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Review on Generating Electrical Energy Using Biogas with Peltier Effect

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Abstract -
The project "Generating Electrical Energy Using Biogas with Peltier Effect" focuses on producing renewable electricity from organic waste through the combined principles of biogas production and thermoelectric energy conversion. Biogas, generated via anaerobic digestion of organic matter such as food waste, contains a high percentage of methane, making it an effective and eco-friendly fuel source. The methane-rich biogas is combusted to produce heat, which is then converted into electrical energy using Peltier modules based on the Seebeck effect — where a temperature difference across two semiconductor junctions generates voltage. The study successfully utilized four Peltier diodes to produce approximately 6 volts, sufficient to power small electronic devices such as LED lights and charge mobile phones. This system provides a sustainable alternative to fossil fuels, particularly beneficial for remote and rural areas with limited electricity access. By converting waste into usable energy, this research supports global efforts to reduce greenhouse gas emissions, promote energy recycling, and develop cost-effective renewable power solutions for low-energy applications.

Keywords: Waste heat from Biogas, waste heat Recovery, TEGs, Electricity.

1. INTRODUCTION

The growing global demand for energy, coupled with the depletion of fossil fuel reserves and the adverse environmental effects of conventional energy sources, has led to an urgent need for the development of sustainable and renewable energy alternatives. Fossil fuels such as coal, petroleum, and natural gas have long served as the primary sources of power generation, but their extensive use has resulted in serious environmental issues such as air pollution, greenhouse gas emissions, and global warming. To address these challenges, researchers and engineers have been exploring renewable sources such as solar, wind, hydro, geothermal, and biomass energy. Among these, biogas has emerged as a promising and eco-friendly alternative that not only generates clean energy but also helps in managing organic waste effectively.

Biogas is produced through the anaerobic digestion of organic materials such as agricultural residues, animal manure, food waste, and sewage sludge. This biological process results in a mixture of gases, primarily methane (CH_4) and carbon dioxide (CO_2), with small traces of hydrogen sulfide and other gases. The high methane content makes biogas an excellent fuel that can be used for cooking, heating, and even electricity generation. One of the most significant advantages of biogas production is its dual environmental benefit — it reduces the volume of waste that would otherwise decompose and emit methane into the atmosphere and simultaneously provides a renewable source of energy that can replace fossil fuels.

In parallel with biogas utilization, modern research has also focused on thermoelectric generation, which directly converts heat energy into electrical energy using the Peltier effect (or Seebeck effect). A thermoelectric module, often referred to as a Peltier diode, functions on the principle that a temperature difference across two dissimilar semiconductor materials generates an electromotive force. The greater the temperature difference, the higher the voltage output. This property can be effectively used to harness energy from various heat sources, including waste heat from combustion or other industrial processes.

The present study integrates these two sustainable technologies — biogas generation and thermoelectric conversion — to develop a system capable of producing electricity from organic waste. In this system, biogas generated from food and organic wastes serves as the heat source, and the heat produced from burning the methane-rich gas is applied to a set of Peltier modules. The Peltier modules convert the heat energy into electrical energy, producing a measurable voltage and current output. In the conducted experiment, four Peltier modules successfully generated around 6 volts of electricity, sufficient to power small electronic devices such as mobile chargers and LED lights.

This method of energy recovery from biogas heat represents a cost-effective, compact, and environmentally friendly approach to power generation, particularly useful in remote or rural areas where conventional electricity supply is irregular or unavailable. Moreover, this approach contributes significantly to waste management and climate change mitigation by transforming food and organic waste into valuable energy resources instead of allowing them to emit harmful greenhouse gases. Hence, the integration of biogas and Peltier-based thermoelectric systems offers a sustainable pathway toward achieving global renewable energy goals and reducing dependence on fossil fuels.

2. Problem Identification

- The rapid increase in global energy demand has led to the excessive use of fossil fuels, resulting in environmental degradation, air pollution, and greenhouse gas emissions.
- Many rural and remote areas still lack consistent access to electricity, limiting development and the use of basic electronic devices.
- A large amount of organic waste such as food scraps, agricultural residues, and animal manure is discarded daily,

contributing to methane emissions and environmental pollution.

