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Feasibility Study for Energy Recovery from Internal Combustion Engine's Waste Heat

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Abstract – *To mitigate the world's energy problems and global warming, researchers are focusing on renewable energy, regenerate energy, efficient energy usage and finding alternative energy. In an automobile, Internal Combustion Engine (ICE) also produces heat which is released as waste heat which have a potential to generate energy. Power distribution of an automotive is showing that only about 20% of the power from engine combustion is convert to wheel or driving power and more than 60% of the power will be wasted. One way to convert heat to useful work is by using Rankine cycle. Research study to described the effects of thermal properties of an organic working fluid on the turbine power had also been reported. This research is to investigate the actual potential energy and power from the waste heat released by the an actual passenger car's ICE through radiator. Feasibility study is conducted, to investigate the capability of the system and to help developing a system that can be used in an actual automobile. With the collected data, an efficient waste heat recovery system for the passenger car's engine will be develop in the future. From the experiment result, the power output up to 800 W from heat released in the radiator as the temperature difference about 35 °C (heat in and out difference). From this study, it is found out there is a significant problem when the radiator cooling fan operates. The power from the waste heat intended to reduce and also becoming unstable. A power storage system and the radiator cooling fan control will be vital to obtain high usable energy from ICE heat.* **Copyright © 2014 Praise Worthy Prize S.r.l. - All rights reserved.**

***Keywords**: Energy Recovery, Rankine Cycle, Waste Heat, Potential Power, Engine Radiator*

Nomenclature

$\dot{m}$	Mass flow rate, kg/s
W	Work, kJ/kg
h	Enthalpy, kJ/kg
n	Polytrophic index
P	Pressure, MPa
T	Temperature, °C or K
$\dot{W}_P$	Pump power, W
$\dot{W}_T$	Turbine power, W
$\dot{Q}_C$	Heat release at condenser, W
$\dot{Q}_E$	Heat gain in evaporator, W
v	Specific volume, m^3/kg

I. Introduction

To mitigate the world's energy problems and global warming, researchers are focusing on renewable energy, regenerate energy, efficient energy usage and finding alternative energy.

For an automobile, engines also produce heat which is now released as waste heat which have a potential to generate energy.

Power distribution of an automotive is showing that only about 20% of the power from engine combustion is transform to wheel or driving power, where else about 70% is release as waste heat [1]. To use energy efficiently, this waste heat have to be reused as a power supply to other system in the automobile.

The research organic Rankine cycle (RC) to convert heat into useful work have been done for many years. Research study to described the effects of thermal properties of an organic working fluid on the turbine power had also been reported [2]. Previous research by the author showed also that the expansion ratio and turbine efficiency should play an important role to achieve high efficiency of an organic RC system [3].

Commercial RC system the converts waste heat into electricity were also introduced [4], [5]. The research to use waste heat from automobile engine had been done but until now there is no application to actual vehicle due to efficiency problems.

There were also two heat resources that have been studied in the ICE vehicle. The main study was to recover energy from heat released in the exhaust manifold line. The other method is to recover energy from heat released in the radiator system. In this research the Rankine cycle energy recovery system was built inside an actual automobile for feasibility study, to investigate the capability of the system and to develop a

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system that can be used in every automobile. A compact RC system to be used in the engine room will be design and tested in the actual vehicle running condition. The potential power output from this RC system was measured to investigate and analyzed the possible amount of energy/work that can be used from the waste heat released in the radiator of the passenger car.

II. Experiment of Rankine Cycle for Waste Heat Recovery

II.1. Rankine Cycle Outline

Fig. 1 shows a schematic of the operation principle of a closed Rankine cycle. The organic Rankine cycle (ORC) is a Rankine cycle in which an organic working fluid is used [6], [7]. The Rankine cycle consists of five main components: a pump, evaporator, expander, condenser, and working fluid.

