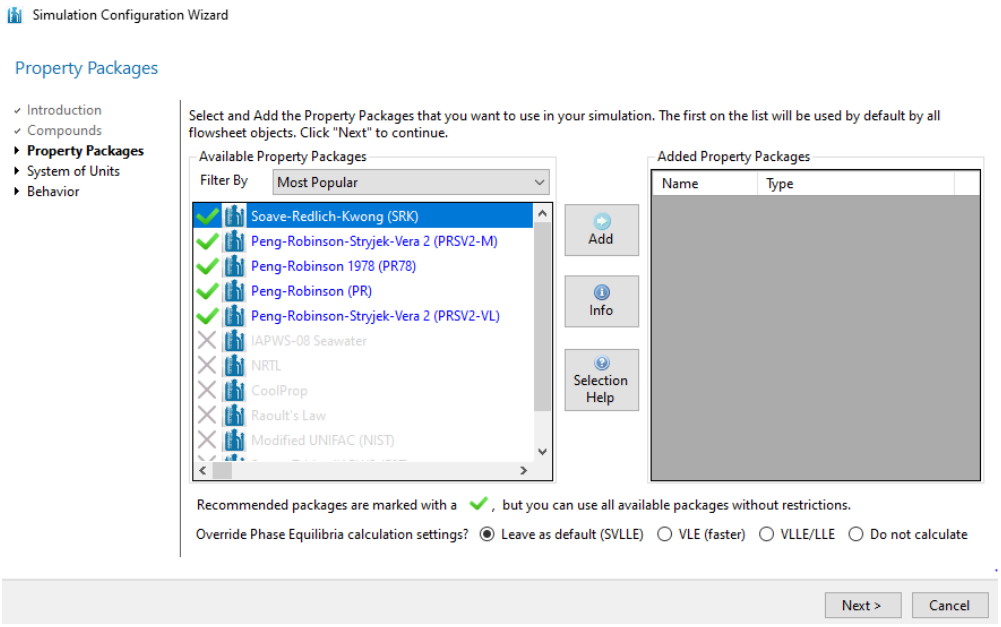


**Fig 3.8 Thermodynamic models layout from DWSIM**

### 3.5.1.2 UNIT OPERATIONS

DWSIM offers a wide range of unit operation models, including distillation columns, absorption columns, flash separators, and more. These models can be utilized to simulate various purification processes used in biogas treatment, such as pressure swing adsorption (PSA), amine scrubbing, water scrubbing, and membrane separation.

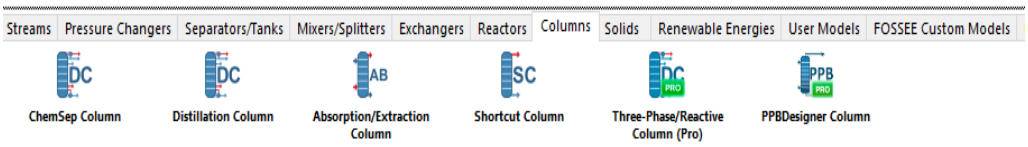


**Fig 3.9 Unit Operation layout from DWSIM**

### 3.5.1.3 COMPONENT DATABASE

DWSIM includes an extensive database of chemical components, which can be customized and expanded as needed. This feature enables users to define the properties and characteristics of biogas components, impurities, and solvents

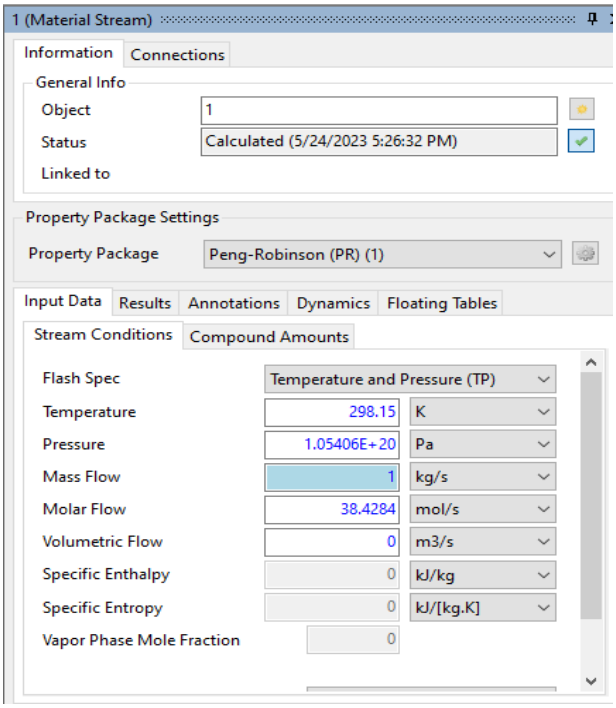


**Fig 3.10 Component Database layout from DWSIM**

### 3.5.1.4 SOLVENT DESIGN

DWSIM provides tools for designing and analyzing solvent-based purification processes. This can be particularly useful when considering processes like amine scrubbing, where a solvent is used to selectively remove impurities like $CO_2$ and $H_2S$ from biogas.

### 3.5.1.5 SIMULATION AND ANALYSIS

DWSIM allows users to set up process simulations by connecting unit operations and defining operating conditions. The software can perform steady-state and dynamic simulations, enabling users to evaluate process performance, optimize operating parameters, and analyze the behaviour of the biogas purification system.

