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CASE STUDY ON THE TECHNIQUES FOR UPGRADATION OF BIOGAS

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Abstract— **Growing awareness worldwide of disposal methods of bio-degradable waste by Aerobic Digestion (AD) and converting it into useful fuel and organic manure. Biogas production has been recognized as an effective and well-developed technology. However, its commercial application remains constrained due to the necessity for on-site upgrading of the biogas before it can be transported or combusted. The upgradation of bio gas requires removal of other gases from it and make it fit for having max-content of Methane. In the face of the growing demand for renewable energy sources and the environmental impacts related to the process of global warming, the development of new technologies for CH_4 capture has become a critical environmental issue, and certainly one of the greatest challenges of humankind. This growing demand underscores the necessity for innovative solutions to mitigate the adverse effects of climate change, which is driven by the increasing concentration of greenhouse gases in the atmosphere. In this regard, the degradation of urban solid wastes leads to the production of huge amounts of biogas. The process of anaerobic digestion in landfills and other waste management facilities breaks down organic materials, resulting in the release of these gases.**

Keywords— **Biogas purification, Biogas upgradation, Scrubbing system, Methane**

I. INTRODUCTION

Biogas upgrading, also known as biogas purification, is the process of removing impurities from biogas to produce a high-quality biomethane that can be used as a renewable energy source. Methane (CH_4), in particular, is known to promote harmful impacts on the environment, considering its contribution to global warming, at least 20 times more aggressively than carbon dioxide (CO_2). This is due to methane's high global warming potential (GWP), which makes it a significant driver of climate change despite its lower concentration in the atmosphere compared to CO_2. The capture and utilization of methane from biogas not only help reduce greenhouse gas emissions but also provides a renewable source of energy that can be harnessed for various applications , such as electricity generation and heating.

"In order to increase its calorific value, improve biogas combustion, and decrease corrosion problems, CH4 concentration must be increased and impurities must be removed. It is known that CH4 is a clean fuel, the combustion being without any soot particles or other pollutants. Apart from CO2, biogas also contains a small quantity of hydrogen sulphide (H2S). When water is present, H2S is dissolved and the aqueous solution is highly corrosive, making the biogas unusable. When the biogas is burned, H2S is oxidized to sulfur oxides which react with water and form acid (H2SO3). This acid is also corrosive and attacks the metallic surfaces of gas pipelines. The non-flammable CO2 in biogas not only reduces its calorific value but also corrodes pipelines when water is present. On average, the biogas calorific value is 21.5 MJ/m³, while that of natural gas is 35.8 MJ/m³."[1]