The evaporator and condenser are heat exchangers which absorb heat into the cycle and release it from the cycle. The cycle is started by the pump pushing the working fluid to the evaporator. In the evaporator, the hot source water heats the working fluid up to the saturated or superheated vapor state. Then, the vapor expands and rotates the expander to produce power. After the vapor leaves the turbine, the cold source water cools and condenses the working fluid into the liquid state in the condenser. Then, the pump re-circulates the fluid. Fig. 2 shows the pressure–enthalpy $(p-h)$ diagram corresponding to Fig. 1.

Process $1 \rightarrow 2$ shown in Fig. 1 and Fig. 2 is the isentropic compression by the pump. The ideal pump power is given by:

$$\dot{W}_P = \dot{m}_{WF}\left(h_2 - h_1\right) \quad (1)$$

Process $2 \rightarrow 3$ is the heating of the working fluid at a constant pressure in the evaporator. The heat absorbed by the working fluid is given by:

$$\dot{Q}_E = \dot{m}_{WF}\left(h_3 - h_2\right) \quad (2)$$

Process $3 \rightarrow 4$ is the isentropic expansion in the expander. The expander power is given by:

$$\dot{W}_T = \dot{m}_{WF}\left(h_3 - h_4\right) \quad (3)$$

Process $4 \rightarrow 1$ is the cooling of the working fluid at a constant pressure in the condenser. The heat released from the working fluid is given by:

$$\dot{Q}_C = \dot{m}_{WF}\left(h_4 - h_1\right) \quad (4)$$

Potential power released from ICE can be calculated by the following equation:

$$\dot{Q}_E = \dot{m}_{WF}\left(h_{3'} - h_{2'}\right) \quad (5)$$

II.2. Potential Energy Calculation

In this study, it is measured the possible energy that can be achieved from the heat source from ICE $(\dot{Q}_E)$. This is done by measuring the temperature and pressure of the hot water flow out from the engine, before it enters the radiator for cooling purposed. The value can be achieved using the Eq. (5). Although there are researches concluded that the expansion ratio inside an expander is an important for power output [8], the potential energy from heat that wanted to reuse is needed to be known before can be decided whether the energy is can be recovered efficiently or not.

For all equations, enthalpies and entropies were calculated using the given pressure and temperature for each process. REFPROP ver.8 developed by the NIST [9] should be used in the calculation.

II.3. Experiment Setup

Rankine cycle is used to convert waste heat into energy in this waste heat recovery system. The waste from ICE can be obtained in the exhaust manifold and also from the engine radiator system.

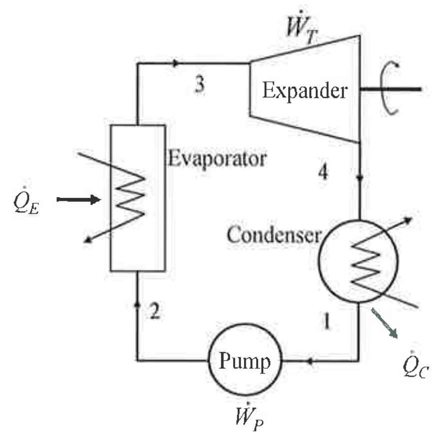

Fig. 1. Schematic diagram of operation of closed Rankine cycle

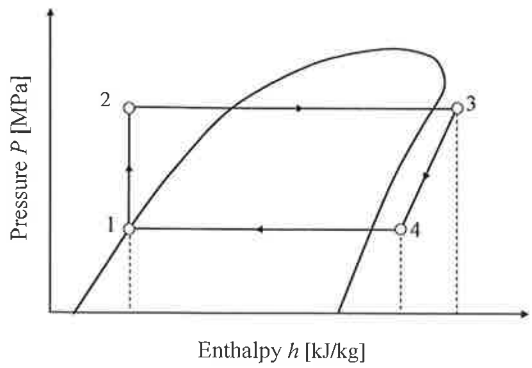

Fig. 2. Diagram of $(p-h)$ for closed Rankine cycle

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In this study it is focused on the waste heat released in the radiator water.

