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Lightening Future with Non-Degradable Waste

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Abstract

This project focuses on addressing the growing problem of non-biodegradable waste, which creates major environmental and management issues. It proposes a smart system for waste segregation and energy production using the Arduino UNO R4 platform. The system classifies waste into three types dry, wet, and metal by using various sensors such as proximity, moisture, infrared, temperature, and weight sensors. After segregation, dry waste is sent to an incineration chamber where it is burned to produce heat, which is further converted into electrical energy. Wet waste is processed to generate biogas, while metal waste is collected separately for recycling purposes. To minimize pollution, an exhaust system along with water filtration is used to control harmful emissions. A K-type thermocouple is used to monitor temperature and ensure safe operation of the system. Additionally, real-time data can be viewed on a mobile device for continuous tracking. A lead-acid battery is included to provide backup power. The ash produced from burning can be utilized for landfill applications, and plantation around the system helps in reducing carbon emissions. Overall, this project provides an eco-friendly and efficient approach to waste management along with sustainable energy generation, encouraging ecological balance, environmental consciousness, renewable sustainability, and cleaner communities.

Keywords: Waste segregation, waste to energy, Arduino UNO R4, Seebeck effect, thermoelectric generation

INTRODUCTION

Rapid urban growth has led to a significant rise in non-biodegradable waste, posing major environmental concerns and demanding smarter waste management approaches. This project introduces an automated waste segregation and energy generation system built around the Arduino UNO R4.

It employs a combination of sensors, such as proximity, infrared, moisture, temperature, and weight sensors, to identify and sort waste into categories such as dry, wet, and metallic. Based on the data collected, actuators, including servo and stepper motors, guide the waste into designated compartments, enabling efficient and sustainable handling.

Dry waste is directed into a combustion chamber, where it is incinerated in a controlled environment to produce heat. This thermal energy is then converted into electrical energy using a thermoelectric generator (TEG) that operates on the Seebeck effect and generates voltage from a temperature gradient. The electricity produced was used to power a 4V DC indicator bulb. A K-type thermocouple continuously measured the temperature to ensure safe and stable operation. The generated electrical output is then conditioned, stored in a lead-acid battery, and regulated through a DC-DC converter for efficient use. The system is

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equipped with an exhaust and filtration unit designed to minimize the release of harmful pollutants into the environment. Organic (wet) waste is routed toward biogas generation, and metallic waste is isolated for recycling. It also features real-time monitoring through mobile connectivity, allowing users to track the system performance. A battery backup was included to maintain uninterrupted operation. Overall, the design combines automation, energy recovery, and emission control to offer a practical and sustainable approach to modern waste management.

PRESENT THEORIES AND PRACTICES

The development of modern waste management and energy generation systems is based on several established theories and practical approaches presented in existing literature. The theory of renewable energy utilization, emphasizing the need to shift towards sustainable energy sources to reduce environmental impact [1]. Their work highlights the importance of integrating alternative energy generation methods, which supports the concept of converting waste into usable energy in the proposed system for this study. Practical strategies for efficient energy generation and utilization using micro combined heat and power systems [2]. Their work supports the idea of optimizing energy conversion processes, which is relevant to the controlled energy generation approach used in this study. Municipal waste management strategies and waste-to-energy (WTE) technologies explain how proper waste segregation and processing can enhance energy recovery and reduce landfill usage [3, 4]. This justifies the implementation of automated waste segregation in the proposed system. An analysis of electrical energy generation from urban solid waste demonstrated that waste materials can be effectively used as a source of power [5]. This supports the concept of generating electricity from dry waste via combustion.

The practical implementation of waste-to-energy technologies, particularly incineration processes and their role in reducing waste volume while producing heat energy. This aligns with the combustion chamber used in this system [6]. The theory of biomass characterization highlights that dry waste materials possess significant calorific value and can be used as efficient solid fuels. This justifies the use of dry waste for heat generation in project [7].

The use of bio-briquettes as alternative fuels, demonstrating that waste materials can be converted into energy-efficient fuel forms [8]. This supports the concept of utilizing waste as a sustainable energy source A detailed numerical and experimental analysis of thermos-fluidic and low temperature-difference energy systems, focusing on the efficient conversion of thermal energy into usable power [9]. Their study demonstrates that even a small temperature gradient can be utilized effectively for energy generation using advanced thermal systems. The research highlights the importance of maintaining a proper temperature difference and heat flow for achieving better efficiency. This concept is directly applicable to the proposed system, where a thermoelectric generator (TEG) utilizes the temperature difference between the hot combustion chamber and the cooled surface to generate electrical energy based on the Seebeck Effect. A comprehensive analysis of integrated waste treatment systems, focusing on environmental, energy, and economic aspects [10]. Their study emphasized that combining different waste processing methods, such as waste segregation, energy recovery, and emission control, leads to improved system efficiency and reduced environmental impact. The paper also highlights the importance of minimizing harmful emissions such as CO_2 and optimizing resource utilization. This supports the design of the proposed system, which integrates waste segregation, energy generation, and pollution control mechanisms to ensure a more sustainable and environmentally friendly approach to waste management.

Problem Statement

The increasing generation of non-degradable waste due to rapid urbanization has become a major environmental concern, leading to pollution and inefficient resource utilization. Traditional waste management systems lack proper segregation at the source, making recycling and disposal processes less effective. A significant portion of dry waste, which has potential for energy generation, is not utilized efficiently. Additionally, existing systems do not provide real time monitoring or automation, resulting in reduce efficiency and safety issues. This project aims to develop a smart solution that combines waste segregation, energy generation, and environmental protection.