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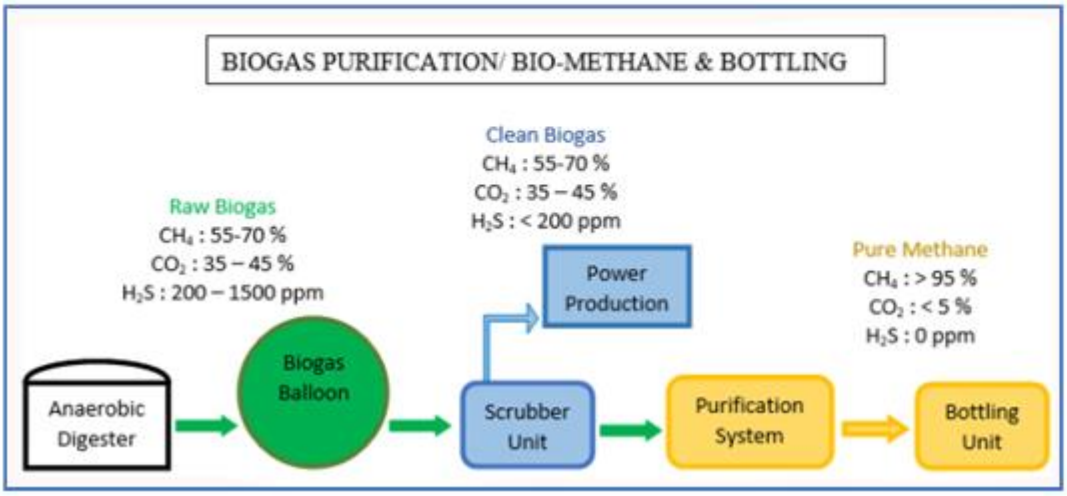
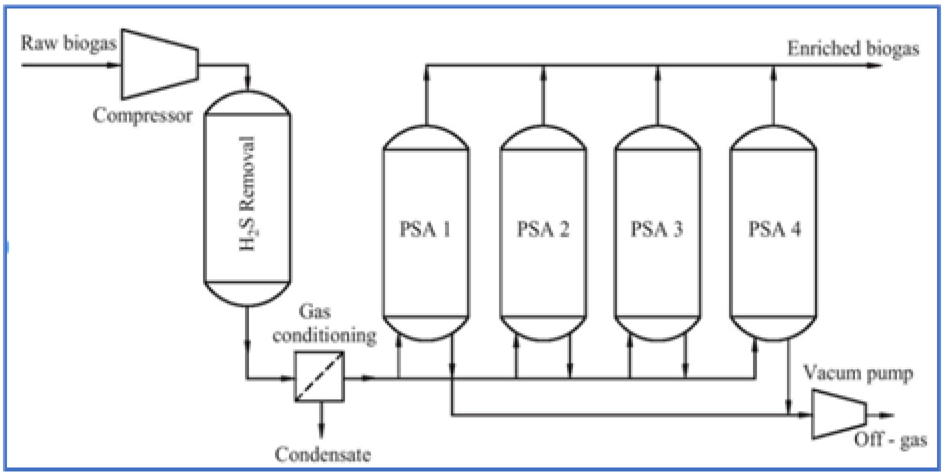


Here's an overview of the biogas upgrading process:
Raw biogas contains:
- Methane (CH4): 50-70%
- Carbon dioxide (CO2): 30-50%
- Hydrogen sulfide (H2S): 100-10,000 ppm
- Water vapor: 5-10%
- Other impurities (e.g., N2, O2, NH3)

Upgrading biogas removes impurities: -
Increasing the methane content to 90-99%, making it suitable for:
- Injection into natural gas grids
- Vehicle fuel
- Power generation
- Industrial applications

Biogas upgrading technologies:

1. Pressure Swing Adsorption (PSA): is widely used for the purification of biogas or upgradation of biogas this technology works by using the adsorbent materials to separate methane from CO2 and other impurities. The working principle of PSA uses the adsorption properties of solid materials to separate methane from impurities like CO2, H2S, and N2. The process involves alternating high and low pressure cycles to adsorb and desorb impurities.



Process Steps:
1. Pre-treatment: Biogas is filtered and compressed to remove large particles and moisture.
2. Adsorption: Compressed biogas is passed through an adsorbent material (e.g., zeolites, activated carbon) at high pressure (5-10 bar). Impurities like CO2, H2S, and N2 are adsorbed onto the material, allowing methane to pass through.
3. High-Pressure Hold: The adsorbent material is held at high pressure for a short period, allowing maximum adsorption of impurities.
4. Depressurization: The pressure is reduced, allowing the adsorbed impurities to desorb from the material.

