**DECLARATION**

**BY**

**SUPERVISOR**

I hereby, declare I had read through this thesis entitled "Conceptual Design of Thermoelectric Power Generator (TEG) for Automotive Waste Heat Recovery" and I agree that this thesis had fulfilled the quality and scopes that worth it to award Degree of Mechanical Engineering (Thermal-Fluid).

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| Signature | : ………………………… |
| Supervisor's Name | : ………………………… |
| Date | : ………………………… |

# CONCEPTUAL DESIGN OF THERMOELECTRIC POWER GENERATOR (TEG) FOR AUTOMOTIVE WASTE HEAT RECOVERY

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Thesis submitted in accordance with the requirements of the Universiti Teknikal Malaysia Melaka for the degree of Bachelor of Engineering Mechanical (Thermal-Fluid)

Faculty of Mechanical Engineering
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May 2009

**DECLARATION**

I hereby, declare this thesis entitled “Conceptual Design of Thermoelectric Power Generator (TEG) for Automotive Waste Heat Recovery” is the results of my own research except as cited in the reference.

Signature : …………………
Author"s Name : …………………
Date : …………………

**DEDICATION**

*For my beloved family,*

## ACKNOWLEDGEMENT

I would like to express my appreciation to all those who gave me the support to complete this thesis. I have to thank my supervisor Mr. Mohamad Firdaus Bin Sukri, for his valuable suggestions and encouragement.

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# *ABSTRAK*

Projek ini bertujuan untuk menghasilkan satu reka bentuk konseptual Penjana Kuasa Thermoelektrik (PKT) untuk sistem penyejukan automotif. PKT telah memainkan peranan yang penting dalam menukar haba buangan kepada tenaga elektrik. Dalam projek penyelidikan ini, hanya kaedah mekanikal pemasangan PKT difokuskan. Radiator daripada sistem penyejukan automotif telah dipilih untuk mengintegrasikan PKT kerana ia boleh menyediakan satu perbezaan suhu yang konsisten. Kerja-kerja penyelidikan PKT yang sebelum ini dikaji bagi menentukan keadaan optimum untuk reka bentuk radiator baru. Tenaga elektrik secara teori yang dihasilkan oleh PKT ditentukan menggunakan Konduksi Haba Hukum Fourier. Kemudian kerja penyelidikan diteruskan untuk mencari jalan penyelesaian menerusi mereka bentuk satu system yang mengintegrasi PKT pada radiator yang diubahsuai. Sebanyak 40 modul dipasang pada radiaotor untuk menghasilkan 76.6 W tenaga elektrik. Kuasa keluaran reka bentuk PKT bergantung kepada angka merit bahan PKT.

# ABSTRACT

This project aimed to produce a conceptual design of Thermoelectric Power Generator (TEG) for automotive cooling system. TEG has played an important role to convert the waste heat into useful electrical power. In this research project, only the method to assemble mechanical part of the TEG is focused. The radiator from the cooling system of automotive is selected to integrate TEG because it can provide a consistent temperature. Previous research works were study to determine the optimum condition for new radiator design. The theoretical electrical power produce by the TEG is calculated using the Fourier"s Law of Heat Conduction. Then the research work continues on finding solution through design a system to integrate TEG into the modified radiator. The modified radiator has totally 40 modules build on it which can produce 76.6 W of electrical power. The output power of the design TEG system can be improve when the TEG material"s merit of figure increased.