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Methodology

The proposed system, as shown in Figure 1, is designed to perform automatic waste segregation, processing, and energy generation using an Arduino UNO R4 and multiple sensors.

Waste enters the system through an inlet, where a proximity sensor detects metal and wet waste is detected by using IR drop sensor the sensors to sort it into dry, wet, or metal categories, while a weight sensor records its quantity. Based on these readings, the servo or stepper motors guide the waste into the appropriate sections. Dry waste is moved to a combustion chamber, where it is burned in a controlled manner to produce heat, with a K-type thermocouple continuously tracking the temperature for safe and efficient functioning.

The heat produced is converted into electrical energy using a thermoelectric generator (TEG) that operates on the Seebeck effect. This energy is then conditioned, regulated through a DC-DC converter, and stored in a lead-acid battery for backup use. A 4V DC LED bulb was powered to indicate successful energy generation. At the same time, wet waste is sent for biogas production, and metal waste is separated for recycling. The system also features an exhaust setup with cooling and filtration to limit harmful emissions, along with mobile-based monitoring for real-time data, such as temperature and system status. Any ash produced is collected for safe disposal, thereby ensuring minimal environmental impact.

RESULT AND DISCUSSION

Result-1

In the first experiment, the initial mass of dry waste was 0.25 kg, and after combustion, the remaining ash weighed 0.05 kg. This indicates that 0.20 kg of waste was effectively consumed during the process. The total time taken for combustion was 20 minutes, resulting in a burning rate of 0.01 kg per minute. The waste segregation efficiency was observed to be 88%, indicating reliable performance of the sensor-based sorting mechanism. During operation, the temperature reached approximately 180°C, while the surrounding humidity was recorded at 60% RH. Figure 2 illustrates the real-time data after waste burning.

The performance of the proposed waste-to-energy system is evaluated based on waste consumption, burning rate, efficiency, and thermal conditions during operation.

$$W_{initial}=0.25 \text{ kg}$$

$$W_{final}=0.05 \text{ kg}$$

$$Wc_{onsumed}=W_{initial}-W_{final}$$

$$W_{consumed}=0.25-0.05=0.20\text{kg}$$



Figure 1. Actual experimental setup.

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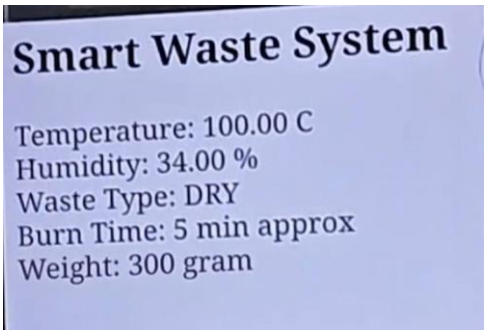


Figure 2. Real time data after burning the waste.

T=20min

BR= $\frac{\text{Wconsumed}}{T}$

BR=$\frac{0.20}{20}$=0.01kg/min

η=88%

Temperature=180°C

H=60%RH

The above results indicate that the system achieves efficient combustion of dry waste with a stable burning rate. The temperature obtained is sufficient to create a temperature gradient across the thermoelectric generator, enabling successful energy conversion as indicated by the illumination of a 4V DC LED bulb. The efficiency of segregation confirms the proper functioning of the sensor-based classification system.

Result 2-

The second observation evaluated the system under slightly different operating conditions. The initial weight of the dry waste was 0.30 kg, and after combustion, the remaining ash weighed 0.06 kg, indicating that 0.24 kg of waste was effectively consumed. The combustion process took 25 minutes, resulting in a burning rate of 0.0096 kg per minute. The segregation efficiency improved to 90%, reflecting a better accuracy in waste classification. During operation, the temperature reached 200°C, and the humidity level was recorded at 55% RH.

$W_{initial}$=0.30kg

W_{final}=0.06kg

$Wc_{onsumed}=W_{initial}-W_{final}$

$W_{consumed}$=0.30−0.06=0.24kg

T=25min

BR= $\frac{\text{Wconsumed}}{\text{T}}$

BR=$\frac{0.24}{25}$=0.0096kg/min

η=90%

Temperature=200∘C

H=55%RH

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In this case, a slightly higher temperature resulted in improved thermoelectric performance owing to the increased temperature difference, which enhanced voltage generation based on the Seebeck Effect. The marginal variation in burning rate is due to differences in waste composition and moisture content. A higher segregation efficiency indicates reliable sensor accuracy and improved system performance.

CONCLUSION

The primary objective of this study was to develop a reliable device that enhances vehicle safety by preventing accidents and damage caused by brake switch failures. By providing clear indications of the operational status of the brake switch, this system aims to significantly reduce the risk of accidents in two-wheelers, including trains and boats. The experimental results indicate that the rear drum brake exhibits superior performance, with a maximum brake force of 395.565 kgf and a torque of 51.42 kgf-m, compared to the front drum brake's 270.234 kgf force and 35.13 kgf-m torque. This emphasizes the importance of the rear braking system in emergency situations, where effective braking is crucial for maintaining the stability and safety of the vehicle.

Declaration of Interest

All authors declare that there are no conflicts of interest regarding the publication of this paper.

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