- The heat energy produced from biogas combustion or other industrial processes is often wasted without being utilized efficiently.
- Existing renewable energy systems like solar and wind are costly and dependent on specific weather conditions, making them unsuitable for continuous small-scale power generation.
- There is a pressing need for a cost-effective, compact, and eco-friendly system that can convert organic waste into electrical energy while reducing greenhouse gas emissions.
- Efficient integration of biogas and thermoelectric (Peltier) technologies remains an unexplored area with great potential for sustainable power generation.

3. Literature Review

He, K., et al. (2024), This systematic review synthesizes experimental and field studies on anaerobic digestion (AD) of food waste, covering pretreatment, microbial pathways, reactor types (batch, CSTR, UASB), operating conditions (temperature, pH, HRT, C/N ratio), and common inhibitors. The authors compare mono-digestion versus co-digestion (with manure, wastewater sludge) and evaluate performance metrics: biogas yield, methane content, and VS/TS degradation. They highlight process bottlenecks — feedstock variability, ammonia inhibition, and lack of standardized monitoring — and summarize optimization strategies such as thermal/chemical pretreatment, co-substrate balancing, and microbial augmentation. The review concludes that co-digestion and optimized operational control significantly increase methane yields and stability, but scale-up challenges and techno-economic gaps remain.

Shilpa, M.K., et al. (2022), This review focuses on commercial Peltier (thermoelectric) modules: materials (Bi_2Te_3), device architecture, modeling, applications (cooling, sensing, energy harvesting), and limitations (low efficiency, heat-sinking needs). It compiles experimental studies assessing module performance under different ΔT, load conditions, and heat exchanger designs. The authors analyze mathematical models for coupled heat–electric behavior and provide a gap analysis for low-power energy harvesting (IoT, sensors). Key findings: Peltier modules are robust and maintenance-free for small-scale applications, but electrical power density remains low unless module geometry, thermal coupling, and high-ZT materials are simultaneously improved. Practical suggestions include hybridization with photovoltaics or batteries and optimized thermal interfaces.

Mahek, M.K., et al. (2024), This article surveys thermoelectric cooling and its cross-over with energy harvesting, with emphasis on device physics, engineering tradeoffs, and thermal management strategies. It reviews material advances, module packaging, transient thermal response, and system-level integration in battery/thermal management systems. The authors analyze cooling COP, achievable ΔT, and practical limits imposed by contact resistance and module aging. They also discuss using modules bidirectionally (cooling vs. generation) and the penalties when re-purposing cooling modules for power generation. The main conclusion stresses that while thermoelectrics are mature for niche cooling, realizing competitive power-generation systems requires high-performance materials and superior heat exchangers to maintain large ΔT.

Issahaku, M., et al. (2024), This review examines why many household/small digesters fail and synthesizes best practices for design, operation, and community adoption. Coverage includes sizing methodologies, feedstock preprocessing, insulation, mixing, gas storage, and simple instrumentation. Socio-technical barriers (user training, maintenance, feedstock seasonality) and environmental co-benefits are evaluated. Findings show that appropriate sizing, control of feeding regime, and simple thermal insulation dramatically improve continuity of gas production. The paper emphasizes participatory design and local supply-chain readiness (spare parts, training) as critical for long-term adoption. Recommendations address low-cost monitoring (manometers, temperature strips) and modular designs to ease repairs.

Bhakta, S., et al. (2024), This review analyzes automotive TEG research: exhaust-mounted modules, heat-exchanger geometries, thermal expansion management, and system-level impacts on fuel consumption and emissions. It compares experimental bench studies and vehicle demonstrations, and models for placement (exhaust manifold, catalytic converter region). Key performance drivers identified are hot-side temperature, cold-side heat rejection, contact thermal resistance, and durability under vibrations/soot. The authors report realistic net electrical output in current studies (tens to low hundreds of watts) and note that, while TEGs can reduce fuel use marginally, economic viability depends on material costs and long-term reliability. Integration with hybrid/electrified drivetrains offers the most promising ROI.

Francisco López, A., et al. (2024), Focused on upgrading technologies, this review compares water scrubbing, pressure swing adsorption, membrane separation, and chemical scrubbing for converting raw biogas to pipeline-grade biomethane. Metrics compared include CH_4 recovery, CO_2 rejection, energy penalty, and CAPEX/OPEX implications for small/medium plants. The authors stress the importance of feedstock contaminants (H_2S, siloxanes) and pre-treatment needs. Findings indicate membrane and adsorption systems provide modular scaling for decentralized plants but require careful pretreatment; water scrubbing shows low complexity but high water use. The paper suggests hybrid upgrading trains and policy incentives are key to scale biomethane markets.