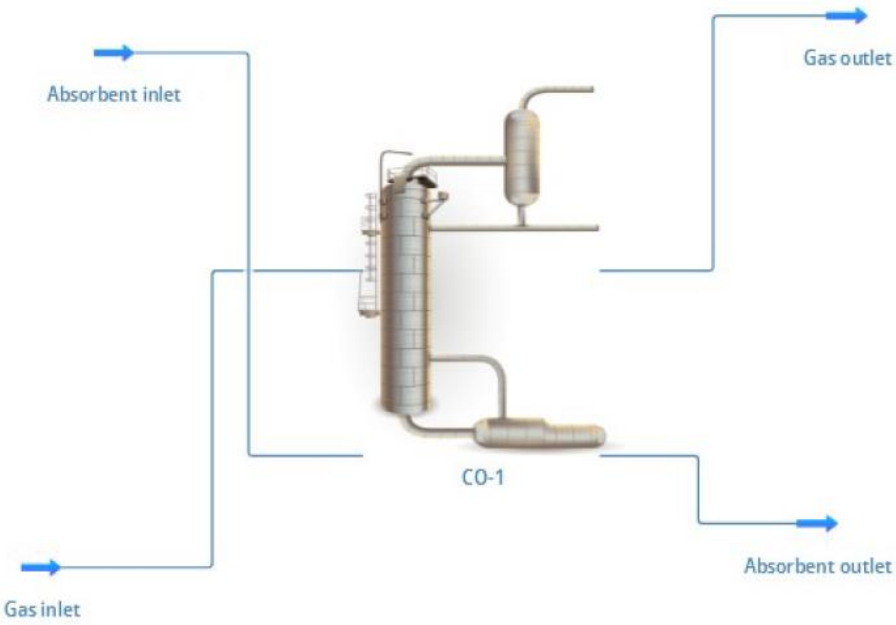


**Fig 3.11 Model in DWSIM software**

**Table 3.4 Inlet parameters used in the DSWIM software.**

| Parameters | This study |
|---|---|
| $P_{absorber}$ (bar) | 1 |
| $T_{absorber}$($^oC$) | 25 |
| $T_{gas}$($^oC$) | 37 |
| Number of theoretical stages (absorber) | 20 |
| Product gas (mole fraction) | |
| $CO_2$ | 0.379 |
| $CH_4$ | 0.416 |
| $O_2$ | 0.205 |

## 3.6 FUZZY – ANALYTICAL HIERARCHY PROCESS

### 3.6.1 CREATING THE PAIRWISE COMPARISON MATRIX.

Pair – wise comparison matrix is created with the help of scale of relative importance.

**Table 3.5 Pairwise Comparison matrix.**

| | |
|---|---|
| 1 | Equal importance |
| 3 | Moderate importance |
| 5 | Strong importance |
| 7 | Very strong importance |
| 9 | Extreme importance |
| 2,4,6,8 | Intermediate values |
| 1/3,1/5,1/7,1/9 | Values of inverse comparisons |

### 3.6.2 FUZZY MEMBERSHIP FUNCTION.

In this research triangular membership function is used. The triangular membership function is the most commonly accepted and utilized membership function (MF) in the design of fuzzy controllers. The triangle that is used to fuzzify the input can be characterized by three parameters: a, b, and c. Among these parameters, c determines the base, while b determines the height of the triangle.

$$\mu_A(x) = \begin{cases} 0 & if\ x \le a \\ \dfrac{x-a}{b-a} & if\ a \le x \le b \\ \dfrac{c-x}{c-b} & if\ b \le x \le c \\ 0 & if\ x \ge c \end{cases}$$

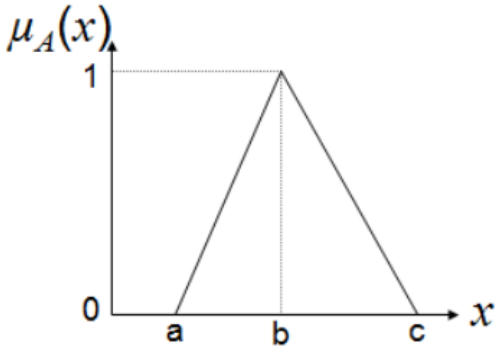


**Fig 3.12 Triangular Fuzzy Membership Function**

**Table 3.6 Pairwise Comparison Matrix in Triangular Membership Function.**

| | |
|---|---|
| Equal | (1,1,1) |
| Moderate | (2,3,4) |
| Strong | (4,5,6) |
| Very Strong | (6,7,8) |
| Extremely Strong | (9,9,9) |
| Intermediate values | (1,2,3) |
| | (3,4,5) |
| | (5,6,7) |
| | (7,8,9) |

**Table 3.7 Pair – wise comparison matrix**

| | Absorbent Pressure (bar) | Biogas flow (l/min) | Absorbent flow (l/min) | Biogas Outlet Temperature ($^oC$) |
|---|---|---|---|---|
| Absorbent Pressure (bar) | 1 | 4 | 3 | 5 |
| Biogas flow (l/min) | 1/4 | 1 | 1/2 | 7 |
| Absorbent flow (l/min) | 1/3 | 2 | 1 | 5 |
| Biogas Outlet Temperature ($^oC$) | 1/5 | 1/7 | 1/5 | 1 |