It is measured the possible energy from the heat that can be converted into electric energy by calculating the potential energy from circulate cooling water in the radiator. The water or coolant from the radiator will enter the ICE to absorb the heat from the ICE.

Then this coolant will be condensed in the radiator by releasing the heat to ambient. The data from the waste heat were measured to understand its potential power.

The experimental work was conducted using a Proton Gen-2 car with 1.6 liter petrol engine. The detail of the engine specifications are listed as in Table I.

The cooling water that flow to the radiator was reconnected to a heat exchanger. After flowing out from the heat exchanger the cooling water will enter the radiator for condensing process.

At this heat exchanger the heat temperature and pressure will be measured to obtain the potential energy and power output that can be re-used from the radiator cooling water.

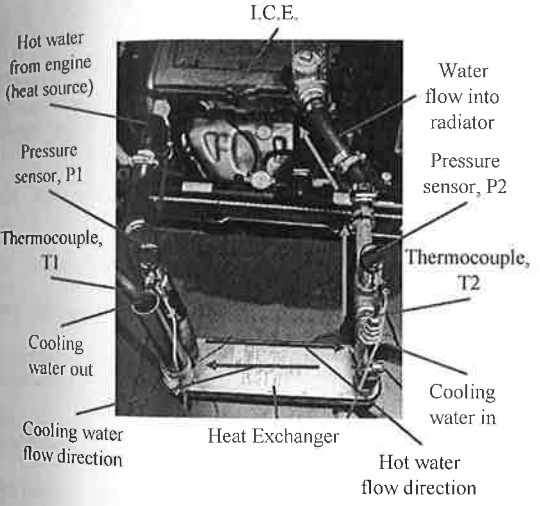

Fig. 3. Equipment setup to measure energy from ICE released heat

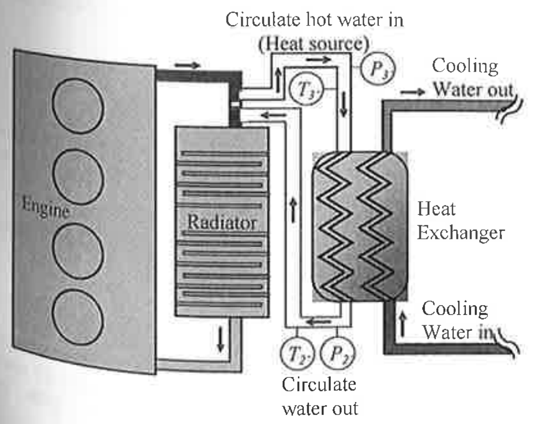

Fig. 4. Schematic of the experimental setup

TABLE I
SPECIFICATION FOR A PROTON GEN-2 INTERNAL COMBUSTION ENGINE

Description	Specification
Number of cylinders	4 in-line
Combustion chamber	Swirl chamber
Total displacement cm	1,597 cc
Cylinder bore × Piston stroke	76.0 × 88
Bore/stroke ratio	0.86
Compression ratio	10.0:1

III. Results and Discussion

From the data has been measured, the graphs of potential power released by heat vs. time is plotted. In Fig. 5, it is observed that the energy increased as the temperature differences increased.

Fig. 6 showed that 10 minutes after the engine started, the power in the circulated water (from engine to radiator) increased drastically. The reason for this is because the circulated water have changed phase from liquid to vapor and due to the changes, potential energy or the enthalpy increased.

The temperature differences between circulate water in and out are about 43 to 49 °C, but the enthalpy differences are in the range of 2495 kJ/kg to 2503 kJ/kg which gave higher potential power.

