

Design And Development of Hybrid Diesel Electric Tractor

Sarthak Gosavi

Department of Mechanical Engineering
Vishwakarma institute of technology, Pune, India

Dr. Sampada Dravid

Department of Mechanical Engineering
Vishwakarma Institute of Technology,
Pune, India

Honrao

Department of Mechanical Engineering
Vishwakarma institute of technology, Pune, India

Harsh Shirole

Department of Mechanical Engineering
Vishwakarma Institute of Technology,
Pune, India

Abstract - Agricultural tractors use large quantities of diesel fuel in field operations. In conventional diesel engines, approximately 30-40% of the total energy generated during combustion is lost as heat in the exhaust gases. This waste heat energy is usually dissipated into the atmosphere and is not put to any use

The present work proposes the design and development of a Hybrid Diesel-Electric Tractor integrated with a Thermoelectric Generator (TEG) based Exhaust Heat Recovery System (EHRS). The thermoelectric generator utilizes the Seebeck effect to convert exhaust heat energy directly into electrical energy. The electricity produced is stored in a rechargeable battery pack and used later to power an electric motor connected to the tractor transmission system.

The diesel engine is the prime mover for heavy agricultural operations such as ploughing, cultivation, rotavation, etc., and the thermoelectric generator continuously charges the battery with the waste heat of the exhaust. The tractor can work in the electric mode by using the stored energy of the battery during the road transportation and light load conditions.

The suggested system enhances fuel efficiency, reduces diesel consumption, controls harmful emissions and makes optimum use of waste heat. The project is aimed to provide a sustainable and energy efficient solution for future agricultural vehicles.

I. INTRODUCTION

Agriculture is the backbone of the economic development of developing countries like India. Tractors and mechanized farming equipment have become an integral part of modern agriculture to enhance productivity and to minimize human efforts. Tractors are widely used for ploughing, tilling, harvesting, transportation, spraying, cultivation and other farm operations.

The vast majority of modern agricultural tractors use a compression-ignition diesel engine. Diesel engines are used

because of their high torque, good fuel economy and reliable operation under heavy load conditions. The diesel engines have such advantages, but their thermal efficiency is poor. Only a very small fraction of the chemical energy in the fuel is used to do useful mechanical work.

The major energy losses incurred during the process of combustion include:

- Heat losses in exhaust gases
- Heat losses in cooling water
- Heat losses due to friction
- Heat losses by radiation

Of all the above-listed energy losses, one of the most important energy losses occurs in the form of exhaust gases. Investigations reveal that around 30 to 40 percent of the total energy contained in the fuel entering diesel engines escapes through exhaust gases. The temperature of the exhaust gases exiting from tractor engines ranges from 300°C to 500°C.

Such heat from the exhaust gas is normally wasted into the environment, and therefore, leads to lower efficiency of the engine and increased fuel consumption. The conversion of such wasted energy to produce some usable form of energy will increase the fuel efficiency and lower environmental pollution.

In this project, we have designed an Exhaust Heat Recovery system for a Hybrid Diesel-Electric Tractor using a Thermoelectric Generator (TEG). Thermoelectric generator is an electronic device which converts heat energy to electricity using Seebeck effect.

In the proposed design, the TEG modules will be fitted on the exhaust pipe of the tractor's engine. The hot side of the TEG modules will absorb the heat of the exhaust gases, whereas the other side will be cooled using heat sinks and air-cooling systems. As a result of the difference in temperatures on both sides, the modules generate electricity.

The electrical energy produced by the TEG modules will be used to charge the rechargeable battery pack, which will then provide energy to an electric motor attached to the tractor transmission system. In this way, the tractor will become a hybrid diesel-electric car.

The tractor will run in two modes, namely:

I. Diesel Mode

In ploughing, rotavation, and cultivation applications when heavy torque and power are needed, the diesel engine becomes the main power source.

II. Electric Mode

For transportation and low load applications, the tractor will run on electric energy provided by the battery pack. In this case, the electric motor will drive the tractor wheels.

Some advantages of the proposed system include:

- High fuel efficiency
- Low diesel fuel consumption
- Low exhaust emission
- Efficient energy usage
- Lower running cost
- Environmentally friendly operation

The goal of this project is to produce an innovative agricultural vehicle that will use waste exhaust heat effectively.