$A^{-1} = (l, m, u)^{-1} = (1/u, 1/m, 1/l)$

e.g. $(3,4,5)^{-1} = (1/5, 1/4, 1/3)$

**Table 3.8 Pair – wise comparison matrix**

| | Absorbent Pressure (bar) | Biogas flow (l/min) | Absorbent flow (l/min) | Biogas Outlet Temperature (°C) |
|---|---|---|---|---|
| Absorbent Pressure (bar) | (1,1,1) | (3,4,5) | (2,3,4) | (4,5,6) |
| Biogas flow (l/min) | (1/5,1/4,1/3) | (1,1,1) | (1/3,1/2,1/1) | (6,7,8) |
| Absorbent flow (l/min) | (1/4,1/3,1/2) | (1,2,3) | (1,1,1) | (4,5,6) |
| Biogas Outlet Temperature (°C) | (1/6,1/5,1/4) | (1/8,1/7,1/6) | (1/6,1,5,1/4) | (1,1,1) |

# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1 GENERAL

Chemical absorption technique using different solution concentration and at varying parameters is being studied by using bubble column absorption tower so that the effect on reducing the $CO_2$ in biogas purification process can be studied. Furthermore, the interaction of the absorbent and gas molecules can be studied through DWSIM software.

## 4.2 EXPERIMENTAL RESULTS

### 4.2.1 PURIFYING BIOGAS BY PURE WATER TO ELIMINATE $CO_2$

When carbon dioxide dissolves in water, it can undergo a series of transformations that result in the formation of carbonic acid, bicarbonate, and carbonate. However, altering the biogas flow rates during the experiment resulted in only minor changes in the amount of methane produced. This outcome can be attributed to the inability of water in the bubble column absorption tower to dissolve carbon dioxide, which made its treatment impossible.

### 4.2.2 PURIFYING BIOGAS BY SODIUM HYDROXIDE TO ELIMINATE $CO_2$

Table 3.1, Table 3.2 and Table 3.3 from chapter 3, shows the quantities of $CH_4$ remaining in digester D1, D2 and D3 after treatment with sodium hydroxide solutions of varying concentrations (0.625 mol and 0.9375 mol) and different biogas flow rates (1.25 l/min and 3.33 l/min). The results indicate that the highest

methane level (86.2%) was attained when the biogas flow rate was 1.25 l/min and sodium hydroxide solution of 0.9375 mol was used. These findings suggest that the biogas treatment efficiency can be influenced by the type and concentration of the solution, as well as the flow rate of the biogas. Specifically, a high biogas flow rate could decrease the quantity of methane produced.

**Table 4.1 Purifying biogas by Sodium Hydroxide to eliminate $CO_2$.**

| Biogas Flow (l/min) | Max. $CH_4$ composition (%) | | | | | |
|---|---|---|---|---|---|---|
| | Sodium Hydroxide 0.625 mol | | | Sodium Hydroxide 0.9375 mol | | |
| | D1 | D2 | D3 | D1 | D2 | D3 |
| 1.25 | 63.7 | 75.1 | 82.4 | 66.7 | 78.6 | 86.2 |
| 3.33 | 58.1 | 68.5 | 75.2 | 60.7 | 71.5 | 78.5 |

