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Experimental Investigation of 560 Watt Organic Rankine Cycle System using Plat Solar Collector as Heat Source

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***Abstract*—New and renewable energy sources such as solar, geothermal, and waste heat are energy sources that can be used as a source of energy for Organic Rankine Cycle system because the Organic Rankine Cycle (ORC) requires heat at low temperatures to be used as energy source. The experimental of ORC systems with solar energy as a heat source was conduct to investigate a small-scale ORC system with R134a as a working fluid by varying the heat source at temperature 75ºC-95ºC. The experiment resulted a maximum efficiency, power of system is 4.30%, and 185.9 Watt, where the temperature of heat source is 95ºC, the pressure and temperature of steam inlet turbine is 1.38 MPa and 67.9ºC respectively. Solar energy as the main energy source in the ORC system can reduce energy use up to 49.9% or 4080.8 kJ where the temperature of the water as the heat source in the evaporator is 51°C.**

Keywords—Organic Rankine Cycle, Thermal Efficiency, R134a, Solar Energy

I. INTRODUCTION

Global human growth is increasing, accompanied by energy growth that increases [1] and the growth in energy demand will cause a significant energy crisis throughout the world [2]. Currently, most of the energy needs are fulfill by fossil energy especially for power generation [3]. Due to the use of fossil energy that is greater than the discovery of new reserves, fossil energy are predict to be a limited energy source [4]. In addition to its limited reserves, the use of fossil energy also pollutes the environment so that as a result global warming has increased in recent years, therefore the development of new energy without causing environmental pollution is needed [5].

Therefore, replacing the use of fossil energy to new and renewable energy continues to be carried out. New and renewable energy sources such as solar, geothermal, and waste heat are energy sources that are expect to meet the world's energy demands. Organic Rankine cycle is one of the efforts to meet energy needs, especially in electrical that can utilize new and renewable energy as its energy source. Because the ORC requires heat at low temperatures to be used as an energy source, thus new and renewable energy can be utilized in this system [7].

The ORC system uses heat at low temperatures to heat and vaporize a working fluid that has a low boiling point, where the steam produced is use to rotate the turbine blades connected to the generator [8]. One of the new and renewable energies that can be utilize as a heat source in the ORC system is solar energy and Indonesia has very good potential in developing a solar power generation system specifically for the ORC system [9].

The ORC system uses a working fluid that can evaporate at a lower temperature than water [10] which is a modification of the Rankine cycle which uses water as the working fluid where the pressure and temperature are high, thus water is not suitable for use as a working fluid in the ORC System. Therefore, organic fluids like hydrocarbons, CFCs, HCFCs, PFCs, and others have lower boiling points than water and are ideal for use in the ORC system [11]. The main component of the Organic Rankine cycle (ORC) is an evaporator, turbine, condenser, and pump [12].

Experiment of ORC system was conduct in previous studies by applying a low-temperature as a heat source. An experiment was conduct by using R-245fa as a working fluid with a pressure range of 1-3 bar, resulted 1.02 kW of power with an efficiency of 5.64% [4]. Experiment of organic Rankine cycle systems using R134a as working fluid with helical evaporators and condensers by varying heat sources 75°C, 85°C, and 95°C resulted, the highest efficiency and thermal power are respectively 3.33% and 279.58 Watt at temperature 95° C [12].

The experiment of ORC system was carried out by using of a hot spring in the cimanggu area as a heat source with a temperature of 78°C for the ORC system and uses the R227ea as working fluid, by varying the temperature of cooling fluid 15°C, 20°C, 25°C resulted the highest thermal power and efficiency is 3.8 kW and 7.28% at the temperature 15°C [13]. Other experiment was carried out with collecting energy on the waste heat from air produced by solar ventilation systems with the highest outlet temperature are is about 120°C and resulted the ORC efficiency are 6.2% [14]. This research aims to investigate the effect of variations in heat source temperature on the value of the efficiency of the ORC system.