II. LITERATURE REVIEW

The use of hybrid technology in automobiles has become a very significant area of study owing to rising fuel costs, depletion of fuel resources, and the environmental pollution associated with internal combustion engines. Researchers in the recent past have been looking into ways of increasing efficiency and reducing exhaust gases emitted by automobiles and farm tractors. Farm tractors use considerable amounts of diesel fuel for their activities, and most of the energy in the form of exhaust gas goes to waste.

Various research studies have revealed that almost 30–40% of the energy produced by diesel engines is wasted via exhaust gases. The temperature of exhaust gases in tractor engines varies between 300°C and 500°C according to the loading and working conditions of the engine. Several techniques for the recovery of waste heat have been investigated, including turbo-compounding systems, Organic Rankine Cycle systems, heat

exchangers, and thermoelectric generators. Among all these approaches, thermoelectric generators can be said to be more appropriate for small and medium-sized vehicles due to their compact size, reliability, light weight, and minimum maintenance requirements.

The thermoelectric generator works on the principle of the Seebeck effect whereby electricity is produced due to the temperature difference across two ends of semiconductor material. Several studies have confirmed that the use of thermoelectric generators for conversion of exhaust heat to electrical energy for automobiles and industrial engines is feasible. The results show that sufficient amounts of electrical energy can be produced using thermoelectric generators to charge batteries and auxiliary power. The major benefit of using thermoelectric generators lies in silent operation since the process of conversion of heat to electricity involves no mechanical components.

Studies have also examined hybrid tractor systems, which involve the use of a diesel engine and an electric motor to enhance efficiency in fuel usage. In a hybrid tractor, the diesel engine generates power for agricultural activities while the electric motor contributes when the machine needs to move. Hybrid systems improve fuel consumption and torque. The challenge faced by hybrid technology in tractors lies in battery recharging.

Recent developments in exhaust heat recovery systems have shown that waste heat from diesel engines can be effectively utilized for generating electrical energy. Integrating thermoelectric generators with hybrid tractors can improve overall energy utilization by converting unused exhaust heat into useful electrical power. The generated electrical energy can be stored in batteries and later used to drive electric motors for vehicle propulsion. This approach reduces dependency on diesel fuel and contributes to sustainable agricultural mechanization.

From the literature review, it can be seen that there is very little research regarding the use of hybrid agricultural tractors with thermoelectric generators. Currently, most agricultural tractors are fully dependent on diesel engines, which waste a considerable amount of energy in the form of heat energy from exhaust gases. Hence, the objective of the current study is to design a hybrid diesel/electric tractor by incorporating a thermoelectric generator that will recover exhaust heat energy and charge batteries.

III. PROBLEM STATEMENT

The conventional tractors used for agriculture mainly run on diesel engines. Despite the fact that diesel engines give adequate power and performance, these engines have low efficiency rates due to their tendency to generate excessive amounts of heat in the process of operation. The majority of fuel energy provided to an engine turns out to be lost during exhaust, heat dissipation, and friction.

Of all those losses, exhaust gases include some quantity of thermal energy which is discharged into the environment without any further utilization whatsoever. This leads to the poor use of energy resources and higher fuel expenditures. Moreover, regular exploitation of diesel engine powered tractors causes atmospheric pollution by gases like carbon dioxide, nitrogen oxides, hydrocarbons, and particulates.

Since the usage of a tractor in agriculture will be of long duration under varied loading conditions, there will be an increase in both fuel costs and the cost incurred in operating a farm. In today's world, the increased fuel prices, along with the environmental issue, create the need for finding solutions that would be beneficial for agriculture purposes.

Currently, there is no use of the exhaust gases in tractors for any productive purpose. Hence, the creation of a system that can efficiently utilize the wasted exhaust gases through conversion of their heat energy into electrical energy becomes necessary.

The current project deals with this issue through the development of an Exhaust Heat Recovery System using a Thermoelectric Generator incorporated in a hybrid diesel-electric tractor.

IV. OBJECTIVE

The primary goal of the proposed project is the design and development of the Hybrid Diesel-Electric Tractor, which incorporates a Thermoelectric Generator-based Exhaust Heat Recovery System to increase energy efficiency and decrease diesel fuel usage in agriculture.

This research project will attempt to utilize the waste heat energy contained in the exhaust gas emissions produced by a tractor engine and convert it into usable electrical energy using the thermoelectric generators. Conventional diesel engines emit vast amounts of thermal energy through the exhaust gases, which this research project will capitalize on rather than waste.

