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Harvesting Heat Energy as Alternative Renewable Energy

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ABSTRACT

Research on renewable energy resources evolves as its technological diversification ensures energy liability at feasible economy. Immense demand in transportation sectors with regards to continuing growth in passenger and freight activity exhibits automotive industry plays a vital role in global warming via greenhouse gas emissions. In order to curb efforts mitigating greenhouse gases (GhG) emission via transportation, wasted heat from vehicle engine has been used as fuel. Exothermic reaction used to initiate temperature difference aids thermoelectric cooler (TEC) to convert them into electrical energy. In this study, TEC has been exercised to harvest heat exerted from chemical reaction. Influence of waste heat harvest on velocity and energy efficiency of designed lab scale thermoelectric cooler car (TECar) has been weighed along.

Key words: Greenhouse Gases, Transportation, Thermoelectric Cooler, Waste Heat Harvest.

1. INTRODUCTION

Emerging globalization observes increasing trend in greenhouse gas emission (GhG). The causes of global warming are multifaceted and caused by nature as well as mankind. One important contributor to rising temperatures on our planet is the emission of man-made CO2 [1].

Figure 1 affirms transportation industry is a significant contributor to GhG. Indeterminately, application of renewable energy in automotive industry certainly reduces the dependency on petroleum and its ramifications.

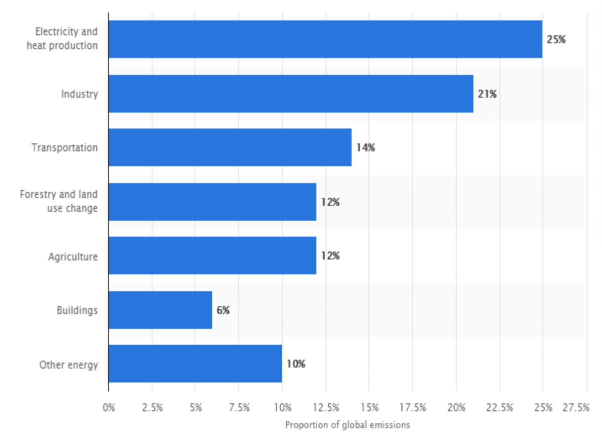

Figure 1: Global Greenhouse Gas Emissions by Sector as of 2014 [2]

Present use of internal combustion engines in vehicles causes nearly two third of total energy input to output as waste heat via engine coolant and vehicle exhaustion. Engine efficiency and environmental impact could be alleviating upon recovery and recycle of heat energy [3]. Some of the existing renewable energy includes rain, wind, sunlight, rain, waves, and geothermal heat. The usage of heat as electricity had been studied by Yang Yang and Jing Liu, 2010 [4] using thermoelectric generator (TEG). TEG requires a bidirectional DC to DC converter for a regulated power supply [5-6]. In this paper, a low-cost alternative has been explored; thermoelectric cooler (TEC) is used to harvest wasted heat converting into electricity.

Ultimately main contributions of this research work are as follow: Firstly, electricity generated by voltage booster aided TEC is sufficient to power up a lab scaled car. Secondly, TEC is shown to incur lower cost in terms of energy supply as compared to battery and TEG. Thirdly, harvesting wasted heat from car engine to create electricity results in significant increase of energy efficiency.

2. LITERATURE SURVEY

Automotive industry is learnt to be the main contributor in global warming; withholding 70% of GhG emissions [7]. Renewable energy lests the consequences of petroleum dependency by reducing CO2 gas emission, ensuring good air quality. On the other perspective, employing renewable energy benefits automotive industry via reduced capital investment, energy and footprint costs. Modified transportation infrastructure using these continuous energy resources allows flexibility in yield fuel production. Besides that, renewable energy facilitates recycle and recovery [8].

