AI Enabled Smart Waste-To-Energy and Carbon Recovery System

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***Abstract*—As plastic and other combustible waste continues to increase, methods to effectively dispose of it must be found that reduce environmental impact and extract useful materials. Conventional disposal methods result in wasted energy and uncontrolled burning can lead to harmful emissions. This project details the design and development of an AI enabled waste-to-energy and carbon capture prototype. The prototype converts heat energy from burning waste into electrical energy whilst monitoring key parameters throughout the process.**

The prototype consists of a combustion chamber, exhaust system, TEG and heat sink, filter, and a Raspberry Pi 3 Model B+ for monitoring. The filter is made with stainless steel mesh and HEPA filters. Throughout the operation temperature and other sensor data will be recorded. A python programme will be used with the linear regression model to analyse the data. This will help understand how the conditions affect energy capture and provide a basis for more intelligent waste treatments. This experiment combines heat energy capturing, monitoring and data analysis. The results of the experiment must be analysed based on the temperature, voltage, filtering and operation data. More testing needs to be done to see how much energy is being produced and how effective it is at controlling pollution. It will also determine if it is viable for carbon capture.

***Index Terms*—Waste to Energy, Thermoelectric Generator, Raspberry Pi, Artificial Intelligence, Linear Regression, Heat Recovery, Waste Management.**

I. INTRODUCTION

Managing waste can cause many problems for the environment. This is due to proper handling being required. Managing plastic waste can be very difficult due to different characteristics depending on the composition and how it is disposed of. However, waste can be recycled or reused. There are methods to utilize the waste to gain energy from it.

Waste to energy technologies aim to convert waste into usable forms of energy. Thermal processes can generate heat which could then be converted into electricity. Thermoelectric generators can be employed to aid in capturing this heat, converting the temperature into usable electricity. As there are no moving parts within these, they are useful to study low power applications [1] [2].

A small-scale waste to energy system needs more than just electrical output. It needs to consider the temperature, the burning process, the exhaust route, the filtering system and the safety. If the system generates electricity but doesn't properly treat the exhaust the overall system won't be satisfactory. If the sensors and controller in the prototype work correctly it should not be deemed successful.

This project aims to create a smart waste to energy and carbon recovery system using artificial intelligence. A small-scale thermal system will be created with electronic monitoring. Thermoelectric generators will be used to study the conversion of heat to electricity. The raspberry pi 3 model B+ will be used to support the software.

Stainless steel mesh and HEPA media will be used as part of the exhaust filtering system.

This project will also look into using linear regression to analyse relationships between chosen sensor data and a chosen operating parameter. This will be a computer-based aspect to aid in observing the data.

Overall, the aim of the project is to create a prototype that integrates waste handling, thermal energy recovery, monitoring and filtering. Testing the prototype will show what can currently be achieved and where improvements can be made.

II. LITERATURE REVIEW

A. Thermoelectric Energy Recovery

Thermoelectric generators use the Seebeck effect to generate electrical energy from a temperature gradient. When a temperature difference is applied across the two sides of thermoelectric modules an electric potential will be generated. The output can be dependent upon several factors including temperature gradient, module properties, thermal coupling, electrical load and heat transfer.

Aridi et al. [1] looked into thermoelectric power generation using thermoelectric generators, heat recovery and issues encountered. Jaldurgam et al. [2] looked at the different structures and geometries of thermoelectric generators. This gives an understanding of the technology behind thermoelectric generators to look into energy recovery in a compact prototype.

The TEG will be used in the thermal energy recovery section of the system. The TEG will have a heat sink to aid dissipation of heat on the correct side. The amount of electrical power the TEG will produce will need to be measured experimentally.

B. Waste Heat Recovery

There will always be waste heat within a variety of industrial and thermal processes. However, only some of this can be used to create useful electrical power. Ochieng et al. [3] looked at different thermoelectric generators for waste heat recovery within various energy consuming processes. This shows the potential of thermoelectric generators; however, they are reliant on the heat source and design of the system.

Due to the small scale of the prototype, there will be heat loss, low temperature gradients and varying conditions which may cause lower output of electrical power. This means that voltage will have to be measured and to gain an understanding of the useful power created, the voltage and current should be measured under an electrical load.