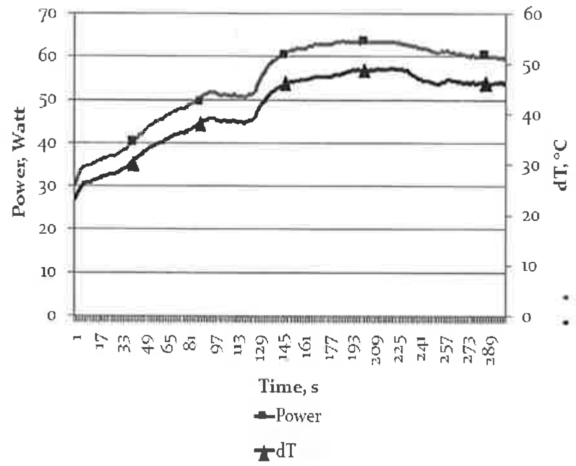

Fig. 5. Potential power measured 1 minute after engine start

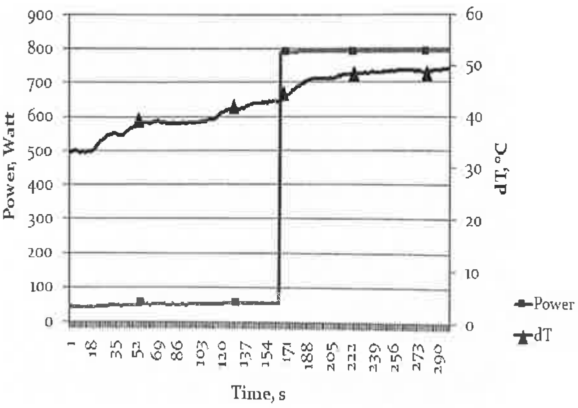

Fig. 6. Potential power measured 10 minute after engine start

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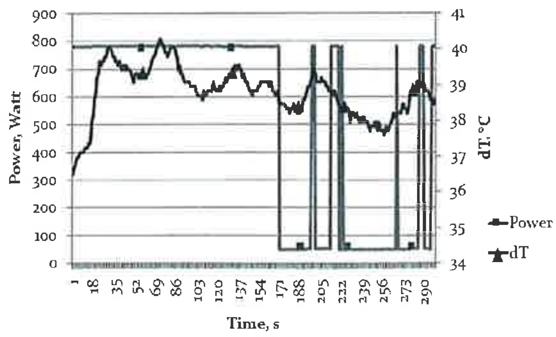

Fig. 7. Potential power measured 20 minutes after engine start with radiator fan operating

Fig. 7 showed an intermittent power decreased after engine running for longer period. At this condition, the circulate water temperature and pressure was affected by the radiator cooling fan operation. This showed that when the radiator fan started to cool down the circulate water, its potential power is not stable, between 63 W to 788 W. At this stage temperature difference between water at heat exchanger in and out are about 38 to 40 °C but the pressure difference resulted the enthalpy difference varied from 160 to 2469 kJ/kg.

From the results it shows that the potential power in the circulated water from ICE to radiator is unstable. It will be difficult to use the potential power directly but it could be converted it into useable energy, so it have to keep the power. A power storage system is definitely vital to capture the potential power produced. One way of storing the power is by converting it to electric energy and keeps it in a battery which it can be used the power when it is necessary.

IV. Conclusion

The experimental work to measure the potential power from the waste heat released in the radiator system. From the data collected the temperature differences between hot source and the cold source after the heat exchanger and its pressure play an important role to decide the power available from the waste heat. The conclusions of our studies are as follows:

i. The temperature difference should be more that 30 °C to gain minimum energy of 37 W.

ii. To achieve a high potential power from the waste heat released in the radiator, the circulate water should be best in a vapour saturation phase. When the circulate water in liquid phase the potential power achieved is only about 64 W, where else in the vapour saturated phase the power achieved can be up to 788 W.

iii. The waste heat released in a radiator can produced power but this power output is not stable due to the effect from radiator fan. The energy recovery system should take into account this effect in order to reuse the energy produced. The actual power obtained will be far below the maximum power, which is recorded in range of 400 to 600 W.

iv. Pressure and temperature play an important role to obtain what phase that the hot water is at, and it will determine the power output from the hot water.

From the above conclusions, it has suggested a power storage system will be necessary to keep the unstable energy from the heat recovery system in ICE vehicle. It also suggests using a radiator fan control system to keep the temperature differences at an optimum condition.

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