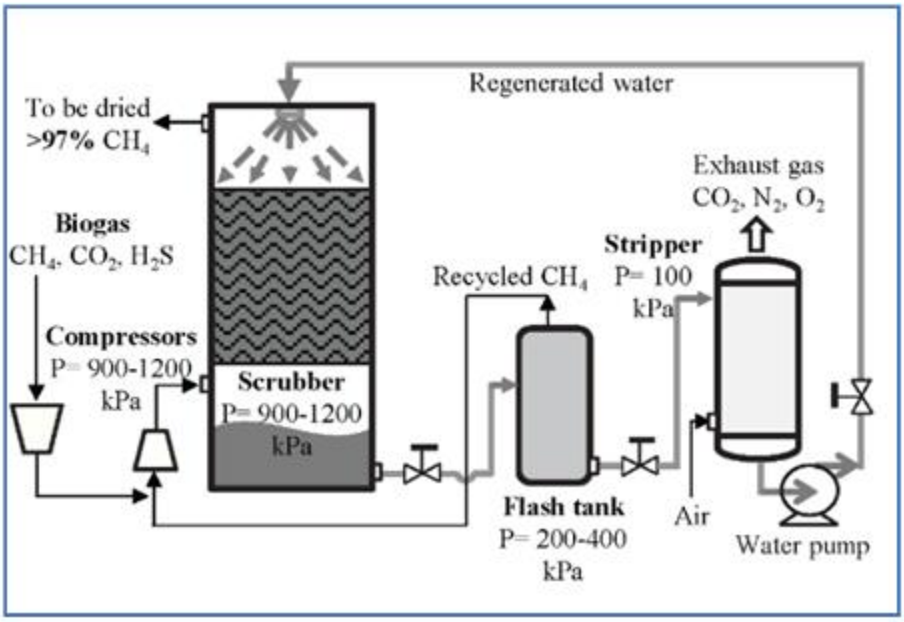
5. Desorption: The desorbed impurities are released from the adsorbent material, and the methane is collected as high-purity biomethane.
6. Regeneration: The adsorbent material is regenerated by reducing pressure and allowing any remaining impurities to desorb.
7. Repeat Cycle: Steps 2-6 are repeated continuously, with multiple adsorbent beds used to ensure continuous biogas processing.

Advantages:
1. High methane purity (95-99%)
2. High efficiency (90-95%)
3. Low energy consumption
4. Compact design
5. Suitable for small to large-scale applications

Disadvantages:
1. Requires high-quality adsorbent materials
2. Can be sensitive to biogas composition and temperature
3. May require additional pre-treatment steps
4. Can be more expensive than other technologies for small-scale applications

Adsorbent Materials:
Commonly used adsorbent materials in PSA include:
1. Zeolites (e.g., 13X, 4A)
2. Activated carbon
3. Silica gel
4. Alumina

2. Water Scrubbing: Uses water to absorb CO2 and H2S, followed by desorption to release methane. Water scrubbing is a biogas upgrading technology that uses water to remove impurities like CO2, H2S, and other contaminants from biogas. Water scrubbing is based on the solubility of impurities in water. Biogas is passed through a water column, where impurities dissolve in water, allowing methane to be separated.



Process Steps:
1. Pre-treatment: Biogas is filtered and compressed to remove large particles and moisture.
2. Water Scrubbing Column: Biogas enters the bottom of a packed column filled with water. Impurities like CO2, H2S, and other contaminants dissolve in water as biogas rises through the column.
3. Counter current Flow: Water flows counter currently to biogas, allowing maximum contact time and impurity removal.
4. Methane Separation: Methane, being insoluble in water, is separated from the water-impurity mixture.
5. Water Regeneration: The water-impurity mixture is regenerated by desorption, releasing impurities and allowing water to be reused.
6. Repeat Cycle: Steps 2-5 are repeated continuously.

Advantages:
1. High CO2 removal efficiency (90-95%)
2. Effective H2S removal
3. Low energy consumption
4. Simple design and operation
5. Suitable for small-scale applications