C. Waste Treatment and Carbon Recovery

There are many different technologies that can be used to treat waste. When treating waste containing plastic care must be taken when using thermal treatments as the emissions will depend on the waste and conditions. The filtration system should be analyzed by measuring the correct parameters.

Research has been done into creating carbon-based materials from waste plastics [4]. However, recovering carbon will normally need to be controlled and the material characterized. Just because there is soot or a dark residue present doesn't mean useful carbon or activated carbon has been recovered.

Carbon recovery is a general aim of this project. To state that carbon has been recovered, the methods used to recover the carbon should be documented. Mass measurements and correct characterization of the material should be carried out.

D. Sensor Monitoring

A microcomputer can be used to monitor sensor values. This will allow for organization of the experimental data. The Raspberry Pi can be used to run Python programs and process data from the correct sensors and interface circuitry [5].

Linear regression is a supervised learning algorithm that can be used to predict numerical targets. Within this system, this can be used to analyse the relationship between certain sensor values and a parameter. The usefulness of this depends on the quality of the training data, what the target variable is and analysis using data that wasn't used for training.

Having a regression will not automatically make the system autonomous or show that it has improved safety. This will need to be tested.

III. RESEARCH GAP

From the literature review, there is knowledge in thermoelectric power generation, waste heat recovery, carbon-based materials and electronic monitoring. However, putting this all together within a compact student-built prototype can introduce issues.

The electrical output from a small TEG will rely greatly on the thermal conditions. The sensor values will need to be logged and analyzed to understand how the system is behaving. The presence of a filter does not show that the exhaust has been treated correctly without the correct tests being carried out. To recover useful carbon-based material there needs to be evidence.

This project looks at overcoming these issues at the prototype development stage by putting together a thermal system, thermoelectric energy recovery, sensor monitoring, Raspberry Pi and mesh/HEPA filtration system. This project contributes by putting

all of this together and analyzing it experimentally. The improvement that this project makes over existing systems needs to be shown by measuring the results and comparing to the correct methods.

IV. PROPOSED WORK

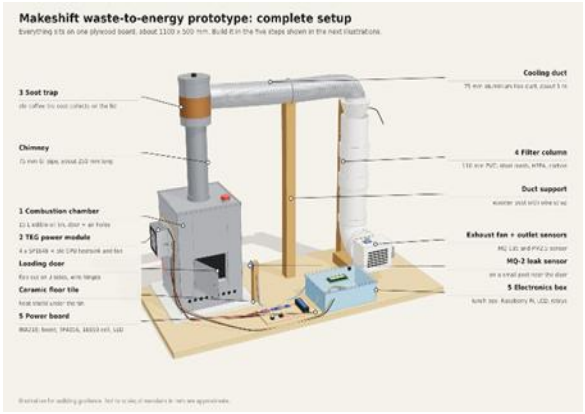
The aim of this project is to create an AI enabled Smart Waste to Energy and Carbon Recovery Prototype. This will utilize methods of Thermal Energy Recovery by converting the heat produced during waste processing.
This system will also utilize sensors and data analysis to observe how effective this is an oil can will be used to create a combustion chamber. An exhaust pipe (metal pipe) will be used. A filtration system will be created using a stainless-steel mesh and HEPA filter. This will need to be tested to see how effective the filtration system is.

A Thermoelectric Generator (TEG) will be included to help observe if the heat can be converted into electricity. Voltage and Current measurements will be taken to observe how effective this is. A heat sink will be used to help dissipate heat.

A Raspberry Pi 3 Model B+ will be used to process sensor data. This will store the results from the experiment using Python. The sensors will be set up to observe certain conditions. This data can be analyzed. A Linear Regression model will be included to observe the relationship between certain sensor data and a numerical output. This will be tested using data collected to see how well it performs. The monitoring system can display the data collected and any alerts using the display and buzzer.

The system will be tested to see how much electricity is produced, how consistent the data from the sensors is and how effective the filtration is. Carbon Recovery can be considered an aim so will need to have a process to recover the carbon and characterize the material.

This project will create a system to observe how waste can be converted into energy, monitored using computation and possibly recover resources. Further testing and improvements will need to be done to see how efficient this is.