Chen, W.H., et al. (2025), This forward-looking review surveys novel materials, device geometries (nanostructures, graded legs, anisotropic designs), and system integration strategies that could push TEGs beyond current ZT limitations. It analyzes non-equilibrium synthesis, heterostructured composites, and asymmetric designs to decouple electrical and thermal transport. The authors benchmark lab-scale material ZTs and prototype module performances, and discuss manufacturability and lifecycle impacts. The central finding: targeted materials engineering combined with innovative geometric designs can significantly enhance power density, but commercialization requires scalable synthesis and reliability testing. They call for system-level demonstrations (transport, industrial exhaust) to validate projected gains.

Kumar, D.J.P., et al. (2024), This wide-scope review covers biochemical pathways of AD, microbial consortia dynamics, digestion kinetics, and process modeling for municipal/ agricultural organic wastes. It compiles performance data across reactor types and temperatures, highlights inhibitors (VFA accumulation, salts, ammonia), and evaluates tech-economic factors for decentralized systems. Notably, the authors synthesize life-cycle and greenhouse-gas comparisons showing AD with energy recovery typically reduces net emissions versus landfilling. The paper recommends enhanced monitoring (online gas composition sensors) and combined value chains (digestate as fertilizer, onsite energy use) to improve economic viability in small communities.

Zhuang, H.L., et al. (2024), This materials-focused review surveys advances in Bi_2Te_3 alloys and microstructure engineering that boosted room-temperature ZT values. Topics include doping strategies, grain-boundary engineering, and processing routes that enhance power factor while reducing lattice thermal conductivity. The authors summarize device-level demonstrations showing improved module efficiencies and discuss stability under thermal cycling. Findings suggest that recent compositional tuning and defect engineering enable reliable, higher-performance modules suited to low-temperature waste-heat sources — a positive sign for near-term Peltier-based power harvesting applications if packaging and thermal interfaces are optimized.

Akarsu, R.T., et al. (2024), This review/meta-analysis compiles techno-economic studies of hybrid systems that combine small-scale biogas, solar PV, and batteries for livestock and rural farms. It assesses LCOE, payback, emissions reduction, and sensitivity to feedstock availability and subsidies. The review shows hybridization increases system reliability and reduces LCOE under realistic local conditions; coupling biogas with PV reduces battery sizing needs and improves load matching. Environmental analyses show substantial GHG savings when biogas displaces fossil fuels and digestate displaces synthetic fertilizers. The authors recommend context-specific feasibility studies and highlight financing mechanisms as primary enablers for deployment.

4. Methodology

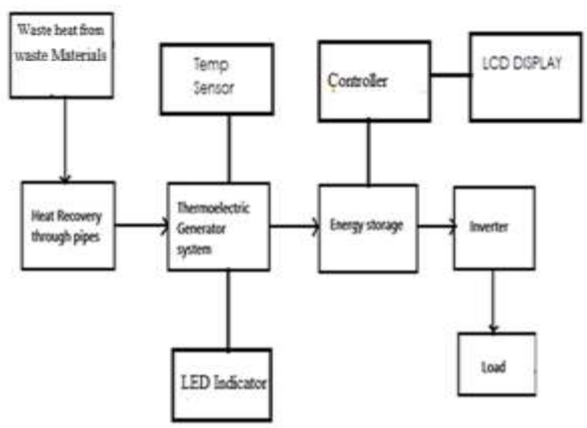

Fig.1. Block Diagram

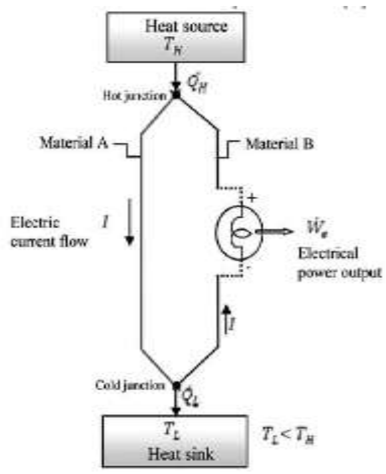

Fig.2. Working Principle

TEG consists of one hot side and one cold side. The hot side with higher temperature, will drive electrons in the n-type leg toward the cold side with lower temperature, which cross the metallic interconnect, and pass into the p-type leg, thus developing a current through the circuit.
If temperature difference is kept constant, then the diffusion of charge carriers will form a constant heat current, hence a constant electrical current.

