ENGINE COOLING SYSTEM WITH ENERGY RECUPERATION

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Abstract: *Internal combustion (IC) engines are main source of power used in the automotive industry. These engines have undergone many up gradation for decades, with an initial goal of increase in power of the unit. Presently, as a result of tightening environmental regulations, research is focused on reducing harmful gases emissions along with increase of the engines efficiency.*

Keywords: ENGINE, RECUPERATION, COOLING SYSTEM.

1. Introduction

Internal combustion (IC) engines are main source of power used in the automotive industry. These engines have undergone many upgrades for decades, with an initial goal of increase in power of the unit. Presently, as a result of tightening environmental regulations, research is focused on reducing harmful gases emissions along with increase of the engines efficiency.

The complexity of most engine systems certainly surpassed solutions used by the first engines designers. However, opening the car's engine covers from the 30s of the 20th century and the beginning of the 21st century, our attention is focused on rectangular radiator, rubber pipe system and expansion or overflow tank.

One gets the impression that the cooling system has been directly transferred out of the car, which is almost hundred years old. Analyzing the problem closer, it appears that in the engine cooling system almost nothing has changed. In reality, the heat transfer is improved by using different materials and bigger active surface of the radiator, but the concept has not changed.

Inherent feature of the cooling systems of IC engines is the dissipation of energy. More than 20% of the energy obtained from the fuel is transferred to the cooling system. For example, the engine which has 100[HP] and 30% of efficiency, in one hour, can produce more than 260[kJ] of energy and has radiator that dissipate almost the same amount of energy.

Presently, constant temperature of the engine is maintained as a result of taking over the appropriate amount of heat by the refrigerant circulating in the engine channels.

The control system consists of two circuits, small one – which includes engine and water pump, and a large one – with radiator (figure1).

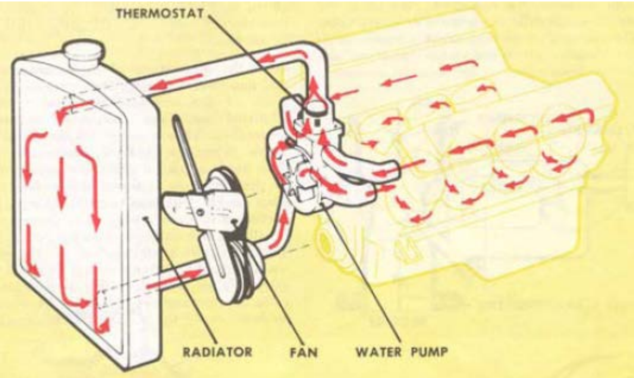

Fig. 1 *Typical engine coolant system [7].*

When the temperature of the coolant in a small circuit raises above a fixed value, the thermostat opens gradually, allows circulation of the coolant in a large circuit. When the coolant temperature drops, decreases the flow through the thermostat.

Considering these facts, it can be concluded that the current engines cooling system is archaic, and also its job is only to dissipate of accumulated heat. It seems feasible to modify the way the IC engines are cooled along with making use of dissipated energy.

It is worth noting, that the automakers are also looking for solutions by making use of dissipated energy. For example, BMW

proposes the use of a steam engine, which uses the heat from the engine exhaust system (figure 2).

Fig. 2 *BMW adds Steam Engine to improve fuel efficiency [8].*

2. Objective of the project

The objective of the project is to innovate the way the internal combustion engine is cooled and use the heat received from the engine to power a steam engine rather than being wasted in the radiator.

The proposed system would use the principle of operation of the ORC (Organic Rankine Cycle) power-station [1-6], which uses hydrocarbons as a working medium. That allows operation of the power-station at lower temperatures of the upper heat source. The system would have two duties, i.e. to keep the engine operating temperature in a certain range, and to convert the received heat for such a form of energy, that can be used in other purposes than just heating the interior of the vehicle.

Widely used in automotive, heat exchange system, where the refrigerant evaporates is an air conditioning system (figure 3).

The air supplied to the interior of the vehicle is cooled as it passes through a heat exchanger, where the refrigerant evaporates. Changing the physical state of the refrigerant requires far more energy than a change in its temperature. For example, a change of 10 degrees in temperature of 1 gram of water requires around 42[J] of energy, and the passage of 1 gram of water from the liquid state to the gaseous state requires over 2250[J] of energy, almost 54 times more. Unfortunately, medium after the evaporation is in a gaseous state and in order to condense at ambient temperature must be compressed by the compressor. This again requires power.

