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CONFERENCE PAPER

EMERGING DEVELOPMENTS OF OPTIMIZATION OF ANAEROBIC DIGESTION PERFORMANCE USING RESPONSE SURFACE METHODOLOGY AND CENTRAL COMPOSITE DESIGN

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Abstract

The study evaluated the conversion of agricultural waste into renewable bioenergy through anaerobic digestion with emphasis on optimization of operating parameters. Agricultural residues including rice husk, sugarcane bagasse, corn stalks, vegetable waste, and cattle manure were considered for their physicochemical characteristics and digestion performance. Response Surface Methodology (RSM) combined with Central Composite Design (CCD) was used to optimize temperature, hydraulic retention time, and organic loading rate. Before optimization, methane purity was 58%; after optimization, methane concentration increased to 72%. The optimized conditions were a temperature of 37°C, retention time of 25 days, and organic loading rate of 2.5 kg VS/m³/day. Under mesophilic conditions, peak gas production was observed around Day 20, with cumulative biogas yield of approximately 140–150 m³. The results demonstrate that parameter optimization improved methane quality and overall anaerobic digestion performance.

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Introduction:-

Anaerobic digestion is a biochemical process in which microorganisms decompose biodegradable organic matter under oxygen-free conditions. Agricultural residues are converted into biogas, primarily methane and carbon dioxide, together with nutrient-rich digestate. The efficiency of the process depends on feedstock characteristics and operating conditions including moisture, total solids, volatile solids, pH, carbon-to-nitrogen ratio, temperature, retention time, and organic loading rate. Optimization is important because anaerobic digestion involves interacting process parameters.

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The thesis identifies Response Surface Methodology (RSM), particularly Central Composite Design (CCD), as a statistical framework capable of modelling response surfaces and identifying interactions among process variables. Artificial Neural Network (ANN) and Genetic Algorithm (GA) approaches are also discussed as computational optimization methods.

Feedstock Characteristics Relevant to Optimization:-

The selected agricultural feedstocks were rice husk, sugarcane bagasse, corn stalks, vegetable waste, and cattle manure. Rice husk had a C/N ratio of 45:1, volatile solids of 78.2%, and pH 6.8. Sugarcane bagasse had a high C/N ratio of 120:1. Corn stalks had a C/N ratio of 35:1 and volatile solids of 88.4%. Vegetable waste had a C/N ratio of 15:1 and high moisture content. Cattle manure had a pH of 7.4 and served as a co-substrate and inoculum source. The analysis confirmed that feedstock composition influences digestion performance. Co-digestion of multiple feedstocks helped maintain nutrient balance and improved methane productivity compared with individual substrates.

Experimental and Statistical Framework:-**Anaerobic Digestion:-**

The digestion process was evaluated under mesophilic conditions. The process progressed through a lag phase, an active methanogenesis phase, and a stabilization phase. Methanogenic microorganisms are sensitive to acidic conditions, while stable operation requires controlled pH and temperature.

Pretreatment:-Mechanical shredding reduced particle size below 2 mm. Alkali pretreatment was then performed using 2% sodium hydroxide at 70°C for 60 minutes. The treatment was intended to disrupt lignocellulosic bonds and improve microbial accessibility.

RSM and CCD:-Response Surface Methodology combined with Central Composite Design was used to optimize operating parameters including temperature, hydraulic retention time, and organic loading rate. The thesis describes ANOVA, regression analysis, model coefficient significance, and statistical evaluation as components of the optimization framework.