Working :

- Biogas Production: Organic wastes, such as food scraps, agricultural residues, and animal manure, are collected and placed in a biogas digester. Through anaerobic digestion, microorganisms break down the organic matter in the absence of oxygen, producing biogas primarily composed of methane (CH_4) and carbon dioxide (CO_2).
- Heat Generation: The methane-rich biogas is directed to a combustion chamber or heat source, where it is burned to produce thermal energy (heat).
- Thermoelectric Conversion: Peltier modules (thermoelectric generators, TEGs) are placed in contact with the heat source. The temperature difference between the hot side (exposed to biogas combustion heat) and the cold side (kept cool with a heat sink) creates a voltage across the Peltier module due to the Seebeck effect.
- Voltage and Current Generation: The Peltier modules convert the heat energy into direct current (DC) electricity. The magnitude of the generated voltage depends on the temperature gradient across the module.
- Energy Regulation and Storage: A temperature sensor monitors the heat source to regulate the output, ensuring stable power. The DC electricity is stored in a battery for later use.
- Load Operation: The stored energy can either directly power low-power devices (LEDs, small electronics) or pass through an inverter to convert DC to AC for standard AC loads.
- Energy Efficiency: This system allows efficient conversion of waste heat from biogas combustion into usable electrical energy, providing a sustainable, renewable power solution for remote or low-energy applications.

5. Benefits

- TEGs are solid-state device, which means that they have no moving parts during their operations. No moving parts so maintenance required is less frequently, no chlorofluorocarbons. Temperature control to within fractions of a degree can be maintained, flexible shape, very small size.

- TEGs can be used in environments that are smaller or more severe than conventional refrigeration. TEG has long life, and also it can be controllable by changing the input voltage/current.

6. Scope of the Study

- By using thermoelectric generator connecting in series /parallel we can generate the power for maximum level
- Even body heat also generate the heat that can be utilizing by using TEG to generate the power to charge the portable equipment like laptop mobile etc
- By installed in the vehicle above the radiator means the vehicle battery will charge self.

7. Advantages

- Clean, Noise less , Cost is less .
- This is a Non-conventional system ,No fuel is require
- Easy maintenance, portable, Charging time is less (maximum temp)
- Promising technology for solving power crisis to an affordable extent.
- Simple in construction, Pollution free, Reduces transmission losses.
- Wide areas of application# Required less space
- It can be use at any time when it necessary.
- Less number of parts required.
- we can charge any electronic devices
- Electricity can used for many purposes
- Efficient and eliminate the grid searching.
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8. Applications

- Rural Electrification: Provides electricity to remote or off-grid areas where conventional power supply is unavailable.
- Low-Power Electronics: Powers small devices such as LED lights, mobile phone chargers, sensors, and IoT devices.
- Waste Management: Converts organic waste into biogas, reducing environmental pollution and landfill usage.
- Renewable Energy Demonstration: Serves as an educational or pilot project to demonstrate sustainable energy solutions using biogas and thermoelectric generation.
- Agricultural Farms: Powers farm equipment or low-consumption devices using energy derived from agricultural residues.
- Emergency Backup: Acts as a backup power source during grid failures or natural disasters.
- Energy Efficiency Enhancement: Utilizes waste heat from biogas combustion that would otherwise be lost.

9. Conclusion

The project is expected to provide a sustainable and eco-friendly source of electrical energy by efficiently converting biogas heat into electricity using Peltier modules. It will demonstrate the feasibility of generating usable power from organic waste, reducing dependence on fossil fuels. The system is expected to produce a stable DC voltage sufficient for charging mobile devices and powering low-consumption electronic loads. By storing energy in a battery and using an inverter, the electricity can also be supplied to AC loads, enhancing its practical utility. Additionally, the project will contribute to waste management and greenhouse gas reduction, as food and agricultural wastes are converted into energy instead of decomposing. Overall, it provides a cost-effective, renewable energy solution suitable for rural, industrial, or household applications where small-scale electricity generation is needed, demonstrating the potential of biogas-based thermoelectric systems.

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