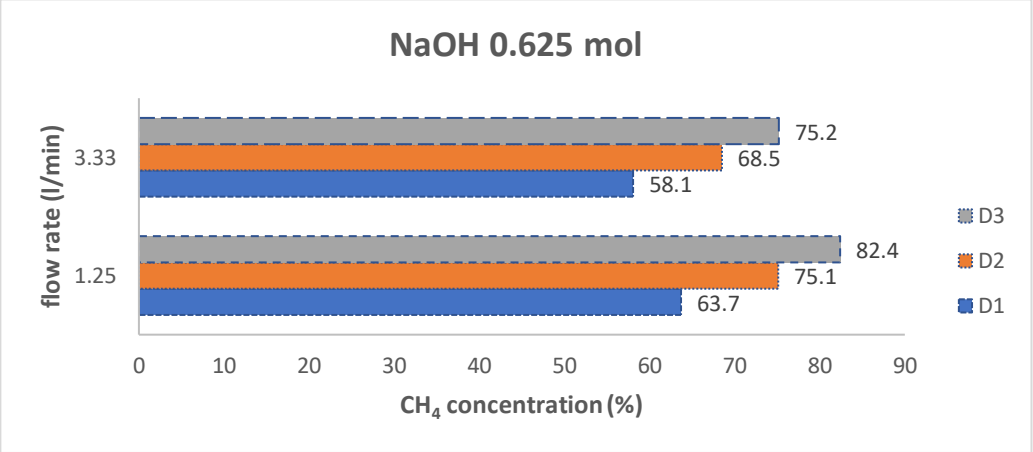


**Fig 4.1 Biogas Purification from Sodium Hydroxide 0.625 mol at a Biogas Flow Rate of 1.25 l/min and 3.33 l/min**

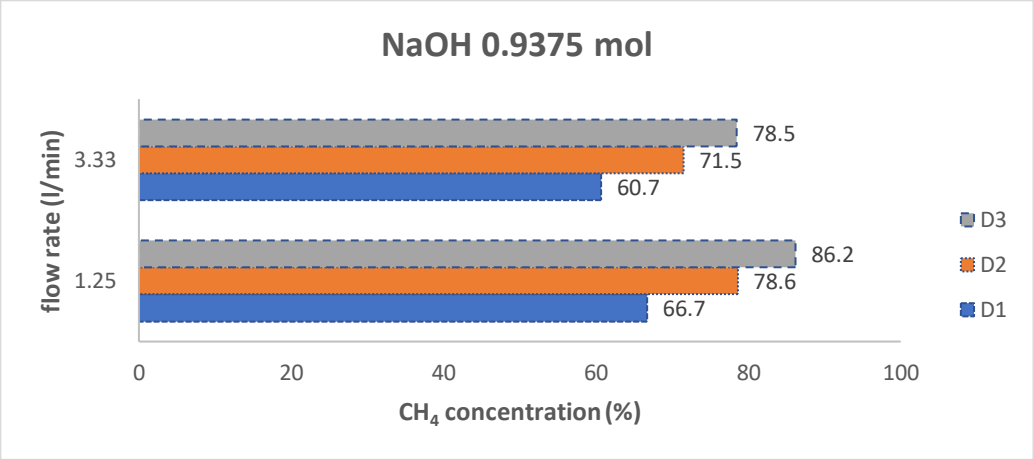


**Fig 4.2 Biogas Purification from Sodium Hydroxide 0.9375 mol at a Biogas Flow Rate of 1.25 l/min and 3.33 l/min**

## 4.2.3 PURIFYING BIOGAS BY CALCIUM HYDROXIDE TO ELIMINATE CO2

The use of Calcium Hydroxide solution at concentrations of 0.625 mol and 0.9375 mol, along with different flow rates for biogas (1.25 liters/min and 3.33 liters/min), resulted in the highest methane levels (79.3% and 84.9%) in the biogas treatments during the experiments. Moreover, a biogas treatment consisting of Calcium Hydroxide solution at a concentration of 0.9375 mol and a flow rate of 1.25 liters/min also yielded the highest methane level (84.9%).

**Table 4.2 Purifying biogas by Calcium Hydroxide to eliminate $CO_2$.**

| Biogas Flow (l/min) | Max. $CH_4$ composition (%) | | | | | |
|---|---|---|---|---|---|---|
| | Calcium Hydroxide 0.625 mol | | | Calcium Hydroxide 0.9375 mol | | |
| | D1 | D2 | D3 | D1 | D2 | D3 |
| 1.25 | 61.3 | 72.3 | 79.3 | 65.7 | 77.4 | 84.9 |
| 3.33 | 55.6 | 65.5 | 71.6 | 60.1 | 70.8 | 77.7 |