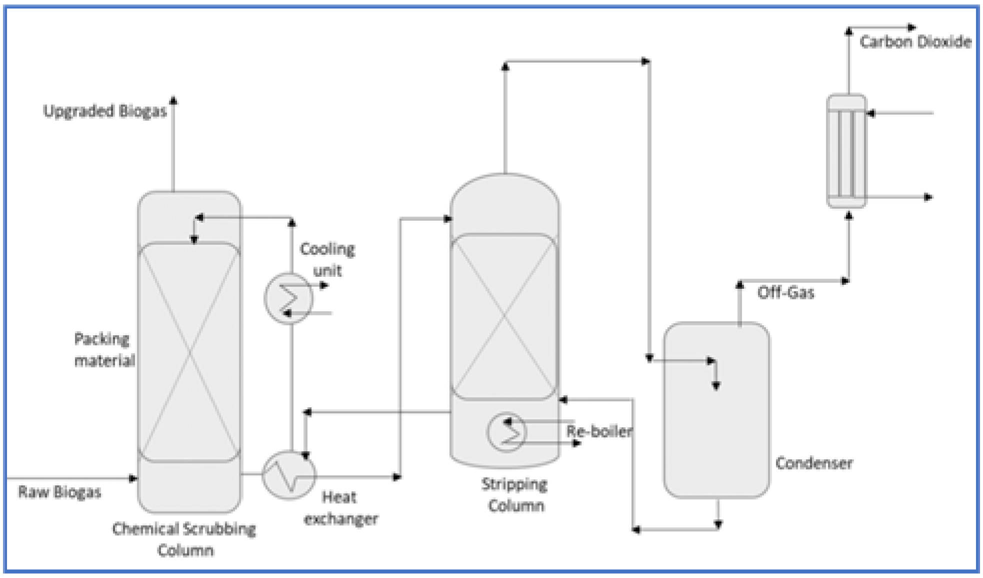
Disadvantages:
1. Limited methane purity (typically 95-96%)
2. Water usage and regeneration requirements
3. Potential for water contamination
4. May require additional pre-treatment steps
5. Not effective for siloxane removal

Water Scrubbing Variants:
1. Packed Column Scrubbers: Use packing materials like rings or saddles to increase contact surface area.
2. Tray Scrubbers: Use horizontal trays with perforations to distribute biogas and water.
3. Membrane Scrubbers: Use semipermeable membranes to separate impurities from biogas.

Design Considerations:
1. Column height and diameter
2. Water flow rate and temperature
3. Packing material selection (if applicable)
4. Biogas flow rate and pressure

Water scrubbing is a reliable and efficient biogas upgradation technology, especially suitable for small-scale applications or when high methane purity is not required.

3. Chemical Scrubbing: Uses chemical solvents to remove impurities. It is a biogas upgradation technology that uses chemical solvents to remove impurities like CO2, H2S, and other contaminants from biogas. This is based on the chemical reaction between impurities in biogas and a solvent, which selectively removes impurities, allowing methane to be separated.



Process Steps:
1. Pre-treatment: Biogas is filtered and compressed to remove large particles and moisture.
2. Scrubbing Column: Biogas enters the bottom of a packed column filled with a chemical solvent (e.g., amines, caustic soda).
3. Chemical Reaction: Impurities like CO2, H2S, and other contaminants react with the solvent, forming a chemical compound that is separated from methane.
4. Methane Separation: Methane, being insoluble in the solvent, is separated from the solvent-impurity mixture.
5. Solvent Regeneration: The solvent-impurity mixture is regenerated by desorption, releasing impurities and allowing the solvent to be reused.
6. Repeat Cycle: Steps 2-5 are repeated continuously.

Chemical Solvents:
1. Amines (e.g., MEA, DEA, MDEA): Effective for CO2 removal, but can be corrosive.
2. Caustic Soda (NaOH): Effective for H2S removal, but can be hazardous.
3. Other solvents (e.g., Selexol, Rectisol): Proprietary solvents with varying selectivity and properties.