Many alternative methods are explored in creating efficient renewable energy. One of the renewable energy technologies for cars includes powering up a car with the use of biofuel from biomass. Producing biofuel from biomass gains a lot of attention from the researchers and investors as it uses waste feedstock as the raw material and this secures energy supply. In Brazil, approximately 3.14 million metric tonne of sugarcane was used to produce bio ethanol in the year 2014 [9] where complicated biological or chemical treatments and processes were required for the production. However, it was shown that the type of biomass, gasification techniques, operating condition [10] and choice of catalyst [11] are important for converting syngas gas to ethanol via thermo-chemical method. Additionally, limited waste feedstock supply may also affect the supply of biofuel [12].

Fuel cell is another type of renewable energy technology that has been explored by the researchers [13]-[15]. Fuel cells convert chemical energy to electricity, via the reaction between hydrogen and oxygen. It is claimed as green technology as it produces only water as the end product. Several fuel cell cars such as Toyota Mirai and Hyundai ix35 are readily available in the market [16]. However, the hydrogen gas tanks have to be delivered to the respective petrol station for the users to refill hydrogen where high carbon footprint is incurred, as big trucks are required for the gas tanks delivery.

Alternatively, hybrid cars are also widely used as one of the renewable energy efforts to ensure efficient energy. Hybrid cars operate with two sources of energies, which are battery and petrol, enabling them to offer better fuel economy and fewer emissions. Typical hybrid cars operate with an on-board sensor that captures upcoming trip data to optimally adjust the vehicle's speed, results in high energy efficiency [17]. Hybrid cars can be modeled with enhanced system configuration to improve its reliability [18-19]. However, HOMER exercised in various renewable energy demands high capital cost in the long run due to expensive batteries and carbon footprint [20].

While the aforementioned literature laid a solid foundation in car's renewable energy, harvesting heat from the car's engine with the use of TEC and voltage booster has yet to be explored. TEC is a device that converts heat energy to electricity when a temperature difference between the heat and cold sides is found. This paper discusses the practicality of using TEC to power up a lab scale car. The performance of a lab scale car is measured by its velocity.

3. EXPERIMENTAL SETUP

3.1 Thermoelectric Cooler with Voltage Booster Powered Lab Scale Car (TECar)

In the proposed TECar, a TEC is placed between the heat source and ice to create Peltier effect, as shown in Figure 2. Hot side of the thermoelectric module has been determined using datasheet provided. Heat supplied by an exothermic reaction between hydrochloric acid and aluminium at the hot side and a cube of ice, weighing 10g on the cold side creates required temperature difference. TEC's hot side has been attached to a heat sink to ensure an equal heat distribution. Output of the TEC is connected to a 2.5V DC-DC voltage booster to ensure a stable flow of electricity. Voltage booster output is then attached to DC motor of the lab scaled car. In order to measure the car's efficiency a load carrying container has been fixed. The generated voltage is measured using a volt meter whereas thermometer is used to measure the yield temperature difference from mixture of chemical solution and ice. Subsequent performance of the car is measured via cost incurred and energy efficiency.

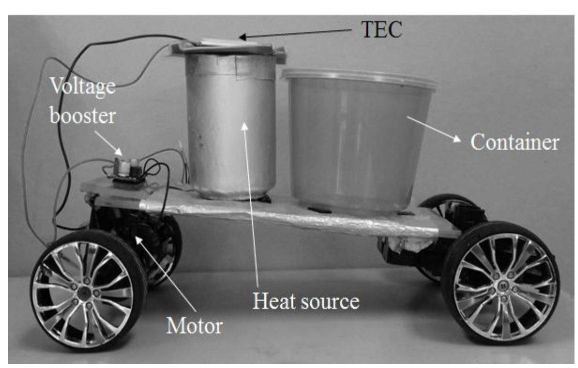

Figure 2: Lab scaled TEC powered car (TECar)

4. RESULTS AND DISCUSSION

4.1 Electrical Modeling of TECar

The proposed TECar works based on a closed loop feedback control system as shown in Figure 3, in which temperature difference (ΔT) is represented by the reference input and power generated is represented as controlled output. Amount of heat produced acts as an error detector. The TEC, voltage booster and motor acts as comparator and controller respectively. Corrective signal generated is represented by the control signal, which is transmitted to TEC. TEC and voltage booster forms the actuator unit whilst DC motor forms the process.

