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EXPERIMENTAL EVALUATION OF A BIOGAS SLURRY FILTRATION UNIT: PERFORMANCE, NUTRIENT CHARACTERIZATION, AND SOCIO-ECONOMIC FEASIBILITY

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Abstract- Biogas slurry, a by-product of anaerobic digestion, presents a sustainable opportunity for enhancing agricultural productivity. However, the direct use of slurry poses challenges related to handling, application, and nutrient variability. The present study aimed to design and evaluated a biogas slurry filtration unit for efficient separation of solid and liquid fractions, assess the manure value of each fraction, and determine the socio-economic feasibility of the system. Performance was evaluated based on separation efficiency, flow rate, and ease of operation. Nutrient content was analyzed in terms of nitrogen (N), phosphorus (P), and potassium (K) levels in both solid and liquid components. A cost-benefit analysis was conducted to assess economic viability. The study revealed that the filtration unit significantly improves the handling and application of slurry and can be an economically feasible solution for small and medium biogas users.
Keywords: Biogas slurry, Filtration unit, Nutrient analysis, Socio-economic feasibility, Anaerobic digestion.

1. INTRODUCTION

Biogas slurry, a by-product of anaerobic digestion, is rich in essential nutrients such as nitrogen, phosphorus, and potassium, making it a valuable organic fertilizer [1], [2]. However, its high moisture content (above 90%) creates challenges in handling, storage, and field application [3]. Without proper management, it can lead to odour issues, nutrient leaching, and environmental pollution [4]. Solid-liquid separation of biogas slurry is an effective solution that enhances its usability [5]. The solid fraction can be composted or applied as slow-release manure, while the liquid fraction, containing soluble nutrients, is suitable for fertigation [6]. This study evaluates a low-cost, crate-based biogas slurry filtration unit developed using high-density polyethylene (HDPE), designed for small-scale, decentralized use [7]. The unit's performance was tested for separation efficiency, nutrient retention, and moisture reduction [8]. Results showed an average separation efficiency of 41.37% and a significant reduction in moisture content over 15 days [9]. Nutrient analysis confirmed that the solid fraction retained most of the NPK content, making it effective as an organic amendment [2], [10]. Additionally, a socio-economic assessment demonstrated that the filtration unit is cost-effective and suitable for rural farmers, offering reduced dependency on chemical fertilizers and improved soil health [11], [12]. This approach supports sustainable agriculture and promotes circular bio economy principles [13], [14].

2. MATERIAL AND METHODS

2.1 Location of Study

The experimental work was carried out at the Department of Renewable Energy Engineering, College of Technology and Engineering, MPUAT, Udaipur, Rajasthan.

2.2 Description of Biogas Slurry Filtration Unit

The filtration unit used in this study was a BAIF 5G model biogas slurry filter, developed for small and medium-scale rural applications. It consisted of six stackable HDPE crates:

- Two crates with coarse mesh (6–8 mm) for primary filtration,
- Two crates with fine green shade net (75%) for secondary filtration,
- Two solid crates to collect the liquid filtrate.

Each crate had a standard dimension of 600 × 400 × 320 mm (L × W × H) and a volume capacity of around 65 liters. The total system could handle 100–120 liters of slurry per day.

2.3 Experimental Procedure

- Input Material: 110 kg of digested biogas slurry was used per test batch.

- Filtration Process: The slurry was poured into the top crates and allowed to separate naturally by gravity.
- Number of Trials: Three experimental runs were conducted.
- Data Collection:
    - Weight of input slurry,
    - Solid and liquid fractions collected,
    - Evaporation loss calculated by difference.

2.4 Analytical Methods

Both the solid and liquid filtrates were analysed for their physicochemical and nutrient properties, including:

- Total Nitrogen (N) – Kjeldahl Method
- Available Phosphorus (P) – Gravimetric method
- Potassium (K) – Flame Photometry
- Moisture Content, Total Solids (TS), Volatile Matter (VM), Fixed Carbon, and Ash Content – Standard proximate analysis techniques

2.5 Socio-Economic Evaluation

To assess the practical adoption and cost-effectiveness of the unit:

- Cost of materials and fabrication was recorded.
- Labour input, maintenance costs, and fertilizer substitution potential were estimated.
- A cost-benefit analysis was conducted using indicators like Payback Period, Benefit-Cost Ratio, and Net Returns.