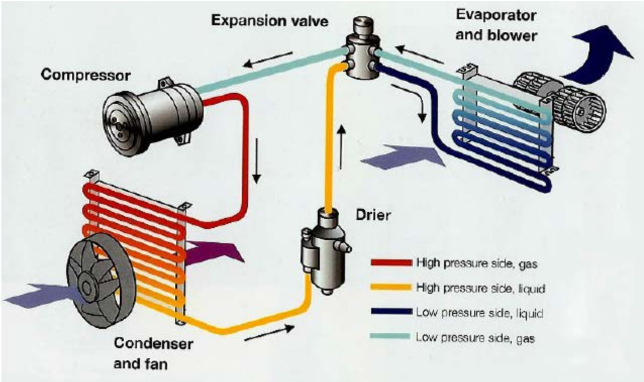

***Fig. 3** The principle of vehicle air conditioning [9]*

3. Proposed solution

The principle of ORC operation is shown on figure 4.

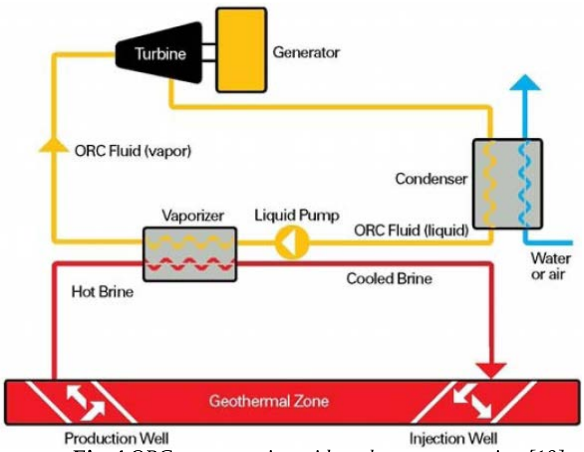

***Fig. 4** ORC power station without heat regeneration [10].*

Heat from the thermal source is supplied to heat exchanger (vaporizer), which causes evaporation of the compressed working fluid in the Rankine cycle. Then, the vaporized fluid drives a turbine connected to a generator. Fluid on the output of the turbine is directed to the condenser where it gets condensed. Liquid ORC fluid goes back to the pump, and then it is compressed.

In the proposed solution is planned that supplied heat will come from the engine cooling system (figure 5).

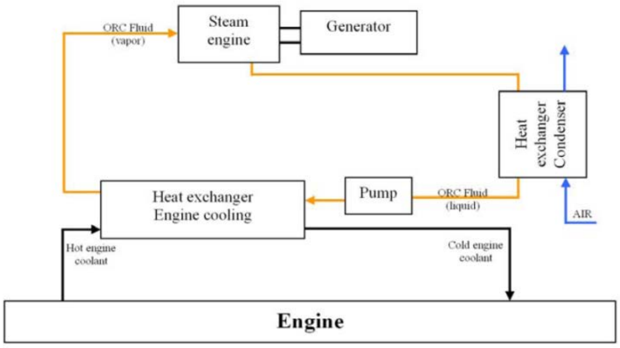

***Fig. 5** Blok diagram of the proposed engine cooling system.*

In addition, it is planned to use the heat from the exhaust system, while working when the engine is cold, or to increase the mass flow of refrigerant. Two solutions for such a system are shown in figure 6.

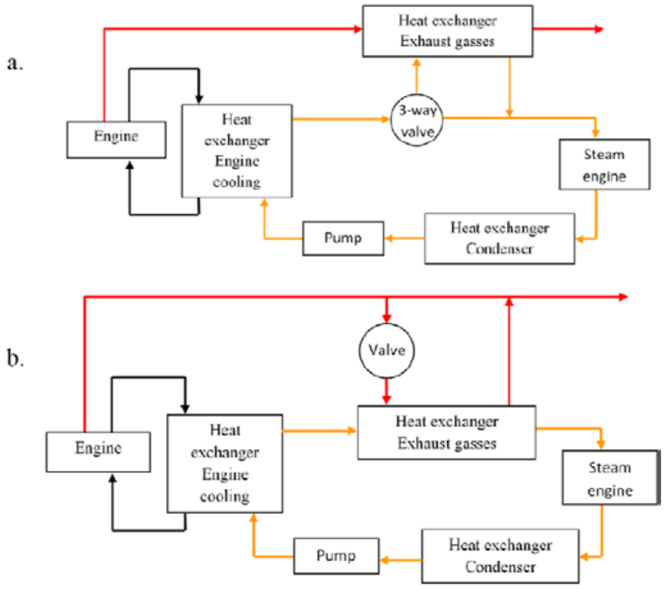

***Fig. 6** Blok diagram of the proposed engine cooling system with using exhaust heat, which is controlled by: a) three-way valve in the refrigerant circuit, b) valve located in the exhaust system.*

In the first case (a) three-way valve is used. It controls the amount of heat supplied to the refrigerant. The valve is mounted in the refrigerant circuit. It could lead the fluid directly to the steam engine, or in the case of a cold engine through the heat exchanger mounted on the exhaust system. In the second case (b), the valve is mounted in the exhaust system and it controls bypassing of hot gasses to heat exchanger.