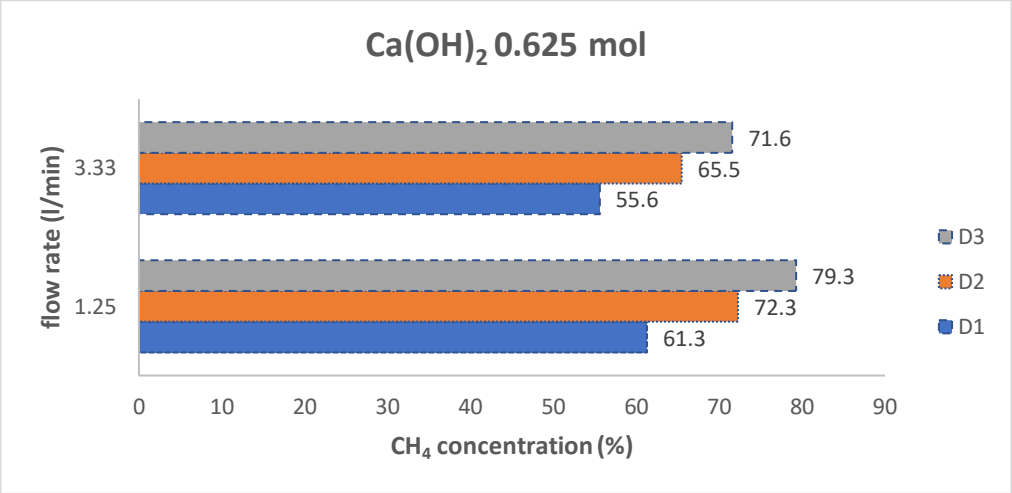


**Fig 4.3 Biogas Purification from Calcium Hydroxide 0.625 mol at a Biogas Flow Rate of 1.25 l/min and 3.33 l/min**

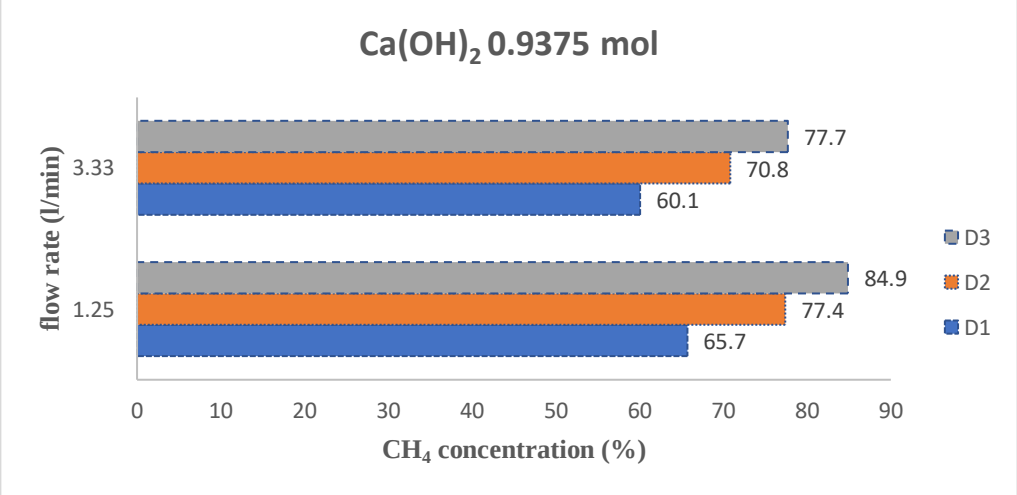


**Fig 4.4 Biogas Purification from Calcium Hydroxide 0.9375 mol at a Biogas Flow Rate of 1.25 l/min and 3.33 l/min**

The flow of bubbles produced by the biogas pipe will ascend towards the absorbent surface. The absorption process is influenced by the size of these bubbles, with smaller bubbles increasing the contact area between biogas and absorbent. As a result, a wider contact area enhances the probability of gas diffusion into the absorbent, thereby leading to a higher absorption rate and increased $CO_2$ absorption.

### 4.2.4 EFFECT OF PIPE DIAMETER ON $CO_2$ ABSORTION

The effect is studied by taking the gas flow rate at 1.25 l/min as constant and the solution concentration of 0.625 mol. As shown in figure 4.5, the smaller the diameter of the pipe, the $CH_4$ concentration reaches 58.1 % with NaOH and 57.4 % with $Ca(OH)_2$.Meanwhile, in the larger hole diameter the percentage of $CH_4$ reaches 54.8 % with NaOH and 53.2 % with $Ca(OH)_2$.The percentage of $CO_2$ absorption decreases with increasing the pipe diameter.

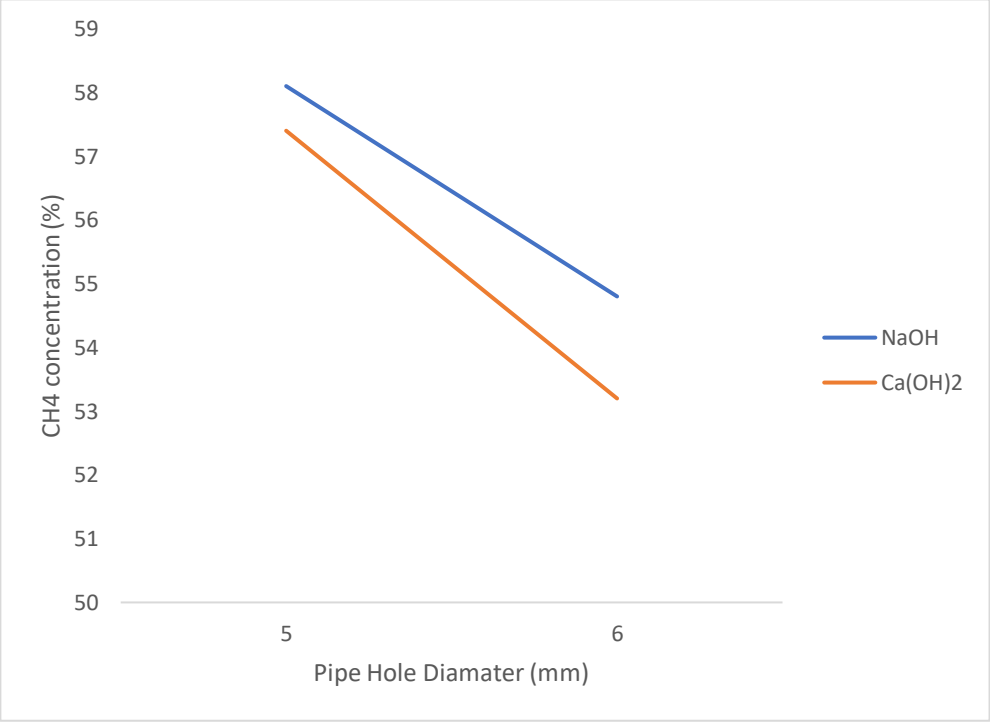


**Fig 4.5 Effect of pipe diameter on $CO_2$ absorption**

## 4.3 DWSIM SOFTWARE

**Table 4.3 Shows the software result of biogas outlet temperature at different input parameters**

| Absorbent Pressure (bar) | Biogas flow (l/min) | Biogas Output Temperature (°C) | | |
|---|---|---|---|---|
| | | Absorbent flow (l/min) | | |
| | | 2 | 4 | 6 |
| 1 | 1.25 | 25.0378 | 25.0376 | 24.9960 |
| | 3.33 | 25.0361 | 25.0246 | 24.7476 |
| 2 | 1.25 | 25.0587 | 25.0586 | 25.0568 |
| | 3.33 | 25.0571 | 25.0438 | 24.7674 |
| 3 | 1.25 | 25.0797 | 25.0774 | 25.0763 |
| | 3.33 | 25.0778 | 25.0634 | 24.7975 |

If the interaction between absorbent molecules and gas molecules increases during the absorption process of biogas purification, it can lead to a decrease in the percentage of $CO_2$ in the biogas. If the interaction between the absorbent molecules and the gas molecules is strong, it enhances the absorption efficiency, allowing more $CO_2$ molecules to be captured by the absorbent. As a result, the concentration or percentage of $CO_2$ in the biogas decreases.

