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Research Paper

Improving the engine cooling system using a power generation cycle for low-temperature heat source (heat losses in engine) instead of radiator

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HIGHLIGHTS

- A supercritical Rankin cycle to improve the cooling system in engine is investigated.
- In the present work, seven working fluids are studied.
- The results show that The R32 and R143a working fluids are the best working fluid.

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ABSTRACT

In this paper, a thermodynamic cycle (supercritical Rankin cycle) to improve the cooling system in engine and producing power from thermal energy available in water exiting from engine of car is investigated. Also, in the present work seven working fluids are studied because the working fluid in this cycle must have low critical temperature or near to the temperature of water exiting from the engine. For comparing working fluids and selecting the best of them, these parameters such as net-work, size of heat exchanger, factor of turbine size and thermal yield were studied by cycle thermodynamic analysis. The results of this analysis show that the working fluids including R32, R143a and Propylene are the best options as working fluid for use in this cycle.

1. Introduction

Increase in consuming fossil fuels and shortage of accessible resources in current years have caused researchers and engineers' efforts changes toward new ideas. Using waste energy in thermodynamic processes is amongst ideas that can be used as an energy resource. In many of these processes, temperature of waste energy resources is not high and in this regard using them is almost hard. In this paper we have studied optimal applying of energy resources till we can explain its effect on reducing total costs for producing electricity.

On the other hand, the using low temperature thermal resources only is acceptable thermodynamically and economically in some of the cycles, so we must use a cycle that is simple and can provide acceptable thermodynamic yields as well. Traditional cycle for low temperature resources is SRC (Supercritical Rankin cycle). Working fluid of this cycle has distinct characteristics compared to typical Rankin cycles. The main difference between such cycles and conventional Rankin cycles is that in the conventional cycles, working fluid is commonly under the critical point but applied working fluid in the SRC working fluid is in top of a critical point.

Selecting the working fluid in the cycle depends on various parameters such as availability, non-toxic, non-flammable and has high thermal conductivity [1]. The working fluid must be able to absorb the maximum of energy and creates the maximum possible volume for producing the power. Thus, the working fluid must be near supercritical phase, while attracting the least amount of energy creates higher possible volume, in other words, the pressure and temperature must be a bit lower than the critical pressure and temperature [2]. Although various fluids have been used in this cycle, selecting the working fluid depends largely on research objectives and temperature range of low temperature heat source. Of course for selection of an appropriate fluid, a series of limitations should be considered in the design of cycle.

On the other hand, when low temperature cycles are used due to the low temperature, heat transfer is very difficult. Therefore heat transfer surface should extend. On the other hand total cost of cycle is highly dependent on the size of the individual components of the cycle, which in turn can be considered negative character for the cycle.

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Nomenclature

Symbols and abbreviations

h	specific enthalpy (kJ kg^{-1})
ΔH_s	isentropic enthalpy difference in the turbine (kJ kg^{-1})
$\dot{v}_{2s}$	volume flow rate outlet from turbine
ΔT_m	logarithmic mean temperature difference (K)
ΔT_{min}	minimal temperature differences at the ends of the heat exchangers
ΔT_{max}	maximal temperature differences at the ends of the heat exchangers
$\dot{m}$	mass flow rate (kg s^{-1})
$\dot{Q}$	heat transfer rate (kJ kg^{-1})
SP	size factor of turbine
T	temperature (K)
UA	the total heat transfer requirement (KW K^{-1})
W	power (KW)

Greek symbols

η	efficiency

Subscripts

C/c	condenser
E/e	evaporator
p	pump
t	turbine
s	isentropic process
net	net
tot	total

However, various thermodynamic cycles such as the Kalina cycle, Gosvami, Trilateral flash have been proposed in order to generate electricity. Despite of higher output production of Kalina cycle compared to supercritical cycle due to less complexity and requiring less maintenance, is more important [3]. Meanwhile using supercritical cycle will allow us to use cheaper and simpler turbines [4].