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# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| ATEG | = | Automotive Thermoelectric Generator |
| CAD | = | Computer Aided Design |
| CHAP | = | Chapter |
| CVD | = | Chemical Vapour Deposition |
| FYP | = | Final Year Project |
| IC | = | Internal Combustion |
| MBE | = | Molecular Beam Epitaxy |
| MMD | = | Malaysia Meteorological Department |
| R&D | = | Research and Development |
| TE | = | Thermoelectric |
| TEG | = | Thermoelectric Generator |
| TEM | = | Thermoelectric Material |
| ZT | = | Merit of Figure |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| $\alpha$ | = | Seebeck Coefficient, V/K |
| $A$ | = | Area, $m^2$ |
| $C_p$ | = | Specific Heat Coefficient at Constant Pressure, kJ/kg K |
| $k$ | = | Thermal Conductivity, W/m K |
| $\dot{m}$ | = | Mass Flow Rate, kg/s |
| $\rho$ | = | Density, $kg/m^3$ |
| $q$ | = | Heat Transfer, kJ/s |
| $rpm$ | = | Revolution per Minute, rev/m |
| $T$ | = | Temperature, K |
| $\Delta T$ | = | Temperature Different, K |
| v | = | Velocity, m/s |
| $\Delta V$ | = | Voltage Different, V |
| $\dot{V}$ | = | Volumetric Flow Rate, $m^3/s$ |
| $x$ | = | Thickness, m |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

This research project had been carried out to design a TEG system, which can integrate into radiator of automobile gasoline powered combustion engine to recovery waste heat lose to surrounding.

## 1.1 Problem Statement

Study on automobiles gasoline powered internal combustion engine shows that only approximate 25% of the fuel energy is used to drive the engine, whereas 40% of the fuel energy is wasted in exhaust gas, 30% in engine coolant and 5% in friction and parasitic losses (refer to Figure 1.1).

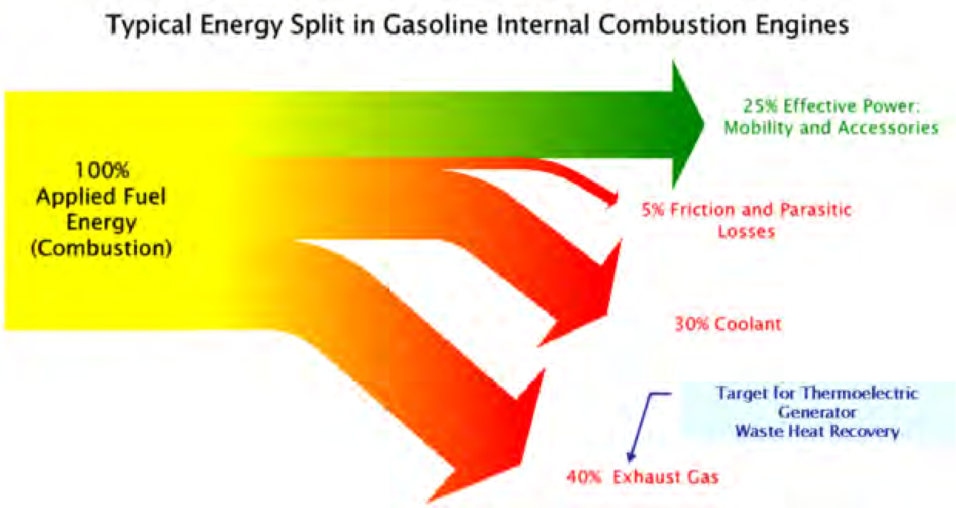


Figure 1.1: Energy Split in IC Engines [2]

For example, a full tank of vehicle capacity is 100 litre fuels, but only 25 litre of fuel is turn into useful mechanical energy to power vehicle, the remaining of 75 litre of fuel is dissipate as heat energy. The petrol price in Malaysia is not stable and subjected to international oil price change. Consequences, the price of 1 litre petrol had increased to RM 2.70 in 5 June 2008. According to this petrol price, one has to pay RM 270 for 100 litres where RM 67.50 pay for the engine to work and RM 202.50 pay for the unwanted heat produce by engine. This is not logic and non economical but this is what vehicle does everyday. Therefore many studies had carried out to recover the waste heat dissipated by vehicle. If the waste heat can recover, not only the every Ringgit spends for fuel is become more valuable, but also can reduce the fuel consumption due to less fuel require to generate electric for vehicle.

As a conclusion, the increasing of oil prices in the world market and low utilization of gasoline powered engine makes it necessary to generate new sustainable sources of electric power in modern automobiles. Furthermore, vehicle nowadays requires more and more electricity energy in order to maintain the communication, navigation, engine control, and safety systems of the vehicle. Therefore TEG is the best solution to recover waste heat through converts the heat energy into electricity. The focus of this research thesis is to design a TEG system which can integrate into the radiator of automobile vehicle to generate electricity.