The effectiveness of the absorption process depends on various factors, such as the choice of absorbent, temperature, pressure, and contact time. Optimizing these parameters can enhance the absorption efficiency and improve the purification of biogas by reducing the $CO_2$ content.

### 4.3.1 EFFECT OF ABSORBER FLOW RATE

Increasing the absorbent flow rate leads to a lower outlet temperature. A higher flow rate allows the absorbent to come into contact with the biogas for a shorter duration, reducing the heat exchange between the two phases. Consequently, less heat is absorbed by the absorbent, resulting in a lower outlet temperature. The absorber column enables close contact between the biogas and the water, allowing

the $CO_2$ molecules to move from the gas phase into the liquid phase. In order to study the interaction between the absorbent and the gas molecules, it was necessary to analyse the effects of different absorber pressure settings on biogas output temperature. The software result depicts that with the increase of the absorber pressure the outlet temperature of the biogas increases which indicates that the interaction of absorbent and gas molecules increases. From the result at absorber pressure of 3 bar, biogas flow rate of 1.25 l/min and absorbent flow of 2 l/min the outlet gas temperature is highest i.e., 25.0797 $^{o}$C. And also, if the absorber pressure and gas flow rate is constant, the temperature of the outlet gas keeps on decreasing with the increase of absorbent flow.

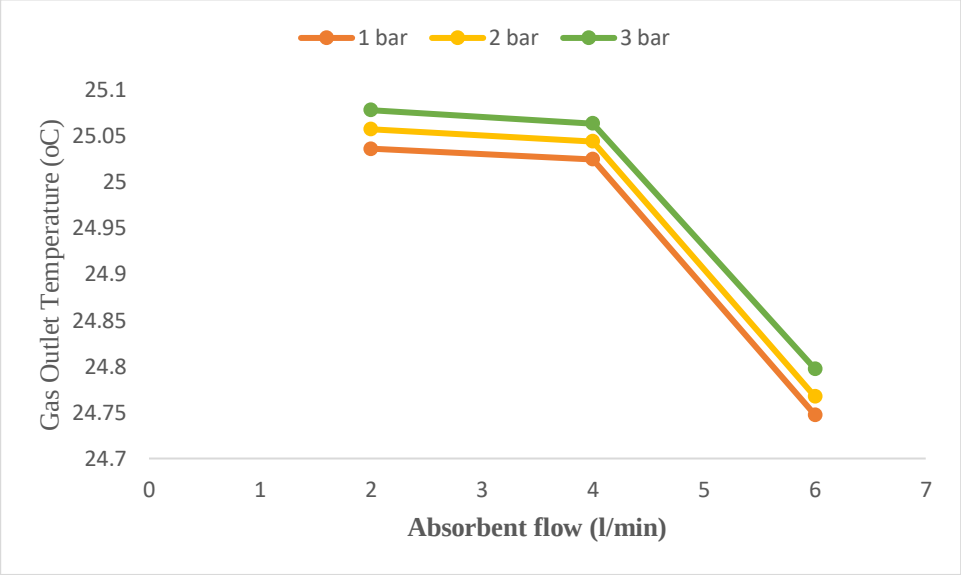


**Fig 4.6 The graph shows the variation in the outlet gas temperature with absorbent flow rate**

### 4.3.2 EFFECT OF ABSORBER PRESSURE

The absorbent pressure can influence the biogas outlet temperature as well. Increasing the absorbent pressure typically results in a higher outlet temperature. When the absorbent pressure is increased, the partial pressure of the biogas components decreases, favoring their absorption into the absorbent. As a result, more heat is released during the absorption process, leading to a higher outlet

temperature. The absorbent flow rate of remained constant at 2 l/min. Figure 4.7 illustrates the impact of absorbent pressure on gas outlet temperature.