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II. METHODOLOGY

A. *Cycle Tempo Simulation*

The Basic design of ORC system is design by using cycle tempo 5.0 simulation, the aim of this simulation is to determined heat and mass balance of major equipment of ORC system such as evaporator and condenser. The cycle tempo simulation were running by assuming capacity of steam turbine, hot water inlet to the evaporator and cool water inlet to condenser are 560 Watt, 95ºC and 10ºC, respectively. Cycle tempo simulation can also calculate the efficiency of the ORC system so that the efficiency between the design and the simulation results can be compare. Cycle tempo simulation for heat and mass balance of ORC system can be show in figure 1 as below:

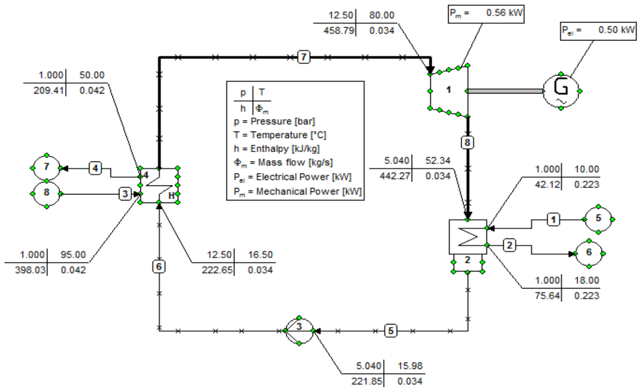

Fig. 1. Heat and mass Balance of Organic Rankine Cycle

B. *Experimental set up*

Power plant with ORC systems have been creating and manufactured at the Energy Conversion Laboratory, Department of Mechanical Engineering, Riau University. The ORC system has a generator capacity of 0.56 kW, and the heat source obtains from the hot water heated by the solar collector system, absorbed by the evaporator, and on the condenser supported by an air cooling system. The TC4S Au tonic temperature controller uses for heating and air conditioning systems. The working fluids used for the ORC and AC systems are R134a, respectively. Temperature data recording performed using Thermocouple type K, and data will record by OMEGA TC-08 data acquisition.

The ORC's main components include the evaporator, scroll expander, condenser, gear pump, solar collector, and other equipment. The solar collector works to heat the source air needed on the evaporator tube to turn refrigerant from looking to steam to rotate the scroll turbine. The turbine expander used is a Keihin HS-090R scroll type compressor, which operates in reverse. The heat exchanger used on the evaporator and condenser is the spiral type, and the tube used is a copper tube with a 3/8 inch diameter. The pumps used in the ORC system are ammonia fluid and gear pumps with a capacity of 1.08 m3 / h, maximum pressure of 2.5 MPa, and a full head of 25 meters with YUEMA type YAL90-4 1 pasha electric motor with 2 HP power. The fluid flow that works on the ORC system is flowed by the gear pump. It can be seen the ORC system in the schematic shown in figure 2.

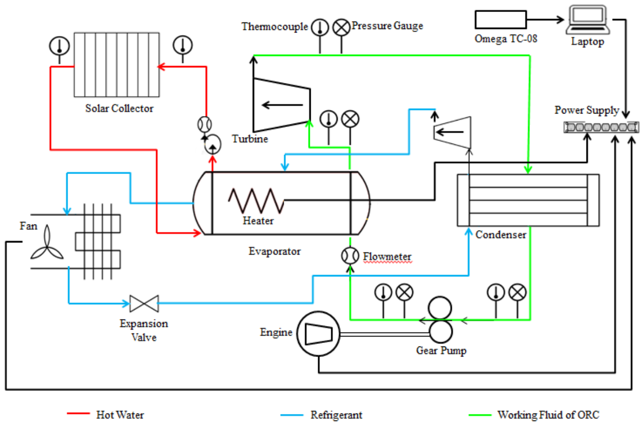

Fig. 2. Schematic of the Organic Rankine Cycle System

C. *Experimental preparation*

There are two heat exchanger systems in the organic Rankine system, the first is the evaporator and the second is the condenser. The evaporator receives heat from the heated water in the solar collector system and the condenser dissipates the heat in the water cooled by the air conditioning system

The ORC and solar collection systems were place with sufficient solar energy where the solar energy collection system is use to heat the water that flows into the evaporator to get the desired heat temperature variation. If the desired water temperature cannot be achieved using solar energy, then electric heater is use to cover the required energy requirements.