## 1.2 Background

A thermoelectric generator (TEG) is a device used to convert heat energy into electric power. The basic concept and principle for TEG is based on the "Seebeck effect", where voltage is produce by temperature difference across two dissimilar legs of semiconductor material. The voltage produce is equal to Seebeck coefficient of the material, α, times the temperature difference across the device. The equation that describes the Seebeck effect is:

$$\Delta V = \alpha\left(T_{Hot} - T_{Cold}\right)$$

where $\Delta V$ = Voltage Produce

$T_{Hot}$ = Hot side temperature

$T_{Cold}$ = Cold side temperature

There are two dissimilar legs made of semiconductor material, one is the p-type and the other is n-type. The p- and n- legs are joined by an electrically conducting material at the p-n junction and are called a thermoelectric couple. One TE couple is the fundamental unit of TE module. When a series of p-n couples care connected electrically in series and thermally in parallel, they form a thermoelectric module. The electrical connectors are separated from the heat source and sink by electrically insulating material. Due to temperature different, the negatively charged electrons in the n-leg and the positively charged holes in the p-leg move from the heat source to the heat sink. This not only produces voltage but also help to transfer heat energy to dissipated site. The flow of electrons disturbs the original uniform charge carrier distribution and produces a current flow in the thermoelectric couple against the flow direction of electrons as show in Figure 1.2.

