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A Comparison on the Use of Isopentane and R22 in an Application of Tesla Turbine and Centrifugal Turbine in Organic Rankine Cycle

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Abstract: *This paper aims to compare the use of Isopentane and Refrigerant 22(R22) as working fluid expanding in an application of Tasla turbine and Centrifugal Turbine in Organic Rankine Cycle (ORC). The working fluid has fixed point below boiling water and works in low-temperature sources between 80-120 ℃ which can be produced from waste heat, solar-thermal energy and geothermal energy etc. The experiment on ORC using Tasla turbine and Centrifugal Turbine reveals that the suitability of high pressure pump for working fluid has result on the efficiency of work. In addition, Thermodynamics theory on P-h diagram also presents the effect of heat sources' temperature and flow rate on any work. Thus, the study and design on ORC machine has to concern mainly on pressure pump, flow rate and optimized temperature. Result of experiment and calculation of ORC using Isopentane efficiency is 30% better than R22 estimate. Result experiment and calculate ORC Machine using centrifugal Turbine efficiency is better than Tesla turbine 28% but Tesla Turbine is much cheaper and easily structure. Further study on the machine can be developed throughout the county due to its low cost and efficiency. The Tesla Turbine is cheaper and easily structure than other turbines which can be applicable on Organic Rankine Cycle Machine. Further study on the machine can be developed throughout the county due to its low cost and efficiency.*

Keywords: Tesla turbine, organic Rankine cycle, low-temperature sources, flow rate, high pressure pump

1. INTRODUCTION

This paper aims to compare the use of Isopentane and Refrigerant 22(R22) as working fluid expanding in an application of Tasla turbine and Centrifugal Turbine in Organic Rankine Cycle (ORC).At present, people in all around the world are concerned with Energy and Environment issues since various countries are entering into the age of energy shortage and climate change. The main reason is from an excess consumption on fossil fuel for developing infrastructure and urging economic growth. Anyway, people those recognizing the critical problems have tried on their efforts to find the solution which promote a sustainable development. One of the most effective solutions is using renewable energy that is friendly to environment. [1-2]. Solarenergy is, therefore,developed to generate electricity because of its low cost and efficiency.[3] The use of organic Rankine cycle with thermal energy storage system produces of electricity will decrease the expense on conventional oil. In addition, the design and test of Organic Rankine Cycle with thermal powerplants using turbine expander can save much more cost due to its source can derive from within country. However, there are some efforts.

The Organic Rankine Cycle (ORC) is Rankine cycle with organic working fluid that has boiling point below water boiling point and it works in low-temperature sources between 80-120 °C. Thus, it is produced from various natural and renewable sources such as geothermal energy, waste heat, solar-thermal energy etc. to generate electricity. [4] The Organic Rankine Cycle consists of solar collector, thermal energy storage system and organic Rankine cycle power system with a comparison on the use of Isopentane and Refrigerant 22 as working fluid and turbine expander for shaft work.

2. THEORY

The actual heat transfer may be computes by calculating either the energy lost by hot fluid or the energy or the cold fluid, as show in equation (1). [5], [6]

$$q_H = \dot{m} C_p (T_{in} - T_{out}) \quad (1)$$

2.1 RANKINE CYCLE: THE IEDEAL CYCLE FOR VOPOR POWER CYCLE [5]

Many of the impracticalities associated with the Carnot cycle can be eliminated by superheating the steam in the boiler and condensing it completely in the condenser, as shown schematically on a T-s diagram and a P-h diagram in

Fig.1. The cycle that results is the Rankine cycle, which is the ideal cycle for vapor power plants. The ideal Rankine cycle does not involve any internal irreversibilities and consists of the following four processes: [5]

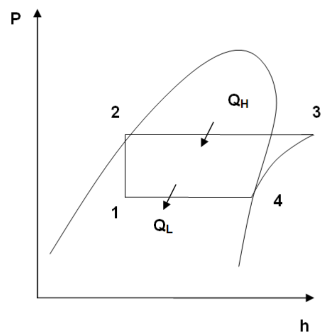

Fig. 1. P-h diagram of the Rakine cycle

1-2 Isentropic compression in a pump

2-3 Constant pressure heat addition in a boiler

3-4 Isentropic expansion in a turbine

4-1 Constant pressure heat rejection in a condenser

2.1.1 ENERGY ANALYSIS Of The IDEAL RANKINE CYCLE

All four components associated with the Rankine cycle (the pump, boiler, turbine, and condenser) are steady-flow devices, and thus all four processes that make up the Rankine cycle can be analyzed as steady-flow processes. The kinetic and potential energy changes of the steam are usually small relative to the work and heat transfer terms and are therefore usually neglected.[8] Then the steady-flow energy equation per unit mass of steam reduces to

$$(q_{in} - q_{out}) + (W_{in} - W_{out}) = h_e - h_{in} \quad (2)$$

The boiler and the condenser do not involve any work, and the pump and the turbine are assumed to be isentropic. Then the conservation of energy relation for each device can be expressed as follows:

Pump $(q=0)$: $W_{pump,in} = h_2 - h_1$ (3)

Boil $(W=0)$: $q_{in} = h_3 - h_2$ (4)

Turbine $(q=0)$: $W_{turbine,out} = h_3 - h_4$ (5)

Condenser $(W=0)$: $q_{out} = h_4 - h_1$ (6)

The thermal efficiency of the Rankine cycle is determined from

$$\eta_{the} = \frac{W_{net}}{q_{in}} = 1 - \frac{q_{in}}{q_{out}} \quad (7)$$

Where

$$W_{net} = q_{in} - q_{out} = W_{turb} - W_{pump,in}$$

2.2 DETERMINATION OF POWER FROM TORQUE AND ANGULAR SPEED [7]

Apart from the direct measurement of power, it can also be calculated from equation (8) once the torque and angular velocity are known

$$P = \tau\omega \quad (8)$$

In paper of Design of Tesla Turbine [7] reference to the change in speed the mechanism becomes very flexible [8]. Mr. Tesla claimed that the total effectiveness of his turbine could reach up to 98% [9]. Professor Warner Rice tried to renew Tesla's experiments. He used pressure air as a work substance. He reached a total effectiveness between 36% and 41% through his experiment [9]. Professor Rice published a mimeographed named "Tesla Turbomachinery" in 1990 [9], where he specified that by using analytic results the effectiveness of the rotor could be very high (up to 95%) with the effect of laminar flow [9].

The most important parameters that affect the performance and efficiency of disc turbomachinery, [5] as outlined by Cairns [8] and Rice [9], are as follows:

(a) spacing between the discs;

(b) characteristics of the fluid and the flow, such as velocity ratio;

(c) conditions of the surfaces of the disc and radius ratio;

(d) radial and axial clearances between the rotor and the housing.

3. EQUIPMENT AND DATA COLLECTING POSITION.

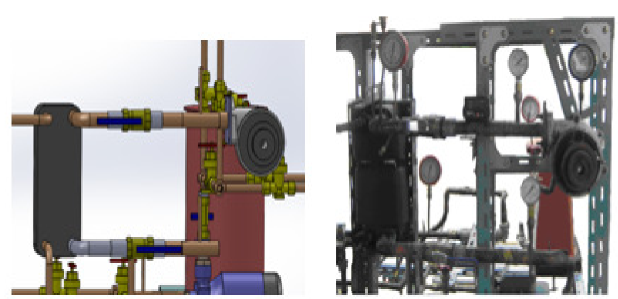

Fig.2. The Organic Rankine Cycle system and data collecting position [10]

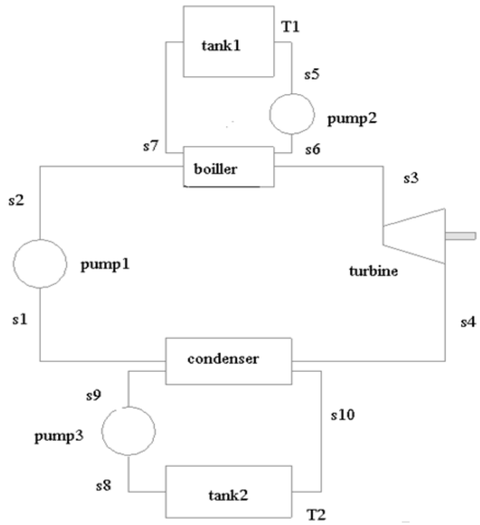

Fig. 3. The diagram of Organic Rankine Cycle system and data collecting position. [10]

3.1 EXPERIMENT METHODS, THE USE OF ISOPENTANE AS WORKING FLUID EXPANDING.

1. Preparing the water in a hot water storage tank at temperature 90°C.
2. Open water valve the hot water storage tank sends the hot water flows to reach inside boiler.
3. Open working fluid valve expanded through Centrifugal Turbine.
4. Recording data saving follow all position.
5. Starting step 1 to 4again by change temperatures in the hot water storage tank at temperature 80 and 70°C respectively.
6. Starting step 1 to 5again by changingTesla Turbine in the system at temperature 90, 80 and 70°C respectively.

3.2 EXPERIMENT METHODS, THE USE OF REFRIGERANT 22 AS WORKING FLUID EXPANDING.

1. Preparing the water in a hot water storage tank at temperature 90°C.
2. Open water valve the hot water storage tank sends the hot water flows to reach inside boiler.
3. Open working fluid valve expanded through Turbine.
4. Recording data saving follow all position.
5. Starting step 1 to 4again by change temperatures in the hot water storage tank at temperature 80 and 70°C respectively.
6. Starting step 1 to 5again by changing Tesla Turbine in the system at temperature 90, 80 and 70°C respectively.