3. RESULTS AND DISCUSSION

3.1 Performance Evaluation

The biogas slurry filtration unit's design was created to handle digested slurry effectively and accomplish the best possible separation of liquid and solid components. The technology is small, easy to use, and appropriate for decentralized biogas facilities, especially small- to medium-sized ones that handle organic waste. Six high-density polyethylene (HDPE) crates make up the unit; they were produced using injection moulding technology to guarantee their strength, longevity, and UV resistance. Two mesh filter crates with 6–8 mm perforations made of HDPE for initial coarse filtration, two fine mesh filter crates equipped with 75% green shade netting for secondary filtration, and two non-perforated crates that act as collection tanks for the filtrate liquid comprise the three functional components of the crate system. With an internal volume capacity of 65 liters and external dimensions of 600 × 400 × 320 mm, the mesh and filter tanks weigh 2.67 kg and 2.25 kg, respectively. The fine mesh box weighs 1.3 kg, is 600 × 400 × 120 mm, is smaller in height, and can carry 23 liters. For rural and semi-urban applications, the whole filtration unit is practical and efficient, with the capacity to handle 100 to 120 liters of slurry per day. Long service life in outdoor operation situations is ensured using UV-stabilized materials.

3.2 Experimental Procedure

In the present study, three tests were conducted to evaluate the separation efficiency of the unit. In each test, a consistent input of 110 kg of biogas slurry was processed. The solid and liquid fractions recovered from each test were weighed, and their values were used to calculate separation efficiency. A summary of the findings is as follows:

- In Test 1, 44.52 kg of solids were recovered, yielding a separation efficiency of 40.47%.
- In Test 2, the solid fraction weighed 42 kg, resulting in an efficiency of 38.18%.
- In Test 3, the solid recovery increased to 50 kg, indicating an efficiency of 45.45%.

The average separation efficiency across all tests was computed to be 41.37%. These results suggest a moderately efficient separation process, with slight variations potentially attributed to differences in slurry composition, moisture content, or filtration consistency during each run. A separation efficiency of solid fraction in the range of 38–45% indicates that a significant portion of the slurry's total mass can be recovered as solid matter, which is rich in organic carbon and nutrients. [3] [8] [9]. Table 3.1 shows the solid and liquid weight fractions of biogas slurry.

Table-3.1 Solid and Liquid Weight Fractions

S. No.	Weight Fractions	First test	Second test	Third test
1.	Biogas slurry	110 kg	110 kg	110 kg
2.	Solid weight	44.52kg	42kg	50kg

3.	Liquid weight	39 liter	41.09 liter	43 liter
4.	Separation efficiency	40.47%	38.18%	45.45%
5.	Evaporation loss	24.07 kg	24.46 kg	15.45 kg

3.3 Nutrient Content Analysis

The nutrient (NPK) analysis of the biogas slurry and its separated components revealed substantial differences in nutrient distribution before and after filtration using 5G filter technology. The raw biogas slurry had a total nitrogen (N) concentration of 0.87%, phosphorous (P) of 0.62%, and potassium (K) of 0.29%, demonstrating its potential as an organic fertilizer source. Following separation, the solid fraction kept the majority of nutrients, with nitrogen reduced to 0.46%, phosphorus to 0.50%, and potassium to 0.23%, indicating that critical nutrients are primarily retained in the solid matrix. In contrast, the liquid fraction had much lower nutrient levels 0.025% nitrogen, 0.001% phosphorus, and 0.051% potassium indicating that nutrients were limited in the liquid phase. However, a noticeable reduction in total nutrient content between the raw slurry and the combined solid and liquid outputs suggests that some nutrient loss occurred during the separation process. This loss is likely due to the volatilization of nitrogen and phosphorus, which are known to evaporate under aerobic conditions during slurry handling and filtration. While the solid portion remains suitable for use as an organic manure to improve soil structure and fertility, the nutrient-dilute liquid fraction is better suited for drip irrigation in kitchen gardens, providing light but continuous fertilization. These findings highlight both the effectiveness and the limitations of the 5G filter system, suggesting that optimization is needed to minimize nutrient loss and maximize resource recovery. Fig. 3.1 lists the main components of the slurry, macronutrients including potassium, phosphorus, and nitrogen (NPK). The analysis's findings showed that the biogas slurry's nutritional concentration was adequate to promote crop development. [1] [3].