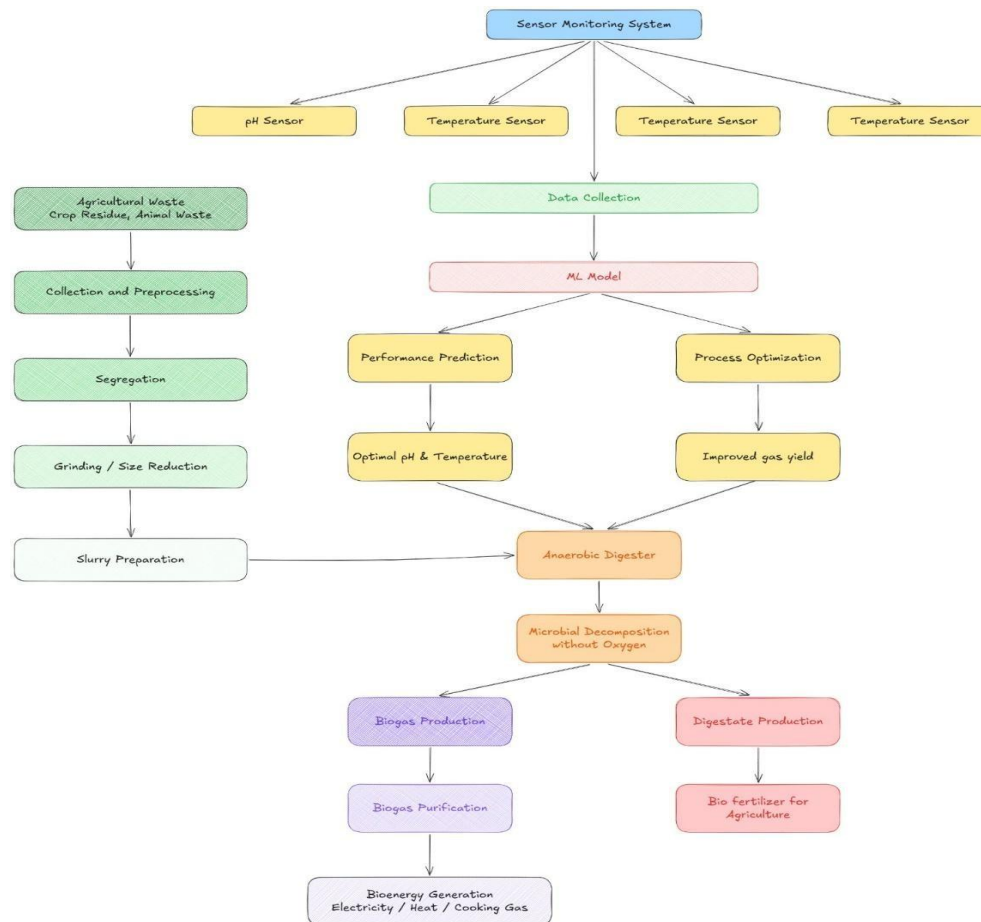


Figure 1. Integrated research methodology framework used in the thesis.

ANN and GA in the Research Framework:-

The thesis also identifies Artificial Neural Network modelling as a method for handling nonlinear relationships between process parameters and biogas yield. Genetic Algorithm optimization is described as an evolutionary approach that can be used with surrogate models to identify favorable operating conditions.

Results and Discussion:-

Pretreatment Effect on Digestion Performance:-

Mechanical shredding and alkali pretreatment improved biomass digestibility. The thesis reports a 24.5% reduction in lignin content, a 42% increase in biogas yield, and a 15-day reduction in digestion time. These findings indicate that improved substrate accessibility contributed to enhanced conversion efficiency.

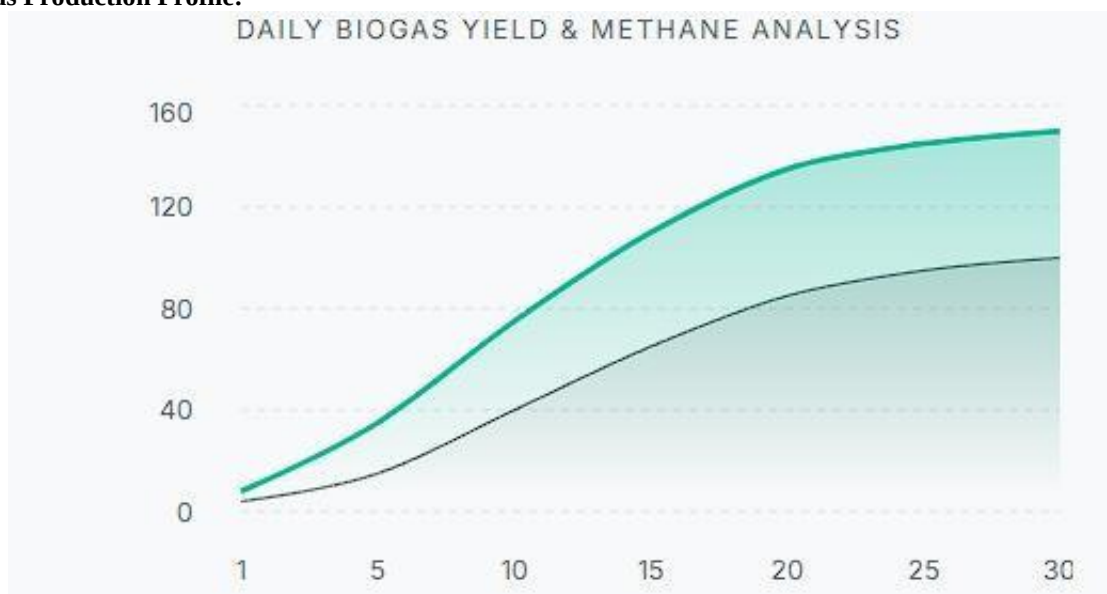
Biogas Production Profile:-

Figure 2. Daily biogas yield and methane analysis.

During Days 1–5, gas production remained relatively low because of microbial adaptation. Between Day 5 and Day 20, rapid microbial activity resulted in substantial biogas generation. Peak production occurred around Day 20, when cumulative biogas yield reached approximately 140–150 m³. After Day 20, production gradually stabilized as biodegradable organic matter became depleted.