V. OBJECTIVES

1. To produce a prototype to explore energy recovery from thermal waste.
2. To include a thermoelectric generator and heat sink into the thermal system.
3. Use a Raspberry Pi 3 Model B+ to process data from sensors.
4. Record appropriate parameters and look at relationship between them and energy production.
5. Implement a linear regression model to solve a clear numerical problem.
6. Include a stainless-steel mesh and HEPA filter into the exhaust.
7. Research into future development objective of carbon recovery.
8. Identify any technical limitations, safety requirements and improvements for further testing.

VI. BLOCK DIAGRAM

The block diagram shows how the AI Enabled Smart Waste to Energy and Carbon Recovery System works. The waste will enter the combustion chamber (oil can). The heat produced will be observed to see how much energy can be recovered using a thermoelectric generator (TEG). The exhaust gases will pass through the exhaust pipe (metal pipe) and filtration system (stainless steel mesh and HEPA filter). The filtered exhaust will then be passed towards the outlet. The monitoring system will include a voltage measurement, DS18B20 Temperature Sensor and Gas Sensor (MQ-2/MQ-135). This will measure the electricity produced, temperature and gas conditions. The data will be sent to the Raspberry Pi 3 Model B+

to be processed. The data will then be analyzed using a linear regression to predict a numerical output. The analysis and predictions can be displayed on the LCD Display. Alarms can be given using the buzzer if the conditions for the alarm are met.

Overall, this block diagram shows how the waste can be processed, monitored for thermal energy, filtered and analyzed. The filtration, electricity recovery and carbon recovery will need to be tested to see how effective they are.

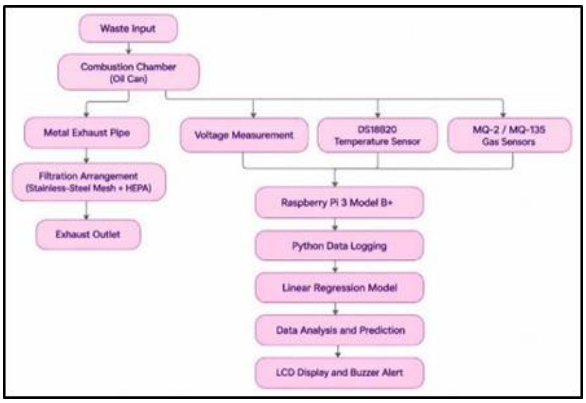


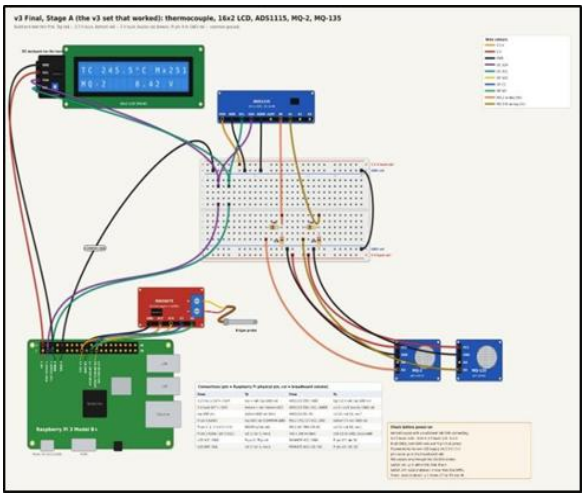
Fig 1. Block Diagram of Proposed System

VII. HARDWARE CIRCUIT DESIGN

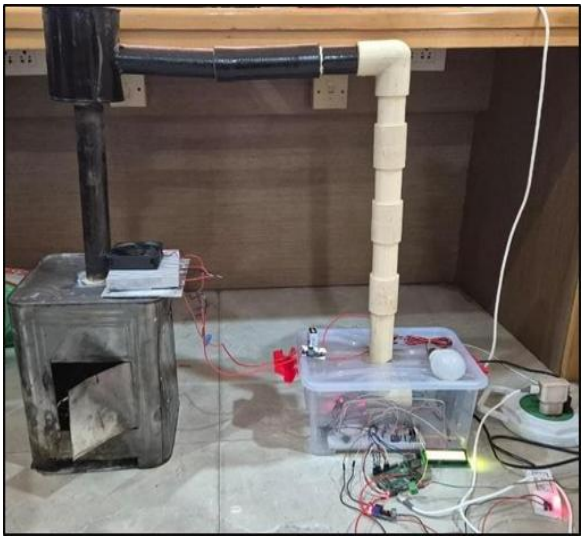
The diagram shows the circuit setup for the sensor monitoring and data collection part of the proposed AI-enabled smart waste to energy and carbon recovery system.