Advantages:
1. High CO2 removal efficiency (95-99%)
2. Effective H2S removal
3. Can achieve high methane purity (98-99.5%)
4. Suitable for large-scale applications

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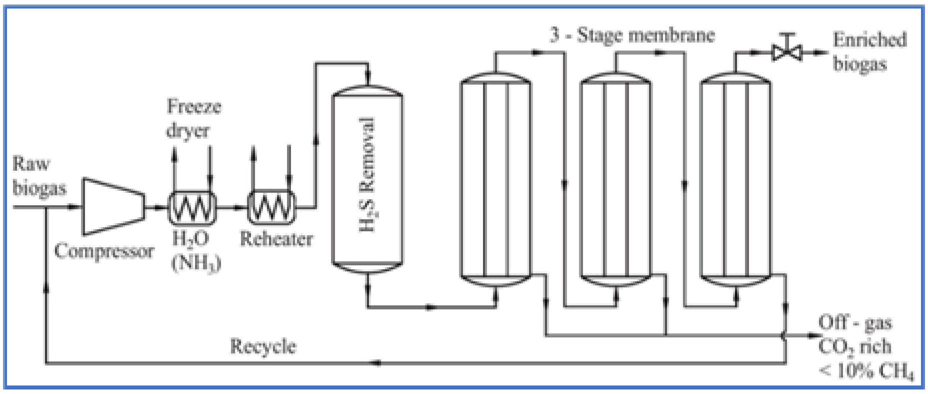
Disadvantages:
1. Chemical solvent costs and regeneration requirements
2. Potential for corrosion and equipment damage
3. Requires careful handling and safety measures
4. May require additional pre-treatment steps
5. Can be energy-intensive

Design Considerations:
1. Column height and diameter
2. Solvent selection and concentration
3. Biogas flow rate and pressure
4. Temperature control
5. Safety measures (e.g., corrosion protection, solvent handling)

Chemical scrubbing is a reliable and efficient biogas upgradation technology, especially suitable for large-scale applications or when high methane purity is required. However, it requires careful consideration of chemical solvent selection, safety measures, and operating conditions.

4. Membrane Separation: Membrane separation is a biogas upgradation technology that uses semipermeable membranes to separate methane from impurities like CO2, H2S, and other contaminants. Membrane separation is based on the selective permeability of membranes, which allow methane to pass through while retaining impurities.



Process Steps:
1. Pre-treatment: Biogas is filtered and compressed to remove large particles and moisture.
2. Membrane Module: Biogas enters a membrane module consisting of semipermeable membranes (e.g., polymeric, ceramic).
3. Separation: Methane permeates through the membrane, while impurities are retained, resulting in a methane-rich permeate stream and an impurity-rich retentate stream.
4. Permeate Stream: Methane-rich stream is collected as high-purity biomethane.
5. Retentate Stream: Impurity-rich stream is either recycled or disposed of.

Membrane Types:
1. Polymeric Membranes (e.g., PDMS, PEI): Cost-effective, but may have limited selectivity and durability.
2. Ceramic Membranes (e.g., SiO2, Al2O3): High selectivity and durability, but may be more expensive.
3. Composite Membranes: Combine polymeric and ceramic materials for improved performance.

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Advantages:
1. High methane purity (95-99%)
2. Compact design and low footprint
3. Low energy consumption
4. Suitable for small to large-scale applications
5. Can be used for CO2 removal, H2S removal, or both

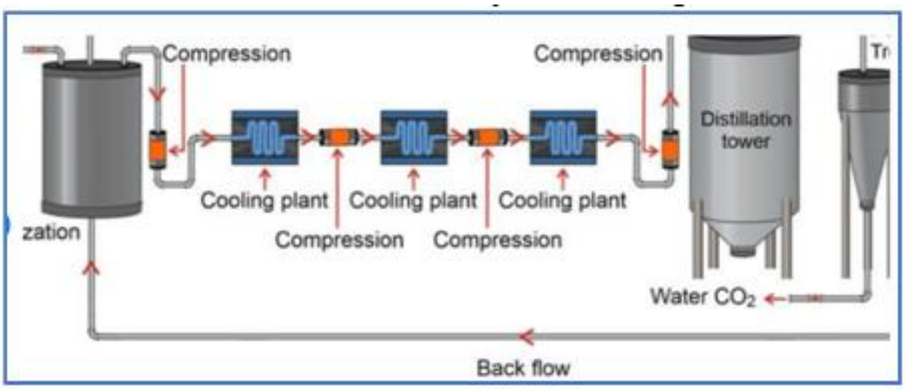
Disadvantages:
1. Membrane replacement costs and maintenance
2. Potential for membrane fouling and scaling
3. May require additional pre-treatment steps
4. Limited tolerance for contaminants like siloxanes