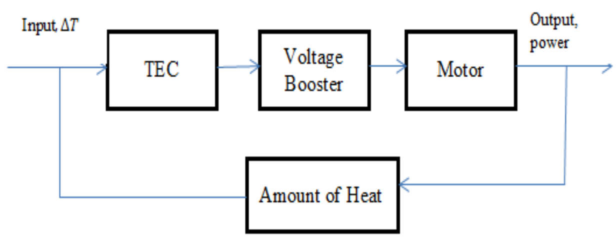

Figure 3: Closed loop feedback control system for TECar

In order to mimic wasted heat from engine exhaustion, an exothermic reaction involving 7.5M of hydrochloric acid (HCL) and aluminium powder has been employed. Figure 4 shows increasing mass of aluminium from 1.5g to 2.5g in hydrochloric acid increases the yield temperature and thus significantly elevates amount of voltage generated from voltage booster aided TEC. However, further increase in the mass of aluminium does not increase the voltage significantly. This portrays maximum capacity of the TEC-voltage booster device is to generate 10~30V with 0.01~0.1A besides insufficient continuous cold temperature supply. Dimension of TEC employed could accommodate only one ice cube per run. Increasing mass of aluminium melts ice on the cold side faster and thus adding resistance to high yield of temperature difference

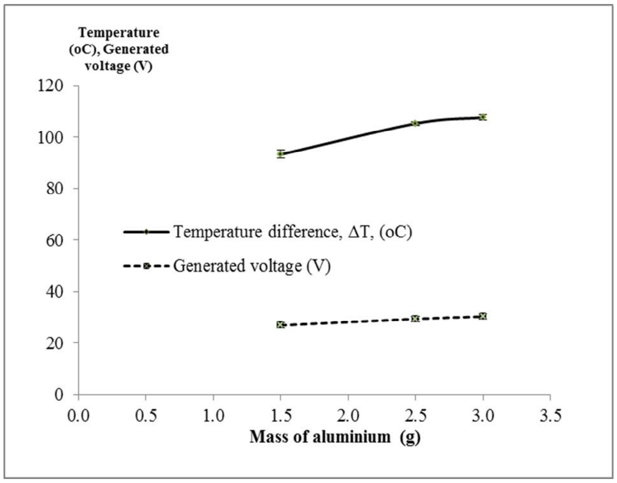

Figure 4: Effect of the mass of aluminium in hydrochloric acid on the temperature different across the TEC and the generated voltage

4.2 Energy Efficiency

Energy efficiency of TECar has been evaluated by measuring distance travelled at the stipulated time. Hence, Table 1 shows the effect on load endurance performance of TECar with increasing load. As the load increases by 200% from its initial load (48.2662g), velocity of the car is found reduced at 31% from its initial velocity. This interprets wasted heat harvest to electricity enables sufficient energy for a heavier car.

Table 1: The performance of the car in terms of velocity

Loads carried by the car [g]	Velocity [m/s]
0.0000	0.2369 ± 0.0316
48.2662	0.2069 ± 0.0153
96.5323	0.1945 ± 0.0098
144.7985	0.1418 ± 0.0087

According to M. Ray Fairchild and Rick B. Snyder et al, 2002 [21], temperature of the engine surface and exhaust system are 140°C and 587°C respectively. Heat generated from four strokes engine compartment in the current vehicle design can be used as heat source for the TEC. Meanwhile, cold side of the TEC can be exposed to the continuous cold air flow from heat exchanger. Figure 5 shows the proposed waste heat recycle and recovery system prior to organic rankine cycle. Converted electricity is to be filled in a generator as a backup fuel source. Perforated fin heat exchanger with cyclohexane as working fluid in the design proposed is found to have 5.3% to 25% of exhaust heat recovery at 1-20 Nm loads [22].