The Raspberry Pi 3 Model B+ is used as the main processing unit and connects to the MAX6675 thermocouple module, MQ-2 and MQ-135 gas sensors, ADS1115 ADC and 16x2 LCD display. The K type thermocouple provides temperature data and the MAX6675 converts the signal to a digital data that is then sent to the Raspberry Pi. The MQ-2 and MQ-135 sensors provide gas related data where the analogue data is converted to a digital value using the ADS1115.

The LCD connects to the Raspberry Pi via an I2C backpack to show chosen data from the sensors and system information. The Raspberry Pi uses Python to process the data collected. Data can be logged and input into the linear regression model for further analysis. The circuit has 3.3V and 5V power rails with a shared ground. Correct voltage regulation and connections are crucial to ensure the Raspberry Pi works correctly and isn't damaged by electricity.



VIII. RESULT



TEG record sheet (one per run)

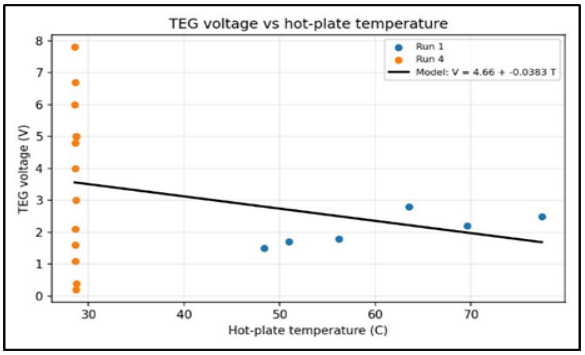
Run no.	1,2,3
Plastic mass (g)	20,50,70

Minute(Run1)	TEG voltage (V)	LED glowing? (Y / N)
1	1.5	N
2	1.7	N
3	2.8	N
4	2.5	N
5	2.2	N
6	1.8	N
7	1.7	N
8	1.2	N
9	1.0	N
10	0.9	N

Minute(Run2)	TEG voltage (V)	LED glowing? (Y / N)
1	0.4	N
2	0.9	N
3	1.5	N
4	5.5	N
5	7.7	Y
6	7.6	Y
7	7.8	Y
8	7.1	Y
9	6.5	N
10	6	N

Minute(Run3)	TEG voltage (V)	LED glowing? (Y / N)
1	0.2	N
2	0.4	N
3	1.1	N
4	1.6	N
5	2.1	N
6	4.8	N
7	5.0	N
8	7.8	Y
9	6.7	N
10	6.0	N

Fig 2. TEG Readings



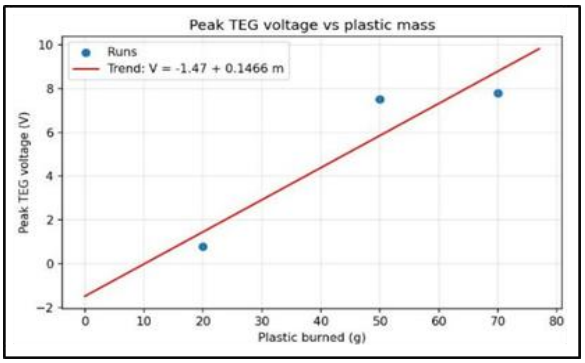


Fig 3. Graphs

IX. EXPECTED OUTCOMES

- Demonstrating how the thermoelectric energy recovery system works.
- Temperature and electrical data can be recorded and analyzed.
- A Raspberry Pi can be implemented to monitor the sensors.
- A linear regression model can be used to predict numerical data.
- The mesh and HEPA filter system can be investigated experimentally.