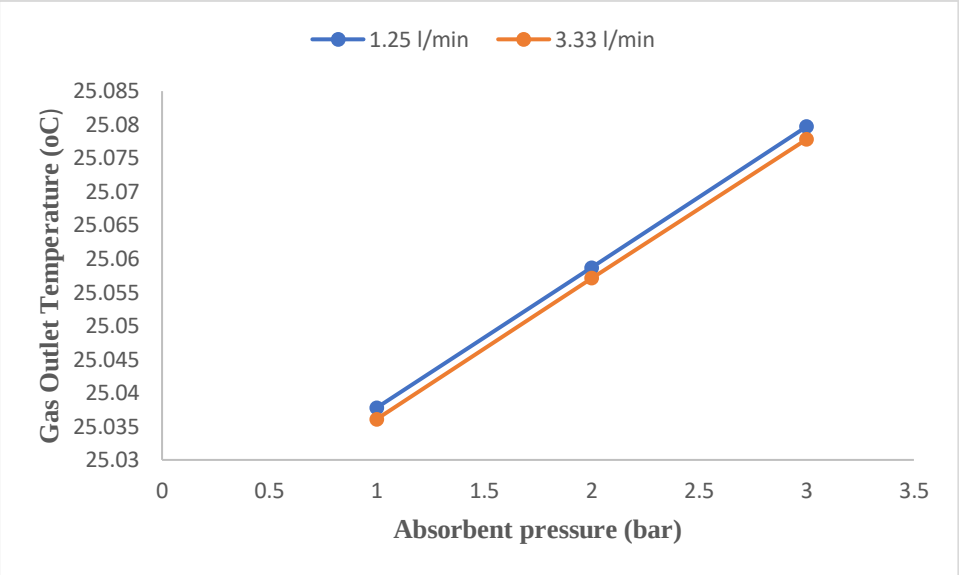


**Fig 4.7 Effect of absorbent pressure on the gas outlet temperature (°C)**

### 4.3.3 EFFECT OF GAS FLOW RATE

Increasing the biogas flow rate tends to decrease the biogas outlet temperature. This is because a higher flow rate means a shorter residence time in the column, resulting in less time for heat transfer between the gas phase and the absorbent. As a result, less heat is transferred to the absorbent, leading to a lower outlet temperature. The absorbent pressure was kept constant, and with the increase in the gas flow rate it was found that the temperature of the gas outlet keeps on decreasing, which indicates that as the flow rate of gas increases the interaction between the absorbent and gas molecules decreases as a result there is decrease in the absorption of $CO_2$ and hence the purification tendency decreases.

An increase in the biogas flow rate can lead to a lower outlet temperature. When the biogas flow rate is high, there is less time for heat transfer between the gas and liquid phases in the column. As a result, the absorbed heat energy from the exothermic absorption process may not dissipate fully, leading to a lower outlet temperature. On the other hand, a lower biogas flow rate allows for more heat transfer and can result in a higher outlet temperature.

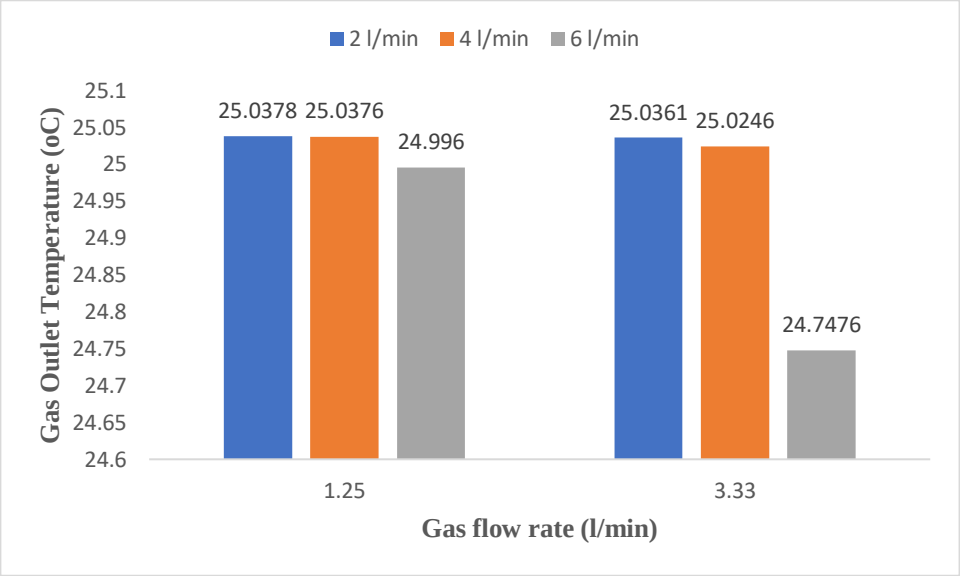


**Fig 4.8 Effect of gas flow rate on the gas outlet temperature (°C)**

## 4.4 CALCULATION OF FUZZY – GEOMETRIC MEAN VALUE ($r_i$)

Geometric mean value is used to calculate the weights. Table 4.4 shows the table for calculating geometric mean value

**Table 4.4 Calculation of Fuzzy – Geometric mean value ($r_i$)**

| | Absorbent Pressure (bar) | Biogas flow (l/min) | Absorbent flow (l/min) | Biogas Outlet Temperature (°C) | Fuzzy geometric mean value ($r_i$) |
|---|---|---|---|---|---|
| Absorbent Pressure (bar) | (1,1,1) | (3,4,5) | (2,3,4) | (4,5,6) | (2.213,2.7831, 3.309) |
| Biogas flow (l/min) | (1/5,1/4,1/3) | (1,1,1) | (1/3,1/2,1/1) | (6,7,8) | (0.435,0.9671, 0.699) |
| Absorbent flow (l/min) | (1/4,1/3,1/2) | (1,2,3) | (1,1,1) | (4,5,6) | (1,0.740,1.732) |
| Biogas Outlet Temperature (°C) | (1/6,1/5,1/4) | (1/8,1/7,1/6) | (1/6,1,5,1/4) | (1,1,1) | (0.2422,0.2749,0.3191) |

$$r_i = ((l_1, l_2, l_3, l_4)^{1/4}, (m_1, m_2, m_3, m_4)^{1/4}, (u_1, u_2, u_3, u_4)^{1/4} \quad (4)$$

### 4.4.1 CALCULATION OF FUZZY WEIGHT ($w_i$)

$$w_i = r_i * (r_1 + r_2 + r_3 + \ldots + r_n)^{-1} \quad (5)$$

Equation 5 is used to calculate the fuzzy weight

**Table 4.5 Calculation of Fuzzy Weight ($w_i$)**

| | **Fuzzy geometric mean value ($r_i$)** | **Fuzzy Weight ($w_i$)** |
|---|---|---|
| Absorbent Pressure (bar) | (2.213,2.7831,3.309) | (0.3651,0.5838,0.8504) |
| Biogas flow (l/min) | (0.435,0.9671,0.699) | (0.07177,0.2028,0.1796) |
| Absorbent flow (l/min) | (1,0.740,1.732) | (0.1650,0.1552,0.4451) |
| Biogas Outlet Temperature (oC) | (0.2422,0.2749,0.3191) | (0.0399,0.05767,0.082) |