One of the other goals of this project is to recharge the battery pack with the generated electricity from the exhaust gas heat recovery process and use it to power the electric motor, which drives the transmission mechanism of the tractor. The tractor will run on electric power in transit mode and low-load applications.

Another important objective of the project is to charge the battery pack using the electricity generated from exhaust heat recovery. The stored electrical energy can then be used to operate an electric motor connected to the tractor transmission system. This enables the tractor to operate in electric mode during transportation and light-load conditions.

Finally, this project aims to lower the usage of diesel fuel and minimize operational costs. The hybrid tractor can run partly on electric power, reducing dependence on diesel fuel.

The lowering of diesel usage is associated with a drop in harmful exhaust gases like carbon monoxide, nitrogen oxide, and particulate matter.

The project will also ensure that the tractor's thermal efficiency is improved through utilization of wasted heat energy. An eco-friendly and sustainable agricultural vehicle for today's farming practices is another key focus area of this project.

Project objectives include but not limited to the following:

- To harvest heat energy wasted in exhaust gases.
- To produce electricity using thermoelectric generators.
- To integrate a diesel-electric tractor system.
- To harness heat energy and use it to charge batteries.
- To reduce diesel fuel usage.
- To decrease harmful exhaust gas production.
- To improve the efficiency of the tractor engine.
- To design an eco-friendly and sustainable farming vehicle.

V. METHODOLOGY

Methodology used in the current research project revolves around the design and development of a Hybrid Diesel-Electric Tractor fitted with Thermoelectric Generator (TEG) Based Exhaust Heat Recovery System (EHRS). The main goal of the methodology is the collection of waste heat energy from exhaust gases of tractor engine and conversion into electrical energy. The methodology consists of analysis, selection of components, thermal energy recovery, electrical energy production and integration with hybrid system.

Firstly, an extensive analysis of conventional tractor engines was done in order to understand various factors related to engine working condition, exhaust gas composition, amount of fuel consumed by engine and thermal energy losses. An analysis of temperature range in which tractor engine exhaust gases operate was done. It was found that temperatures vary from about 300°C to 500°C when the tractor operates in fields.

After analyzing the exhaust heat characteristics, suitable thermoelectric generator modules were selected based on important parameters such as operating temperature range, Seebeck coefficient, electrical output characteristics, thermal stability, compactness, and efficiency. Bismuth Telluride thermoelectric modules seemed to be the most appropriate choice for this type of application due to their superior performance at the desired temperature range.

Design of the exhaust heat recovery system involved installation of thermoelectric generator modules over the exhaust pipe surface. While one side of the TEG would come into direct contact with the exhaust heat source, another one would be fitted with cooling fins and heat sink. Proper thermal contact materials were evaluated in order to maximize heat

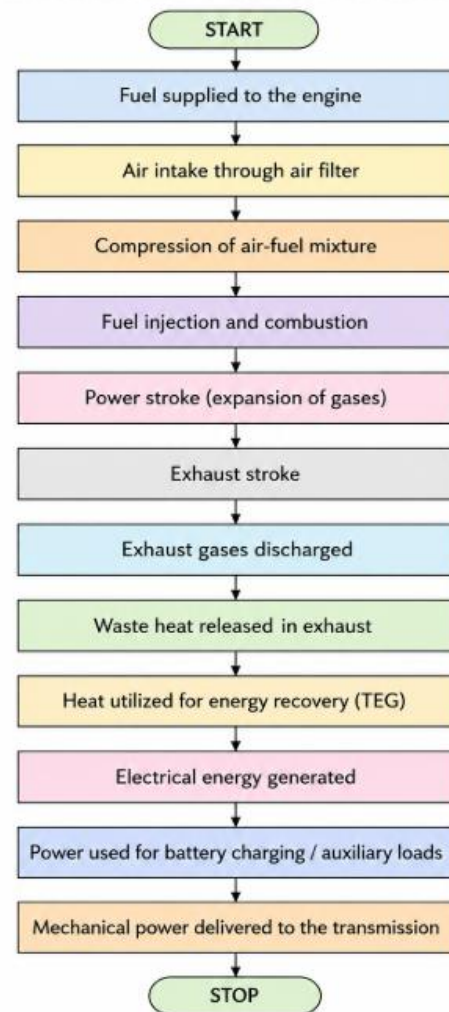
transfer between the exhaust pipe and the thermoelectric module surface.