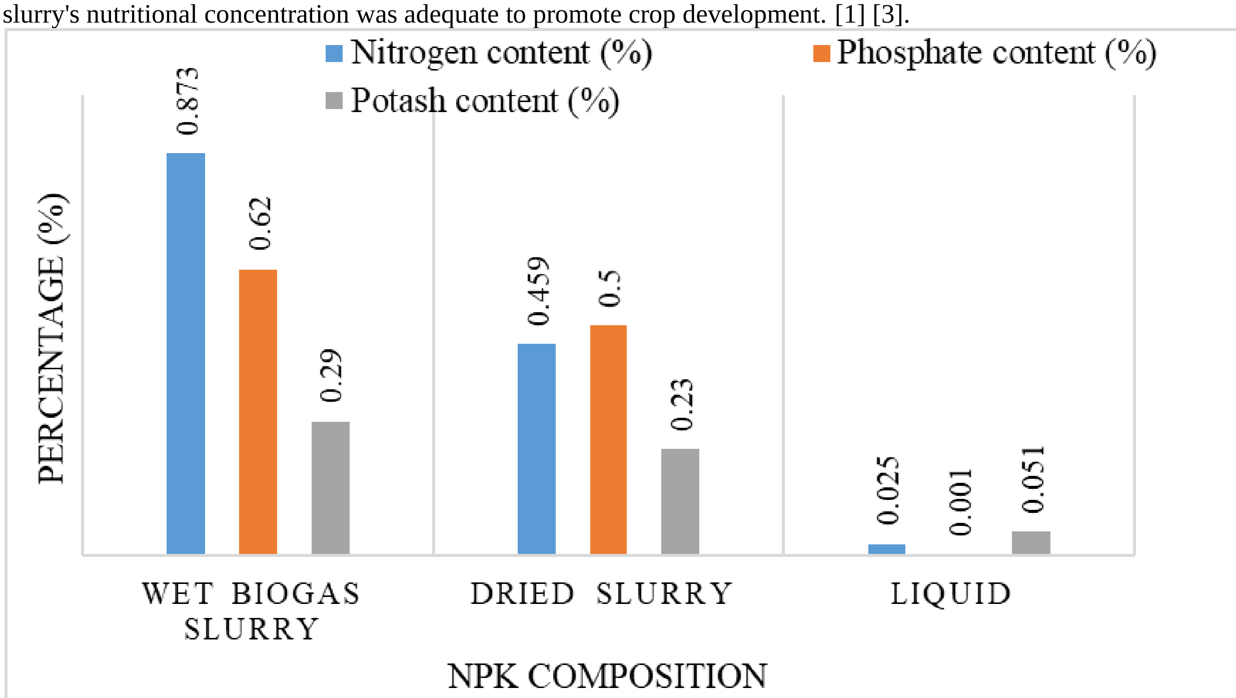

Fig. 3.1 Chemical properties of Biogas Slurry

3.4. Proximate Analysis

3.4.1 Moisture Content

The physical transformation of biogas slurry was assessed by examining its drying behavior over a 15-day period, with a special focus on moisture content (MC%) at various drying intervals. One important physical factor that affects handling, storage, nutrient stability, and separation unit efficiency is moisture content. The slurry samples' initial moisture content of 94.95%, was extremely high and in line with the usual values for new biogas slurry that is directly released from digesters. The moisture content gradually decreased over time as a result of ambient natural evaporation. The moisture level decreased somewhat after seven days, the samples showing moisture value of 70.34%. At this point, the slurry starts to thicken and exhibit early solidification symptoms, reflecting partial dehydration. The ultimate moisture content in some samples dropped to as low as 56.58% on the tenth day, indicating a more noticeable decrease in moisture. As the separation process went on, the moisture content dropped to as low as 32.65% by the fifteenth day, indicating a significant change from a semi-liquid to a semi-solid state. **Fig.2** shows the moisture content of biogas slurry on various days.

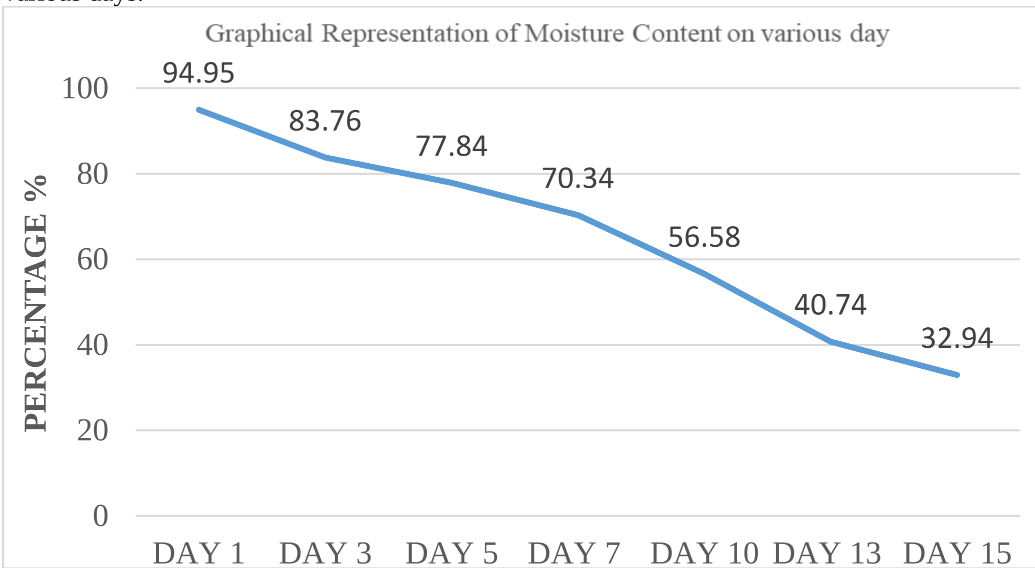

Fig. 2: Moisture Content of Biogas Slurry on Various Days.