4. Evaluation of system capabilities

In order to determine the amount of heat needed to be taken from the engine coolant (water) per time unit, the following simplifications were assumed:

- 30% of the heat (energy) supplied to the engine is converted into an effective power,
- 20% of the heat supplied to the engine is dissipated in the radiator.

Using these assumptions can be determined, what is the heat flow, which must be over taken in the ORC system. Assuming, that the engine power is 81,6 [HP] (60 [kW]) we obtain:

$$Q'_{ch} = 0{,}2\frac{60000}{0{,}3} = 40000[W] \qquad (1)$$

One of the fundamental problems that must be solved is to find a suitable refrigerant, which, on one hand, will evaporate at the temperature about 100[°C], by taking heat from the engine cooling system, but also allow to condensate at ambient temperature – about 50[°C] (of course at a lower pressure). Analysis of system operates using butane as a refrigerant is shown below.

The project assumes that the heat flow determined above will be fully taken over by the refrigerant (butane, figure 7). Liquid butane (50ºC at 20[atm]) in the first stage is heated to boiling temperature (100ºC at 20[atm]), and then the entire amount of butane evaporated ($r_{100^{\circ}C}$ = 210 [kJ/kg]). Butane mass flow can be determined from the formula:

$$\dot{Q}_{CH} = \dot{m}c_p(100^oC - 50^oC) + \dot{m}r \quad (2)$$

$$\dot{m} = \frac{4000W}{2481\frac{J}{kgK}50K + 328360\frac{J}{kg}} = 0{,}088\frac{kg}{s} \quad (3)$$

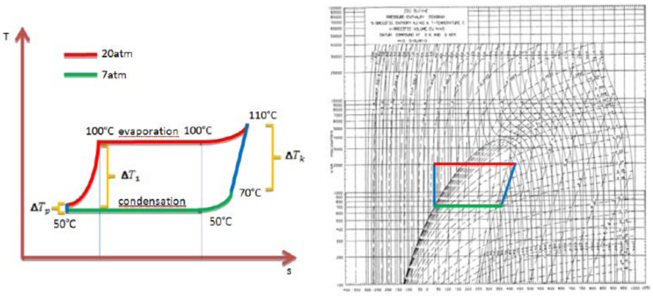

Fig. 7 *Refrigerant (butane) in T-s and p-h.*

The calculations of energy balance of the proposed system (for obtained above butane mass flow) were carried out using basic thermodynamic principles (figure 8). First the required power of pump (≈ 300W) to raise the pressure of butane from 7 to 20 atmospheres then the power which can be used from isentropic expansion of the refrigerant (≈ 3500[W]) and the required condenser cooling capacity (≈ 36800[W]) were calculated.

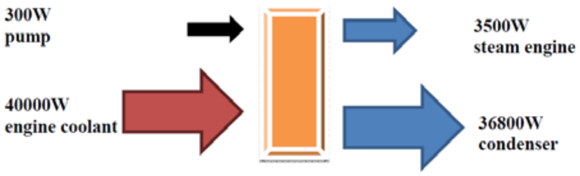

Fig. 8 *Energy balance for proposed cooling system.*

5. Summary

The proposed project consists of two sections- building a test rig and development of computerized heat transfer models. Building up of a test ring and simulation work will be carried out in parallel. This will help in optimization of the ORC in a certain area.

The advantage of this split would create two distinct requirements in terms of range of master's theses, but at the same time taking into account the project, complement it perfectly. Testing at the rig allow to verify the numerical model, which, in turn, the development of the real system with higher efficiency.

It is expected that the amount of saved energy could be used to drive an alternator. It is estimated that the weight of the system components should be less than 50 [kg]. ORC fluid condenser mounted at the front of the car should be smaller than the typical engine radiator. Thus the new system is not going to add huge extra mass to the vehicle.

Acknowledgement
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6. References

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