The air conditioning system is use to cool the water in the condenser tank up to 10°C to kept the phase of working fluid of ORC system in liquid phase and is maintained at a constant temperature using a temperature controller. When the desired water temperature is reach, the working fluid R134a is supplies to the ORC system. Furthermore, the thermocouple temperature-measuring device that has been prepared and connected to each point to be measure is connect to the Omega TC-08 data recorder. After all the experiment preparations have been complete, the data collection process can be start by starting the pump on the ORC system and activating the data recorder. Data collected in mass flow rates, temperatures, and pressures.

D. *Data Collection*

Experiments are carried out by heating water in the solar collector system with temperature variations of 75ºC, 85ºC and 95ºC to keep the working fluid of ORC in the gas phase. This hot water is used as an energy supply to the evaporator so that the working fluid (R134-a) of ORC system can evaporate and drive a steam turbine. In the experiment, the parameters of ORC measured are include the outlet pressure and temperature of the condenser, pump, evaporator, and turbine. Meanwhile, between the pump and the evaporator there is a flowmeter, which is used to measure the flow rate of the working fluid. Temperatures were collected and recorded with the Omega TC-08 data acquisition, while pressure and mass flow rate are read manually at 15-second intervals for 10 minutes for each temperature of working fluid that inlet to the steam turbine. Data starts to be collected at 11am-14 pm and the temperature of working fluid inlet to the steam turbine can be show in figure 3. The data collection process can be repeat using a variety of different heat sources with the same procedure.

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III. Results And Discussion

The experimental resulted that the solar collector is not able to achieve the desired temperature. The water temperature that can be achieved on the solar collector is only 52.3ºC, so to obtain a temperature variation of up to 95ºC an electric heater is needed and connected to the temperature control Au tonic Tc4s to keep the temperature constant. It is known from the results of the experiment that at variations in the heat source of 95ºC, the solar collector can contribute 4307.5 kj/kg from the total heat required 11582,4 kJ/kg or 37.2% of its total heat required. It can be seen in table 1 that the highest solar collector contribution is 4080.8 kJ from the total heat required 8171.9 kJ/kg or 49.9% of the total heat required, at the temperature of heat source is 75°C. So that the highest intensity of solar energy is when data collection for variant temperature is 75°C.

TABLE 1. SOLAR COLLECTOR CONTRIBUTION

Heat source temperature variation	Temperature reach by solar collector	Heat solar collector	Total heat	Solar collector contribution
°C	°C	kj/kg	kj/kg	%
95	52.3	4307.5	11582.4	37.2
85	47.8	3541.4	9874.4	35.8
75	51	4080.8	8171.9	49.9

Experimental investigation was carry out on ORC systems with variations in heat source temperature of 75°C, 85°C, and 95°C. In figure 2, it can be see the efficiency of the ORC system in various water temperature as a heat sources.