Electric energy produced by the thermoelectric modules was examined from the point of view of the Seebeck effect. The electricity produced in this way was used as the input of the battery charging circuit which comprised the voltage regulation and power conditioning unit. A rechargeable battery pack served as the electricity storage device. An electric motor was integrated with the tractor transmission system for propulsion during low-load and transportation conditions. The motor was proposed to be mounted on the transmission shaft so that the existing drivetrain configuration of the tractor could be utilized without major structural modifications. The hybrid arrangement enables dual operating modes consisting of diesel mode and electric mode.

The diesel engine serves as the main power source during intensive farming operations including ploughing, cultivation, and rotavation as high torque is necessary. At the same time, exhaust heat recovery and electrical energy generation are constantly taking place in order to charge the battery. When the tractor is moving, light load operation, the electric motor uses the energy stored in the batteries to run the machine. In this way, fuel and exhaust emission reduction is achieved.

Performance of the entire system was analyzed theoretically with the help of calculations. Temperature difference between thermoelectric generators, electrical power generation, charging current, efficiency, and charging time were calculated. Efficiency of the energy conversion from thermal to electrical energy in the thermoelectric generator system was also estimated to ensure that the hybrid tractor is feasible.

PROCESS FLOW CHART OF ENGINE



VI. PROPOSED SYSTEM

Proposed hybrid diesel–electric vehicle is represented by the Hybrid Diesel–Electric Tractor equipped with the Thermoelectric Generator based Exhaust Heat Recovery System that allows converting waste exhaust gas energy into electricity and using it for battery charging and electric propulsion.

As per the proposed system, the thermoelectric generator modules are attached to the exhaust pipe of the diesel engine in the tractor. As the diesel engine works, high-temperature exhaust gases are emitted out of the engine through the exhaust pipe. The hot end of the generator module captures heat from the exhaust gases whereas the cold end is kept cool with the help of fins/heat sink.

Due to the temperature difference, the thermoelectric generator produces voltage which is then used for charging the battery using battery charging circuit.

Electrical energy from the battery pack is supplied to the electric motor, which is attached to the transmission system of the tractor. In the case of light loads, the electric motor rotates the wheels of the tractor. Thus, the operation of the tractor becomes purely electric.

The proposed system includes the following key parts:

- Diesel Engine
- System of Exhaust Heat Recovery
- Temperature Difference Generator
- Battery Pack
- Electric Motor
- Controller/Inverter
- Tractor Transmission System
- Cooling System

The diesel engine serves as a power source when working on heavy agricultural activities like ploughing, cultivation, and rotavation. At the same time, the recovery of exhaust heat occurs and the battery is recharged.

In the case of road transport of the machine, the work can be performed by electricity from the battery pack in full or partial amount. It results in reduced fuel consumption.

The proposed system is a modern innovative solution for agriculture.

VII. COMPONENTS USED

1. Diesel Engine

Diesel engines serve as the primary sources of energy in agricultural applications.

Roles:

- Powered the tractor during cultivation
- Exhaust gases generation
- Energy supply to TEG

2. Thermoelectric Generator

Thermoelectric generators use exhaust heat energy to generate electricity.

Mechanism:

- Thermal energy transfer from exhaust gases to hot TEG side.
- Heat dissipation through cold side to the environment.
- Generation of electrical potential due to the temperature difference.

3. Battery Pack

- Batteries provide storage of electricity produced by TEG.
- Roles:
 - Energy storage in the form of electricity
 - Energy source for electric motors
 - Enables electric mode of operation
- Types of Batteries:

1. Lithium-Ion Battery
2. Lead-Acid Battery

4. Electric Motor

The electric motor propels the vehicle when running on electric mode.

Mounting options:

- Transaxle shaft
- Drive axle
- Hub

Desired mounting option:

- Driven by transaxle shaft

5. Controller/Inverter

The controller manages electricity transfer between:

- TEG modules
- Battery
- Electric motor

Functions:

- Battery charging regulation
- Electric motor speed control
- Power distribution

6. Heat Sink and Cooling System

A cooling mechanism is necessary to ensure temperature difference among the TEG modules.

Methods of cooling:

- Air cooling
- Water cooling
- Heat sink fins

The proposed system provides an innovative and eco-friendly solution for modern agricultural applications.

VIII. WORKING PRINCIPLES

The principle behind the concept of the Hybrid Diesel–Electric Tractor includes capturing the thermal energy released by exhaust wastes and converting thermal energy into electrical energy using thermoelectric generators.