X. ADVANTAGES

- Thermal energy recovery can be investigated as well as monitored and filtered.
- A TEG can be used to investigate low power energy generation.
- The Raspberry Pi and Python can be programmed to collect the data.
- The data can be analyzed to investigate correlations between operational parameters and numerical data.
- Further sensors can be added, thermal interface can be improved and more advanced data analysis methods can be added in future versions.
- The prototype connects multiple topics such as electronics, thermal systems, embedded systems and machine learning.

XI. APPLICATION

- Educational purposes with demonstrating thermoelectric energy conversion.
- Investigate low power waste heat recovery.
- Monitor small thermal processes using sensors.
- Investigate data analysis of operational parameters.
- Create a prototype for a waste treatment and resource recovery system.

XII. LIMITATIONS

- The TEG would generally produce a low amount of power. The power depends on the temperature difference, thermal resistance and the load.
- Sensor accuracy and data will impact how reliable the monitoring and regression model will be.
- The stainless-steel mesh and HEPA filter media do not demonstrate that all hazardous components in the combustion exhaust can be controlled. The gaseous pollutants, temperature of the filter, airflow

and handling of the exhaust must be controlled appropriately.

- The linear regression model can only be used to predict numerical data for the specific prediction. It will not automatically provide intelligent control or anomaly detection.

XIII. FUTURE SCOPE

- AI Waste Recognition: Computer vision and Machine Learning can be used to identify waste types.
- Increased Energy Generation: Using advanced AI algorithms, optimal conditions can be found and electricity prediction can be made.
- Carbon Capture: Future versions can look into capturing carbon rich gases, and capturing useful carbon-based materials.
- Gas Monitoring: More gas sensors and particulate sensors can be added for monitoring air quality and checking if there are any anomalies in the emissions.
- Internet of Things + Cloud: The system can be connected to cloud so it can be remotely monitored. This can also give real time notifications and data analysis from previous data.
- Scaled Up System: The prototype can be developed into a larger system that can be used in institutions, residential areas, industries and waste management.
- Sustainability: Further research can be carried out to see how energy efficient the system is, how much it will cost to run, how much carbon emissions it produces and if it is viable to recover materials that can be reused.

XIV. CONCLUSION

The design and development of a smart AI based waste to energy and carbon capture system has been presented. The system consists of a combustion chamber, exhaust system, thermoelectric generator, heat sink, stainless steel mesh, HEPA filter media and a Raspberry Pi 3 Model B+. The system also contains a linear regression model to show the numerical relationship between chosen variables and a target variable.

The system can provide a foundation to understand energy recovery and sensor analysis in a small-scale system. However, the system must be tested to prove the effectiveness using measurements such as voltage, current, temperature, model evaluation and appropriate filtration. Carbon capture must also be proven by following a specific process and material analysis.

This project is a prototype investigation. Further testing and engineering must be done to prove how effective the system will be in terms of energy, environmental impact, safety and potential for real world application.

REFERENCES

[1] R. Aridi et al., “Thermoelectric power generators: State-of-the-art, heat recovery method, and challenges,” *Electricity*, vol. 2, no. 3, pp. 359–386, 2021, doi: 10.3390/electricity2030022.

[2] Z. Jaldurgam et al., “A systematic review of structures and geometries of the thermoelectric generators,” *Applied Research*, vol. 2, no. 2, Art. no. e202200074, 2023, doi: 10.1002/appl.202200074.

[3] A. O. Ochieng et al., “Comprehensive review in waste heat recovery in different thermal energy-consuming processes using thermoelectric generators for electrical power generation,” *Process Safety and Environmental Protection*, vol. 162, pp. 134–154, 2022, doi: 10.1016/j.psep.2022.03.070.

[4] R. Bhattacharya, “A review on production and application of activated carbon from discarded plastics in the context of ‘waste treats waste’,” *Journal of Environmental Management*, vol. 325, Part B, Art. no. 116613, 2023, doi: 10.1016/j.jenvman.2022.116613.

[5] Raspberry Pi Ltd., “Raspberry Pi documentation.” [Online]. Available: https://www.raspberrypi.com/documentation/

[6] Scikit-learn Developers, “Linear models: Ordinary least squares,” *scikit-learn Documentation*. [Online]. Available: https://scikit-learn.org/stable/modules/linear_model.html