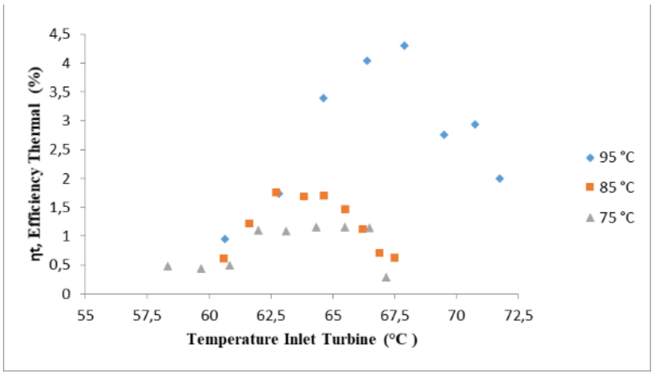

Fig.3 Efficiency of ORC System with Various Water Temperature

Experiment resulted that the highest efficiency data is 4.30% when the steam temperature of inlet turbine is 67.9ºC, the highest efficiency does not occur at the highest temperature turbine inlet. This could be because at the highest temperature, the steam leaving of the turbine is still at a high temperature, so that the heat release in the condenser is not optimal and results in the pump not working optimally because the steam coming out of the condenser is in gas and liquid phases. This phenomenon is similar to the previous research [3, 4, and 12].

The effect of the inlet pressure on the turbine is shown in figure 4 and from the experimental results with variations in the heat source, the higher the turbine inlet pressure will also produce higher ORC power. This is in accordance with the thermodynamic theory that the higher the pressure and temperature will also increase the enthalpy, thus causing the power generated by the turbine is also greater.

The experimental data's highest efficiency is compared with the simulation results to see the difference in efficiency and it has shown in Figure 5. The T-s diagram compares the highest experimental results and simulation results using Cycle Tempo shown in figure 5. The comparison above shows that the simulation results' area is greater than the size of the experiment results. Identifies that the cycle efficiency of the design results are more better than the experiment results. The thermal efficiency of the design with cycle tempo simulation and experimental results are 4.3% and 6.65%, respectively, with a difference of 2.35%. Thus, it can be concluded that the results of the experiments carried out have similar efficiency values in previous studies [4, 12, 13, and 14].

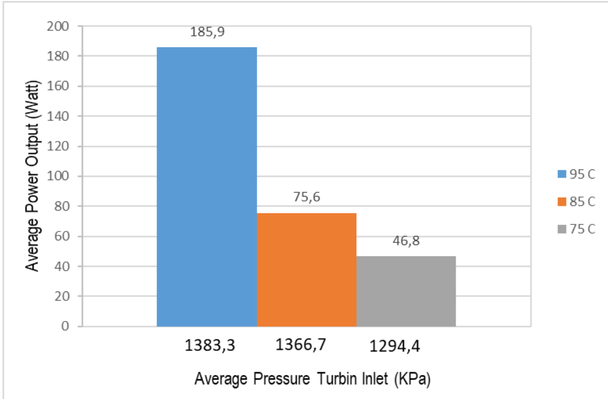

Fig. 4. Turbine Pressure Effect on ORC Power

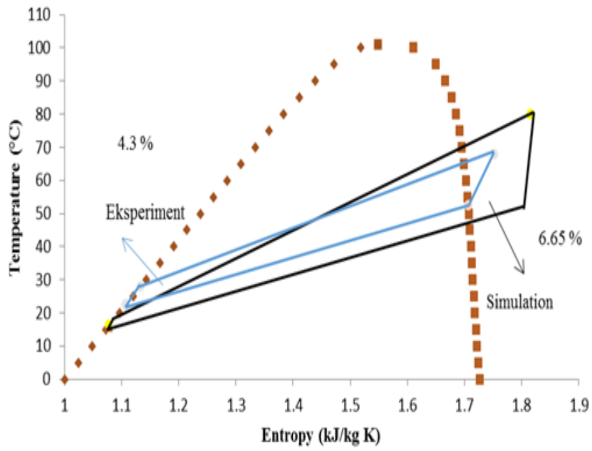

Fig. 5. Comparison of Experiment Performance and Simulation

IV. Conclusion

Experimental investigations of the ORC system using a solar collector as a heat source and R134a as a working fluid have been carry out with variations in the heat source temperature of 75°C-95°C. The optimum thermal efficiency and ORC power are 3.4% and 305.4 Watt respectively, with a heat source temperature of 95°C. The solar collector used as a heat source can save energy up to 49.9% with a hot water temperature of 51°C or equivalent to 4080 kJ where the total energy required is 8171.9 kJ.

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