### 4.4.2 DE – FUZZIFICATION

Centre of Area (COA) ; $w_d = \frac{l+m+u}{3}$ (6)

| | Fuzzy geometric mean value ($r_i$) | Weight ($w_d$) |
|---|---|---|
| Absorbent Pressure (bar) | (2.213,2.7831,3.309) | 0.599 |
| Biogas flow (l/min) | (0.435,0.9671,0.699) | 0.1513 |
| Absorbent flow (l/min) | (1,0.740,1.732) | 0.2551 |
| Biogas Outlet Temperature ($^oC$) | (0.2422,0.2749,0.3191) | 0.0598 |

**Table 4.6 Calculation of Normalized Weight (w)**

| | **Weight ($w_d$)** | **Normalized Weight (w)** |
|---|---|---|
| Absorbent Pressure (bar) | 0.599 | 0.5628 |
| Biogas flow (l/min) | 0.1513 | 0.1421 |
| Absorbent flow (l/min) | 0.2551 | 0.2397 |
| Biogas Outlet Temperature (oC) | 0.0598 | 0.0561 |
| Total | 1.0642 | 1 |

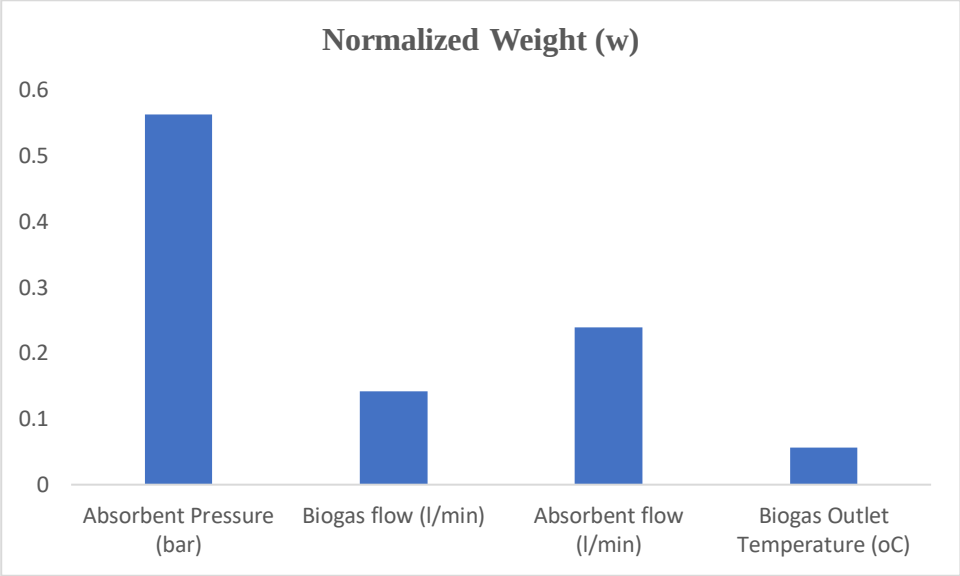


**Fig 4.9 Normalized weight of different parameters**

From the result of MSDM technique; it can be seen that the normalized weight of absorbent pressure is higher as compared to the remaining parameters. So, from the result we can conclude that in the biogas purification process through absorption process the purification or the removal of $CO_2$ is highly effected by the absorbent pressure, which can also be seen from the research work discussed in the previous sections.

# CHAPTER 5

# CONCLUSION

To enhance the quality of biogas, a bubble column absorption tower was employed in this research. The biogas component values were assessed by a biogas analyzer before and after treatment. Two biogas flow rates of 1.25 and 3.33 l/min were employed in the experiment, with each solution tested for 30 minutes. The biogas average component values for D1, D2, and D3 were distinct before treatment. Minor changes were observed when distilled water was used in tests. However, sodium hydroxide solutions with concentrations of 0.625 mol and 0.937 mol resulted in the highest methane values of 66.7%, 78.6%, and 86.2% for D1, D2, and D3, respectively, when the biogas flow rate was 1.25 l/min. Calcium hydroxide solutions with concentrations of 0.625 and 0.937 mol led to highest methane concentrations of 65.7%, 77.4%, and 84.9% for D1, D2, and D3, respectively. The flow rate of biogas of 1.25 l/min and 0.937 mol sodium hydroxide solution had the highest methane level of 86.2% due to the large amounts of solution causing a high-efficiency reaction. The factors influencing carbon dioxide absorption by liquid absorption are the type and concentration of the solution, the biogas flow rate, the diameter of the pipe, the absorbent pressure, the absorbent flow rate. These factors can improve carbon dioxide absorption efficiency by increasing the degree of absorption that occurs as the liquid comes into contact with the gas.

Furthermore, the flow of bubbles produced by the biogas pipe will ascend towards the absorbent surface. The absorption process is influenced by the size of these bubbles, with smaller bubbles increasing the contact area between biogas and absorbent. As a result, a wider contact area enhances the probability of gas diffusion into the absorbent, thereby leading to a higher absorption rate and increased $CO_2$ absorption. From the result of MSDM technique; it can be seen that the normalized weight of absorbent pressure is higher as compared to the other parameters considered in the biogas purification process.

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