3.4.2 Volatile Matter

Volatile matter refers to the portion of organic compounds that vaporize when the sample is heated in the absence of oxygen. A value of 58.93% indicates a high proportion of combustible organic compounds, such as hydrocarbons, cellulose, hemicellulose, and other volatile substances. This is characteristic of organic-rich biomass materials and suggests that the separated slurry retains considerable energy potential. High volatile matter content is also favourable for microbial activity in soil, as it supports faster decomposition and nutrient release [1].

3.4.3 Ash Content

Ash represents the inorganic residue left after combustion and is a measure of the mineral matter present in the slurry. An ash content of 19% is moderate and reflects the presence of essential plant nutrients such as calcium, potassium, magnesium, and trace elements. While high ash content can reduce the calorific value if the material is used for energy purposes, it enhances its value as an organic fertilizer by contributing to soil fertility [2]. The mineral composition of the ash can improve soil structure and buffer capacity.

3.4.4 Fixed Carbon

Fixed carbon is the solid combustible residue remaining after the volatile matter is released. It contributes to the thermal value of the material and indicates the amount of carbon available for long-term soil enrichment if applied as biochar. A fixed carbon content of 22.7% implies that a significant fraction of stable organic carbon remains, which may help in carbon sequestration and improving soil organic matter levels over time [3].

Overall, the proximate analysis of the separated slurry indicates that it is a valuable by-product with dual benefits: agronomic utility through mineral and organic carbon enrichment of soils, and bioenergy potential due to high volatile and fixed carbon content. These properties make the separated solid fraction suitable for composting, direct application as manure, or even further processing like pelletization or bio char production, depending on local needs and feasibility.

3.5 Socio-Economic Feasibility

The BAIF 5G Biogas Slurry Filtration Unit represents a low-cost, modular intervention that enhances the management and utility of biogas slurry, converting it into high-value solid and liquid organic fertilizers. Economically, the unit enables significant savings on synthetic fertilizers (₹7,000–₹9,000 annually) and contributes to increased crop yields (₹4,000–₹6,000 annually), making it highly viable for small and marginal farmers. Its minimal installation cost (₹6,000–₹8,000), low maintenance needs, and operational simplicity (requiring just one person for 1–2 hours daily) make it an accessible solution for rural households. Socially, the technology plays a transformative role in promoting gender equity and rural livelihoods. Women, who are traditionally responsible for livestock and slurry management, benefit from reduced drudgery, improved hygiene, and safer handling of organic waste. The filtration unit minimizes direct contact with raw slurry, improving women's health, dignity, and working conditions. Moreover, it opens avenues for income generation through women-led self-help groups (SHGs) involved in packaging and marketing of organic fertilizers. The unit also fosters employment across fabrication, installation, and maintenance chains, contributing to rural entrepreneurship and skill development. From an environmental health perspective, the system reduces risks of groundwater contamination, odour, and vector-borne diseases by enabling targeted nutrient application and improved slurry management. Thus, the BAIF 5G filtration unit integrates economic viability with social inclusion, environmental sustainability, and gender-responsive development, positioning itself as a holistic solution for decentralized organic waste management in India's rural landscapes.

CONCLUSION

The BAIF 5G slurry filtration unit demonstrated robust performance and clear benefits. It reliably separated 90% of solid digestate from farm slurry, producing a dry, nutrient-dense cake and a clear liquid fraction. Nutrient analyses confirmed the solids are enriched in nitrogen and phosphorus, while the liquid retains potassium – together offering a complete organic fertilizer package. Proximate assays showed the cake's moisture dropped to ~10–20% within two weeks, making it easy to handle and apply. These process outcomes align with sustainable agriculture goals: the output fertilizers can significantly reduce chemical fertilizer use (enhancing yields and soil health) and the system conserves water through recycling. Economically, preliminary calculations indicate positive returns via input savings. Socially, the unit reduces women's labour burden (by cutting firewood use) and fosters new rural enterprises (through bio-input production). In summary, the study confirms that the BAIF 5G filter is an effective and feasible technology for integrated biogas–agriculture systems, advancing India's renewable energy and organic farming objectives.

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ETHICS DECLARATIONS

Ethical Approval and consent to participate

This work does not contain any studies with human participants or animals.

Competing Interests

The authors declare no competing interests.

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Availability of Data and Materials

Not applicable to this study

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