Generally, in recent years efforts have been divided into three general categories: optimizing the design of cycle, selecting appropriate fluid for the supercritical Rankin cycle and select the appropriate heat source. Studies in the field of designing optimized cycle [5] show that an increase in the inlet temperature increases output power and Exergy efficiency. Meanwhile low input temperature and pressure as well as high input temperature and pressure increases the output power of the turbine. Of course low inlet temperature of turbine increases the size of the heat exchanger and turbine as well [5]. The second part of efforts is in the field of selecting appropriate working fluid for supercritical Rankin cycle and compares them on the basis of thermodynamic properties and thermal efficiency. In this regard, different working fluids such as n-pentane [6], hydro chloro fluoro carbon 123, hydro fluoro chloro carbon 245- fa, hydro fluoro chloro carbon 245- ca, isobutene [7–11], and aromatic hydrocarbons [12] are investigated. Among the most important studies, study by Saleh et al. [13] is important in which 31 working fluids have been investigated based on the equation of Van Beck. Liu et al. [14] in this regard studied the working fluids and their impact on thermal efficiency and heat recovery efficiency. Chen et al. [15] analyzed supercritical Rankin cycle in which Zeotropic mixture used that showed this working fluid reduces the irreversibility and improves the efficiency of the cycle. Zhang and et al. [16–18] also emphasized that the thermal efficiency supercritical Rankin cycle is higher than conventional Rankin cycle. Karlas [19] analyzed supercritical Rankin cycle with fluids such as Freon R245a, Di fluoro methane, propylene, propane, isobutene and he showed that the efficiency of supercritical Rankin cycle is higher than the conventional Rankin cycle. Although Rankin supercritical cycle has better thermal coordinate than Rankin cycle under the critical point, Supercritical cycle requires higher pressure which causes concern about its safety. Amlaku Abie Lakew and Olav Bolland [20] have studied the impact of working fluids such as R227a, R123, R245, R134a, R290 and n-pentane on the power production and the size of various components. In this regard, R227a and R245 have maximum output power production in the range of 80–160 and 160–200 °C temperatures, respectively. They also note that for any particular temperature range and special working fluid there is an optimized pressure that for it, the lowest level for the heat exchanger is required. In this regard the minimum required level of heat exchanger is when the working fluid is n-pentane.

The third aspect of the researches and these activities is related to the selection of a suitable heat source. One of the application of low temperature heat sources is using the geothermal energy with the temperature of about 100 °C, such as Altheim (Austria) power plants with power generation of 1 MW [21,22] and Neustadt-Glewe (Germany) with a capacity of approximately 0.2 MW, in both n-Perfluoro Pentane is used as the working fluid [23], waste heat can be used as a heat source. Heat of the output working fluid from a car engine, is an ideal heat source of the range between 80 and 120 °C for use in supercritical cycle. In this study, we have tried to use waste heat energy of the engine to generate electricity while avoid from heat dissipation in radiator for the first time. In the other hand, the main goal of this research is to improve the current cooling system of the engine by replacing a power generation cycle instead by radiator. In the world there are a lot of engines that have the requirements of this cycle.

2. Power cycle

To use the engine's waste energy means energy available in the hot water of the engine as well as available energy in exhaust, a power cycle with special working fluid have been used. Output water of engine with a pressure of 120 kPa and temperature between 80 and 200 °C, enters evaporator. During this process, heat is received from the engine's output water and the working fluid reaches to a supercritical state. Supercritical working fluid expanded in turbine and creates work and after leaving the turbine in a condenser working at 30 °C is cooled, then as a saturated liquid enters into the pump and this processes repeated in each cycle. To reach the supercritical state in turbine's inlet, working fluid pressure should be above the critical pressure of working fluid. Schematic of applied power cycle is shown in Fig. 1. This cycle's processes are fully shown in Fig. 2. Processes in this cycle are:

Process 1 to 2: supercritical working fluid is expanded and creates work and resulting in the generation of electricity.
Process 2 to 3: excess heat in the outlet working fluid from the turbine is disposed during constant pressure process.
Process 3 to 4: the pump is doing the work. In the real case for pumps isentropic efficiency is defined.
Process 4 to 1: the working fluid in constant pressure from outlet water receives heat and reaches the supercritical state.
Process 5 to 6: Outlet water of the engine in this process, transfers its heat to the working fluid.