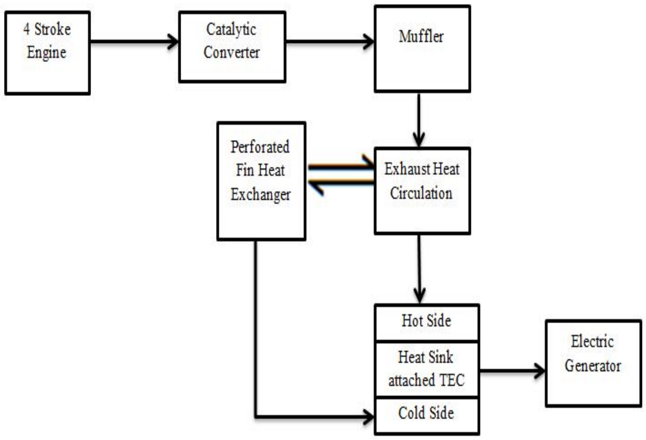

Figure 5: Wasted Heat Recovery System using TEC

4.3 Economic Feasibility

Three energy sources has been employed in this study to fuel TECar; Rechargeable batteries, Thermoelectric generator and thermoelectric cooler. Table 2 shows experiment parameters whilst percentage of cost reduction and energy efficiency are tabulated in Table 3 and Table 4.

Table 2: Experiment parameters

Parameter	Value
Price of chemicals used (2.5g of aluminium and 35 ml of hydrochloride acid)	USD 7.86
Time taken to fully charge the battery	420 minutes

Table 3 shows the percentage of cost reduction with the proposed TECar, as compared to battery and TEG powered lab scaled car. Using rechargeable battery to power up a lab scale car incurred a total amount of USD 49.18. Using TEG, with chemicals to create temperature difference, shows 41.34% cost reduction as compared to battery powered car. In the proposed TECar which is powered by TEC and voltage booster results in 55.94% cost reduction in power supply. Since TEC does not require electricity charges to run, instead it generates electricity with the use of temperature difference created by chemicals, the cost of power supply is therefore much lower than battery operated lab scale car. On the other hand, the cost of TEC with voltage booster is lower than TEG, resulting in higher cost reduction.

Table 3: Percentage of cost reduction

Power Supply	Cost [USD]	Percentage of Cost Reduction as compared to Battery
9V Rechargeable battery + electricity charges [23]	12.48 + 36.70 = 49.18	-
TEG + Chemicals	20.99 + 7.86 = 28.85	41.34%
TEC + Voltage Booster + Chemicals	7.99 + 0.29 + 7.86 = 16.14	55.94%

Table 4 shows the energy efficacy of TEC powered car as compared to battery and TEG. TEG has the lowest energy efficiency; therefore it is used as the benchmark. As compared to TEG, battery powered lab scale car portrays to have 80% much higher energy efficiency. On the other hand, the proposed TECar is shown to exhibit 140% much higher energy efficiency as compared to TEG powered lab scale car. Results exhibits that proposed TECar shows higher cost reduction and elevated energy efficiency which makes it a suitable renewable energy as power supply in the automobile industry.

Table 4: Energy efficacy

Power Source	[Kwh] Generated	[Kwh] after Voltage Booster	Energy Efficacy as compared to TEG
Battery	9V * 0.01A = 0.00009	-	80%
TEG	4.5V l* 0.01A = 0.00005	-	-
TEC	12.0V * 0.01A = 0.00012	0.0012	140%

5. CONCLUSION

Wasted heat recovery system via implementation of thermoelectric cooler in proposed TECar is shown to alleviate cost as compared to rechargeable battery and thermoelectric generator. Perpetual recirculation of wasted heat via exhaustion in vehicles assures deterioration in petroleum reliability. In this study, a lab scale car is powered by TEC and voltage booster, TECar is shown to increase energy efficiency. At 140% of wasted heat recovery, TECar emerges as a prominent solution to global warming reducing greenhouse gas emissions. In future, the idea of TECar could be applied in various sector of industry for a green future.

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