Design Considerations:
1. Membrane selection and configuration
2. Biogas flow rate and pressure
3. Temperature control
4. Module design and staging (e.g., single-stage, multi-stage)
5. Maintenance and replacement strategies

Membrane separation is a reliable and efficient biogas upgradation technology, offering high methane purity and compact design. However, it requires careful consideration of membrane selection, maintenance, and operating conditions to ensure optimal performance. Uses semipermeable membranes to separate methane from CO2 and other impurities. Membrane technology, which is vying for a position among competing biogas purification processes, presents a viable solution. These hybrid processes have been found to incur lower investment and operational costs compared to single-step processes. Moreover, a multi-membrane stage process has been identified as an appealing option, boasting lower investment and operation costs while achieving high CH4 recovery.

The adoption of membrane-based technology for biogas upgrading is anticipated to see substantial growth and frequent application in the future. Therefore, it is crucial for scientists to persist in their efforts to develop membranes with enhanced performance. Various approaches are being explored in the quest for new membrane materials, including the use of neat polymers, neat inorganics, and mixed matrix membranes (MMM).

5. Cryogenic Distillation: Uses low temperatures to separate methane from CO2 and other impurities. Cryogenic distillation is a biogas upgradation technology that uses extremely low temperatures to separate methane from impurities like CO2, H2S, and other contaminants. Cryogenic distillation is based on the difference in boiling points of methane and impurities at very low temperatures.



Process Steps:
1. Pre-treatment: Biogas is filtered and compressed to remove large particles and moisture.
2. Cooling: Biogas is cooled to a temperature around -100°C to -200°C using a refrigerant (e.g., nitrogen, methane).
3. Distillation Column: Cooled biogas enters a distillation column where methane and impurities separate based on their boiling points.
4. Methane Separation: Methane, having a lower boiling point, vaporizes and rises to the top of the column, while impurities condense and fall to the bottom.
5. Methane Collection: High-purity methane is collected from the top of the column.
6. Impurity Removal: Impurities are removed from the bottom of the column and either recycled or disposed of.

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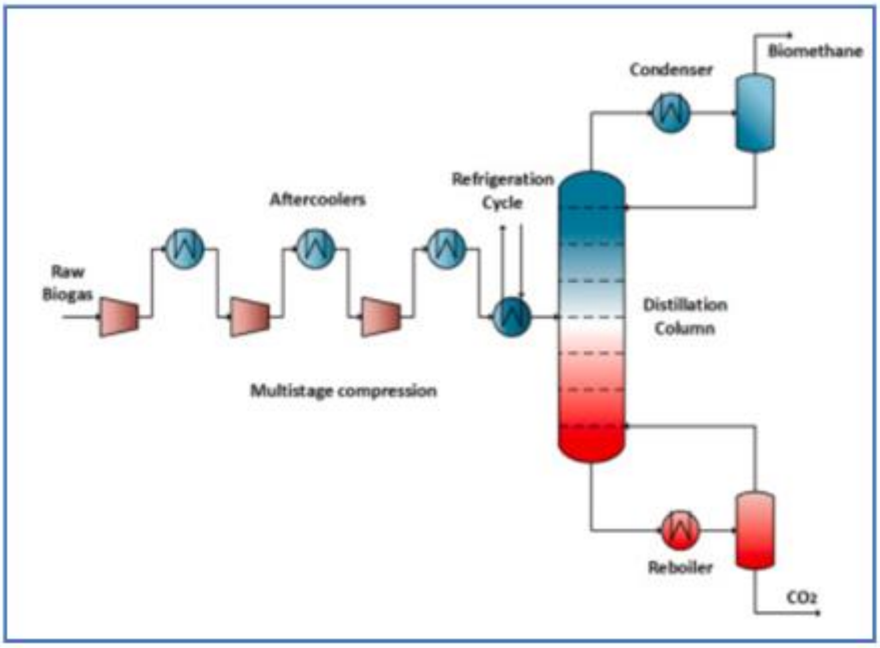