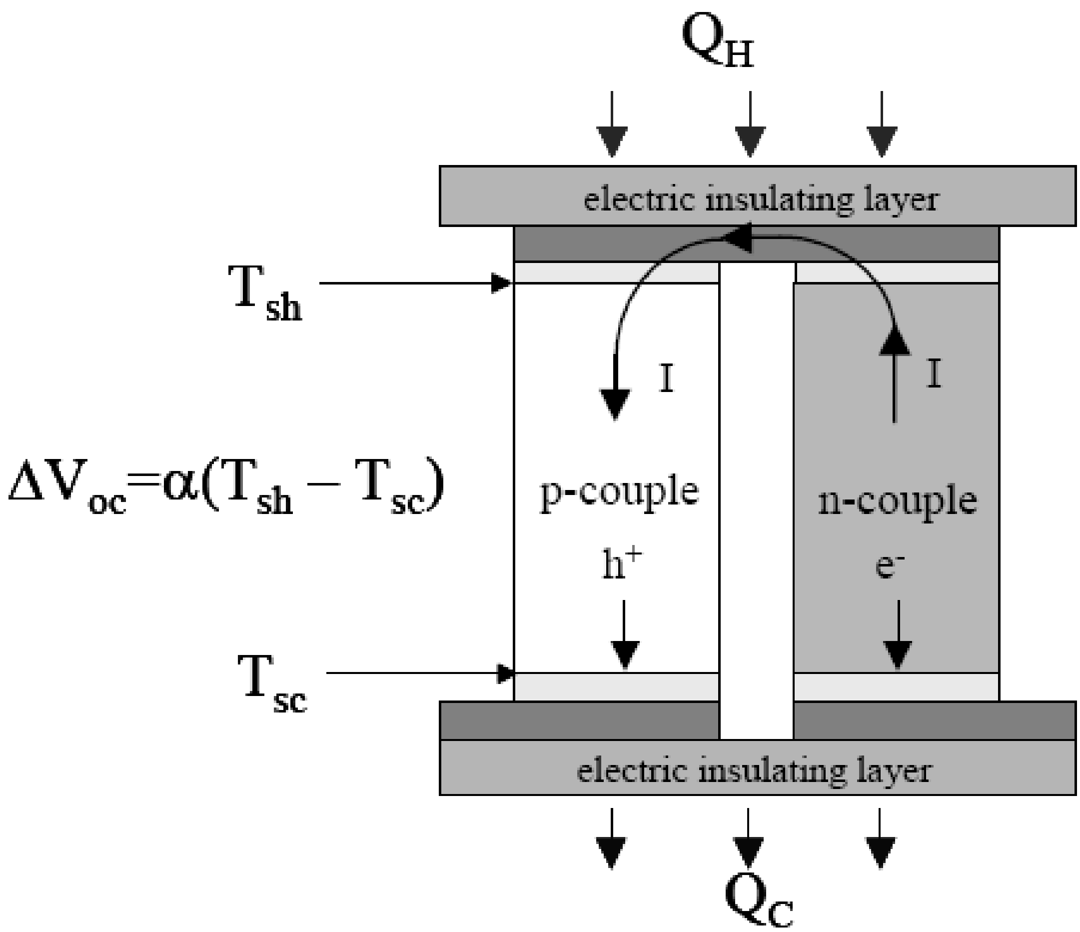


Figure 1.2: Energy Flow through a Thermoelectric Couple [3]

## 1.3 Objective

The objective of this research project is to produce a conceptual design of TEG for automotive waste heat recovery.

## 1.4 Scopes

The scopes for TEG conceptual design include:

a. Literature review on the working principle of the TEG base on Seeback effect as well as the application of TEG in automotive industry.
b. Analysis the parameters of radiator‟s performance such as the engine speed, mass flow rate and the temperature different drop across radiator based on Hakimi‟s research work.
c. Tabulate the electricity power produce based on conduction heat transfer theory.
d. Design a mechanical assembly of TEG in radiator to produce 70 W electricity powers.
e. Discuss the TEG design and include recommendation for the future work.

## 1.5 Summary of Thesis

Chapter 1 has stated the problem statement, background, objective, and scopes of TEG design. Then, Chapter 2 is the literature review that summarizes and evaluates the recent or previous works done by researchers in ATEG. Following is the Chapter 3 that describes about the methodology used throughout this research project. The Chapter 4 involved selection of TEG module and radiator design, which includes radiator specification and calculation of theoretical power produce by the new design TEG system. Next, Chapter 5 shows the individual components and assembly drawing of new TEG design. Chapter 6 discusses the issues such as the material, radiator performance and application of TEG design system. Lastly, Chapter 7 finalizes the thesis with the conclusion and recommendations. Reference, Bibliography and Appendix were placed at last of the thesis.

# CHAPTER 2

# LITERATURE REVIEW

Thermoelectric Generator is a solid state 'heat engine' capable of converting heat to electricity or alternatively capable of converting electricity into cooling. Thermoelectric generators (TEGs) are construct base on the three factors that are source of heat, type of cooling system, and required electric power output. First factor in construct TEG is the sources of heat, which include radioactive materials, fossil fuels, and waste heat. In space applications radioisotope TEGs has been used since 1960s, while fossil fuel powered TEGs has been used in military applications [4]. Waste heat based TEGs on have a varieties range of applications from power plants to transportation and domestic applications. However, only the waste heat TEG in vehicle is discuss in this chapter.

## 2.1 Waste Heat Recovery

Waste heat recovery captures waste heat energy and reuses it by returning it to systems or processes. This can include heating space and water. The cost benefits of a heat recovery system depend largely on the type and scale of the installation, but heat recovery can give substantial long-term energy savings. It often reduces the need to generate heat in the first place, making further energy and cost savings.

## 2.2 Automotive Thermoelectric Generator (ATEG)

ATEG is an electrical generator applied the Seebeck effect to recover lost heat in an internal combustion engine powered vehicle. There are two types of ATEG: exhaust-based ATEGs and coolant-based ATEGs [5]. The exhaust-based ATEG converts the heat lost in the IC engine exhaust whereas the coolant-based ATEG converts the heat lost in the engine coolant, into electricity. An ATEG consists of three main components, they are:

a. Hot-side heat exchanger
b. Cold-side heat exchanger
c. Thermoelectric materials (TEMs)

### 2.2.1 Hot-side Heat Exchanger

The function of hot-side heat exchanger is to extracting waste heat and delivering this heat to the surface of TEM.

### 2.2.2 Cold-side Heat Exchanger

The cold-side heat exchanger is responsible for dissipating heat from TEM to prevent damage on TEM due to high temperature, refer Figure 2.1 for the schematic configuration of waste heat TEG.