As the tractor operates, the combustion of fuel in the diesel engine generates hot exhaust gases. The exhaust gases flow out of the exhaust pipe of the tractor. They possess a lot of thermal energy. This energy is dissipated into the environment in traditional tractors.

In the developed system, the thermoelectric generator modules are installed on the exhaust pipe of the engine of the tractor. While the hot part of the TEG module contacts the exhaust gases, the cold part of the module gets cooled by the heat sink.

Because of the temperature difference across both ends of the TEG module, an electric voltage is produced according to the Seebeck effect. The produced electricity is delivered to the charging controller and accumulated in a battery pack.

In case of road transportation and light load, the electric motor attached to the transmission system of the tractor employs battery energy to rotate the wheels of the tractor. As such, the operation of the tractor becomes possible in two modes:

Diesel Mode

In diesel mode, the engine of the tractor delivers the necessary torque and energy for performing agriculture tasks. The process of exhaust heat utilization also occurs in order to charge the batteries.

Electric Mode

In electric mode, the electric motor rotates the tractor through the use of batteries. This mode can be employed when it comes to road transportation and low load conditions. The system increases efficiency by employing waste heat which was previously dissipated into the atmosphere.

IX. DESIGN CALCULATIONS

1. Assumptions and Design Data

The following assumptions are considered for the design and analysis of the thermoelectric generator system:

Parameter	Value
Exhaust gas temperature	400°C
Cold side temperature	50°C
Temperature difference	350°C
Number of TEG modules	20
Power generated by one module	8 W
Battery voltage	48 V
Exhaust heat available	3000 W

These values are selected based on standard tractor engine operating conditions.

2. Calculation of Temperature Difference

The thermoelectric generator works based on temperature difference between the hot side and cold side.

Formula:

$$\Delta T = T_h - T_c$$

Where:

ΔT = Temperature difference T_h = Hot side temperature T_c = Cold side temperature

Substituting values:

$$\Delta T = 400 - 50$$

$$\Delta T = 350^\circ\text{C}$$

Therefore:

Temperature difference across TEG module = 350°C

A large temperature difference improves electrical output from the thermoelectric generator.

3. Voltage Generation Principle

According to the Seebeck effect:

$$V = \alpha (T_h - T_c)$$

Where:

V = Generated voltage α = Seebeck coefficient T_h = Hot side temperature T_c = Cold side temperature

The generated voltage increases with increase in temperature difference.

4. Total Electrical Power Generated

Power generated by one thermoelectric module:

$$P_m = 8 \text{ W}$$

Number of modules used:

$$n = 20$$

Formula:

$$P = n \times P_m$$

Substituting values:

$$P = 20 \times 8$$

$$P = 160 \text{ W}$$

Therefore:

Total electrical power generated = 160 W

This generated electrical power is used for battery charging.

5. Battery Charging Current

The generated electrical energy is stored in a battery pack.

Battery voltage:

$$V = 48 \text{ V}$$

Power generated:

$$P = 160 \text{ W}$$

Formula:

$$I = P / V$$

Substituting values:

$$I = 160 / 48$$

$$I = 3.33 \text{ A}$$

Therefore:

Battery charging current = 3.33 A

6. Energy Generated Per Hour

Electrical energy generated per hour:

$$E = P \times t$$

Where:

E = Energy generated P = Power generated T = Time

Assuming operating time:

$$t = 1 \text{ hour}$$

$$E = 160 \times 1$$

$$E = 160 \text{ Wh}$$

Therefore:

Electrical energy generated in one hour = 160 Wh

7. Battery Charging Time Estimation

Assume battery capacity:

Battery capacity = 48 V, 20 Ah

Battery energy capacity:

$$E = V \times Ah$$

$$E = 48 \times 20$$

$$E = 960 \text{ Wh}$$

Charging time:

Charging time = Battery capacity / Charging power

$$\text{Charging time} = 960 / 160$$

$$\text{Charging time} = 6 \text{ hours}$$

Therefore:

Approximate battery charging time = 6 hours

8. Efficiency Estimation

Assume:

Heat energy available from exhaust gases = 3000 W

Electrical power generated = 160 W

Efficiency formula:

$$\eta = \text{Output} / \text{Input} \times 100$$

$$\eta = 160 / 3000 \times 100$$

$$\eta = 5.33\%$$

Therefore:

Overall thermoelectric conversion efficiency = 5.33%

Although the efficiency is low, the system utilizes waste heat which would otherwise be lost to the atmosphere.