Advantages:
1. High methane purity (99-99.9%)
2. Effective removal of CO_2, H_2S, and other impurities
3. Compact design and low footprint
4. Suitable for small to large-scale applications
5. Can be used for liquefied biomethane (LBM) production

Disadvantages:
1. High energy consumption for cooling
2. Requires expensive refrigerants and equipment
3. Limited tolerance for contaminants like siloxanes
4. May require additional pre-treatment steps

Design Considerations:
1. Cooling system design and refrigerant selection
2. Distillation column design and configuration
3. Biogas flow rate and pressure
4. Temperature control and monitoring
5. Safety measures (e.g., explosion protection, cryogenic handling)

Cryogenic distillation is a highly effective biogas upgrade technology, offering high methane purity and compact design. However, it requires careful consideration of energy consumption, refrigerant selection, and operating conditions to ensure optimal performance.

Pressure plays a pivotal role in the solubility of these compounds. The process begins with biogas entering a separator at a pressure of 2 bar. At this stage, water and compounds heavier than CH_4 and CO_2 condense out of the gas mixture. The gas is then compressed to a higher pressure of 10 bar and injected into the bottom of a scrubber. Within this scrubber, water is sprayed, effectively absorbing CO_2 from the gas mixture.
The gas that exits the scrubber is subsequently sent to a drying unit, where the CH_4 concentration can reach up to 98%. Meanwhile, the water used in the scrubber is directed to a desorption unit, where the pressure is reduced to 1 bar. This decrease in pressure allows for the regeneration of the water, making it reusable for the scrubbing process.

Suggestion and Recommendations
1. The pre-treatment process must be effective also the filtration, compression, and drying methods must be capable of removing the large particles, moisture, and other contaminations.
2. Selection of the above-discussed purification technology must be done based on the composition of the raw biogas, purity of methane required, treatment of CO_2, and also the economy.
3. Continuous monitoring of the biogas after purification is a must so that the desired % of methane must be obtained regularly.
4. Temperature and moisture play a vital role in the purification of the biogas so these factors must be controlled at the time of purification.
5. The pilot test of the purification system to be adopted must be considered while designing the project before its execution.
6. Regular monitoring and regular maintenance of the purification system will also maintain the purification quality and quantity, also this will help in reducing

electrical consumption, wastage of gases, detoration of the purification elements or components.

7. Last but not least it must always be considered that the adopted purification system must fulfill the desired purification norms laid by different governing bodies.

II. CONCLUSION

Biogas upgradation/purification system is essential as we found that it also increases the calorific value of the gas, making it best to be used as fuel in industries and vehicles as well as on burning / combustion of this gas the emission of the harmful gases is very less. It is a green gas and instead of increasing greenhouse with the help of Aerobic Digestion (AD), the formation of CH4 in a controlled manner can fulfill the need for green fuel demand to some extent. Biogas is one of the renewable sources of energy. Purification of the biogas increases the volume of CH_4 (methane) in the mixture and decreases the quantity of other gases. Removing other gases makes it more feasible as the fuel in the vehicles and fit for bottling. The purification also increases the price value of the biogas in the open market. Also, purification reduces the corrosion in the pipeline, equipment, generators, and cylinders. This also reduces the maintenance of the machines.
Benefits of biogas upgrading:
- Renewable energy source
- Reduced greenhouse gas emissions
- Energy self-sufficiency
- Improved air quality
- Potential revenue streams through biomethane sales

The development of effective CO_2 capture technologies, alongside strategies to manage methane emissions, plays a vital role in addressing climate change and promoting environmental sustainability. Researchers and policymakers are continually exploring innovative approaches to improve the efficiency and feasibility of these technologies, aiming to balance the needs of a growing population with the imperative to protect our planet.

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