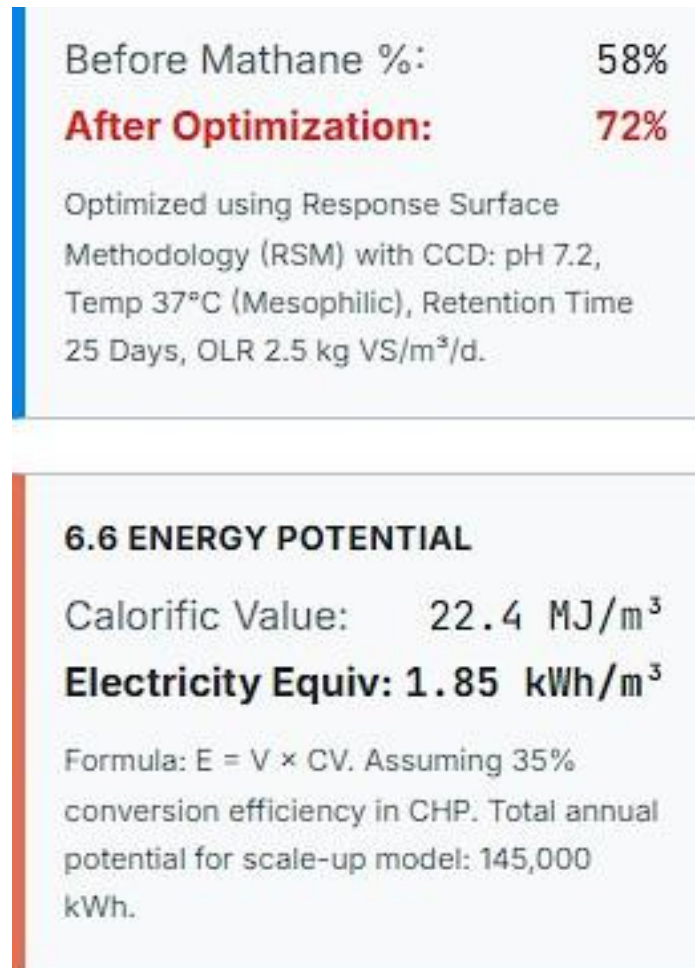
Optimization Results:-

Figure 3. Optimization results and energy potential reported in the thesis.

RSM with CCD was applied to maximize methane yield and improve digester performance. Before optimization, methane purity was 58%.

Following optimization, methane concentration increased to 72%. The optimized operating conditions were:-

Temperature:-

37°C

Retention time:-

25 days

Organic loading rate:

2.5 kg VS/m³/day

The increase in methane purity demonstrates the importance of optimizing operating parameters for improving anaerobic digestion efficiency and methane quality.

Energy Implication of the Optimized Process:-

The calorific value of purified biogas was approximately 22.4 MJ/m³. Electricity generation potential was estimated at 1.85 kWh/m³, and the annual large-scale implementation potential was estimated at approximately 145,000 kWh/year.

Table 1. Results of Pretreatment, Biogas Production, Optimization, and Energy Potential

Parameter	Result
Lignin reduction	24.5%
Increase in biogas yield	42%
Reduction in digestion time	15 days
Days 1–5	Low gas production
Days 5–20	Rapid biogas generation
Peak biogas production	Day 20
Cumulative biogas yield	140–150 m ³
Methane concentration before optimization	58%
Methane concentration after optimization	72%
Temperature	37°C
Retention time	25 days
Organic loading rate	2.5 kg VS/m ³ /day
Calorific value of purified biogas	22.4 MJ/m ³
Electricity generation potential	1.85 kWh/m ³
Annual large-scale implementation potential	145,000 kWh/year

Discussion:-

The thesis findings show that anaerobic digestion performance is influenced by both substrate characteristics and operating conditions. Pretreatment improved substrate accessibility, while optimization of temperature, retention time, and organic loading rate increased methane concentration. The optimized temperature of 37°C falls within the mesophilic operating range described in the thesis. The results therefore demonstrate the contribution of integrated pretreatment and process-parameter optimization to improved anaerobic digestion performance. The literature reviewed in the thesis supports the use of multivariate and computational approaches for anaerobic digestion optimization. RSM-CCD has been used to identify significant process variables and optimal operating regions, while ANN has shown high predictive performance for nonlinear digestion systems. GA has also been reported to reduce hydraulic retention time without reducing methane yield in a CSTR study.

Conclusion:-

The study demonstrated that optimization of anaerobic digestion operating parameters can substantially improve methane quality. RSM combined with CCD identified 37°C, 25 days retention time, and 2.5 kg VS/m³/day organic loading rate as the optimized conditions reported in the thesis. Methane purity increased from 58% to 72%. Together with pretreatment, which reduced lignin by 24.5%, increased biogas yield by 42%, and reduced digestion time by 15 days, the optimized process provides an improved framework for agricultural-waste-to-bioenergy conversion.

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