9. Advantages of Waste Heat Recovery

By recovering exhaust heat:

- Fuel energy utilization improves
- Diesel consumption decreases
- Battery charging becomes possible without external charging source
- Tractor can partially operate in electric mode
- Environmental pollution reduces

X. CONCLUSION

The current work effectively provides a suggestion for the design and development of a Hybrid Diesel-Electric Tractor equipped with a Thermoelectric Generator powered Exhaust Heat Recovery system. The objective of the current work is to design a device that is capable of harnessing the heat energy present in exhaust gases emitted by the diesel engine and converting it into electrical energy using thermoelectric generators..

As we know that diesel engines used in conventional diesel tractors waste a lot of their thermal energy through exhaust gases, which leads to inefficient energy utilization and higher fuel consumption. The current system effectively resolves this problem by harvesting some of this heat energy and using it for battery charging and electric traction purposes.

The thermoelectric generator works under the Seebeck effect, which states that electrical voltage is produced as a result of a temperature difference across two sides of the generator module. Electrical energy thus produced is then utilized to charge a battery pack, which can supply this energy to an electric motor driving the tractor's transmission system, which allows the tractor to operate in electric mode while performing transportation tasks and light agricultural tasks.

In this regard, the proposed hybrid system offers enhanced energy efficiency through the utilization of free waste heat, which is otherwise lost to the surrounding environment. Further, the proposed system will help reduce the fuel consumption, operational costs, and exhaust emission associated with diesel engine operation. Lastly, hybrid operation will provide a more quiet and environmentally friendly form of transport as compared to traditional diesel-only tractors.

Through theoretical analysis and design calculations, the viability of the proposed thermoelectric generator system in producing usable electricity for battery charging is evident. Despite having relatively lower conversion efficiency, the system continues to be viable since it produces usable electric energy by harnessing freely available thermal energy from waste heat without the need for extra fuel consumption.

The proposed project has offered a sustainable means for the future generation of agricultural machinery. Through the development of exhaust heat recovery system integrated with a hybrid tractor concept, there is an indication that future improvements will involve more advanced thermoelectric materials, efficient cooling systems, energy management, as well as the use of alternative energy sources such as solar power.

In summary, the project signifies a critical step towards the design and production of energy-efficient and environmentally-friendly agricultural machinery that can be used in current agricultural practices.

XI. REFERENCES

- [1] V. Ganesan, *Internal Combustion Engines*, 4th Edition, Tata McGraw Hill Education, New Delhi, India, 2012.
- [2] James Larminie and John Lowry, *Electric Vehicle Technology Explained*, 2nd Edition, Wiley Publications, United Kingdom, 2012.
- [3] D. M. Rowe, *Thermoelectrics Handbook: Macro to Nano*, CRC Press, Boca Raton, Florida, 2006.
- [4] S. He, J. Zhang, and X. Li, "Performance Analysis of Automotive Exhaust Thermoelectric Generators," *Energy Conversion and Management*, vol. 89, pp. 327–339, 2015.
- [5] T. Hendricks and S. Choate, "Engineering Scoping Study of Thermoelectric Generator Systems for Industrial Waste Heat Recovery," U.S. Department of Energy Report, 2006.

- [6] R. Kumar and S. Sharma, "Waste Heat Recovery from Internal Combustion Engines Using Thermoelectric Generators," *International Journal of Engineering Research and Technology (IJERT)*, vol. 8, no. 6, pp. 112–118, 2019.
- [7] A. Montecucco, J. Siviter, and A. R. Knox, "Combined Heat and Power System for Automotive Applications Using Thermoelectric Generators," *Applied Energy*, vol. 123, pp. 47–54, 2014.
- [8] S. Kalikatzarakis and T. Frangopoulos, "Multi-Criteria Selection and Thermoeconomic Optimization of Organic Rankine Cycle System for Waste Heat Recovery," *Energy Conversion and Management*, vol. 73, pp. 81–97, 2013.
- [9] M. F. Demirbas, "Future Trends in Hybrid Agricultural Vehicle Technology," *Journal of Cleaner Production*, vol. 65, pp. 95–104, 2014.
- [10] IEEE Power Electronics Society, "Recent Developments in Thermoelectric Energy Conversion Systems," *IEEE Transactions on Energy Conversion*, vol. 30, no. 2, pp. 678–690, 2015.