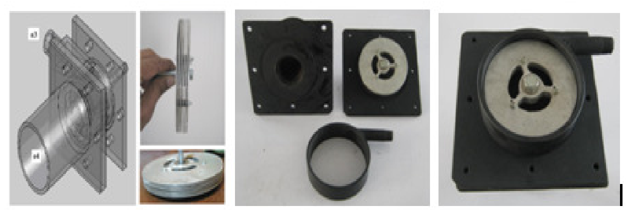

Fig. 4.Tasla turbine plate of the Experiment. [11]

4. RESULTS AND DISCUSSION

4.1 EXPERIMENT METHODS, THE USE OF ISOPENTANE AS WORKING FLUID EXPANDING.

Theory for calculate, Organic Rankine Cycle, using heat source attemperatures 90, 80 and 70 °C respectively, calculating by approximately from the experiment and comparison with P-h and T-s Diagram of a working fluid, as follows.

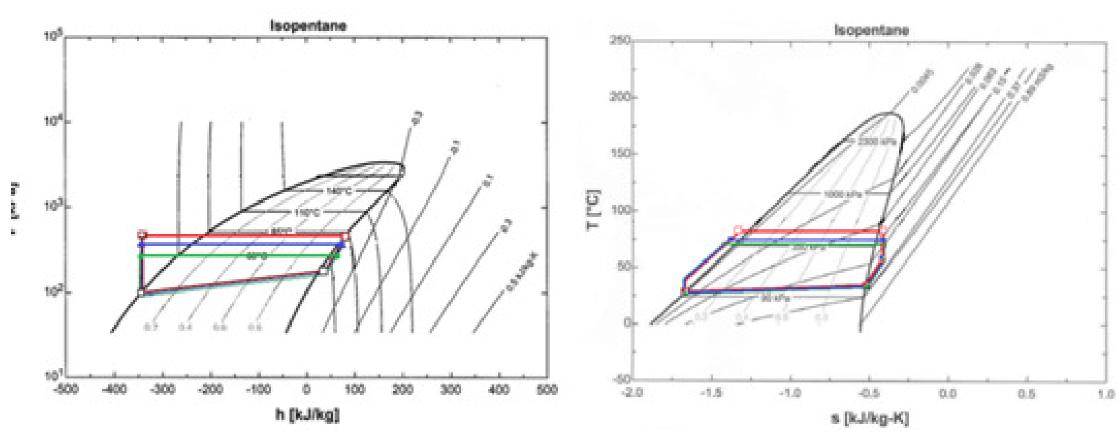

Fig. 5. P-h and T-s diagrams of isopentane application for Organic Rankine Cycle. [10]

-Red line using heat source attemperatures 90°C

-Blue line using heat source attemperatures 80°C

-Green line using heat source attemperatures 70°C

4.1.1 RESULTS (TESLA TURBINE)

Organic Rankine Cycle system, using heat source attemperatures 90°C, result the working fluid through turbine at pressure and temperature inlet state 6 bar and 80 °C respectively, at pressure and temperature outlet state 1 bar and 30 °C respectively, output power 35 kJ/kg and The thermal efficiency equals 8.3%.

Organic Rankine Cycle system, using heat source attemperatures 80°C, result the working fluid through turbine at pressure and temperature inlet state 5 bar and 70 C respectively, at pressure and temperature outlet state 1 bar and 30 °C respectively, output power 24.5 kJ/kg and The thermal efficiency equals 6.2%.

Organic Rankine Cycle system, using heat source attemperatures 70°C, result the working fluid through turbine at pressure and temperature inlet state 4 bar and 60 °C respectively, at pressure and temperature outlet state 1 bar and 30 °C respectively, output power 14 kJ/kg and the thermal efficiency equals 3.6%.

4.1.2 RESULTS (CENTRIFUGAL TURBINE)

Organic Rankine Cycle system, using heat source at temperatures 90 °C, result the working fluid through turbine at pressure and temperature inlet state 6 bar and 80 °C respectively, at pressure and temperature outlet state 1 bar and 30 °C respectively, output power 50 kJ/kg and The thermal efficiency equals 11.9%.

Organic Rankine Cycle system, using heat source at temperatures 80 °C, result the working fluid through turbine at pressure and temperature inlet state 5 bar and 70 C respectively, at pressure and temperature outlet state 1 bar and 30 °C respectively, output power 35 kJ/kg and The thermal efficiency equals 8.6%.

Organic Rankine Cycle system, using heat source at temperatures 70 °C, result the working fluid through turbine at pressure and temperature inlet state 4 bar and 60 °C respectively, at pressure and temperature outlet state 1 bar and 30 °C respectively, output power 20 kJ/kg and The thermal efficiency equals 5.1%.

4.2 Experiment Methods, the use of Refrigerant 22 (R22) as working fluid expanding.

Theory for calculate, Organic Rankine Cycle, using heat source attemperatures 90, 80 and 70 °C respectively, calculating by approximately from the experiment and comparison with P-h Diagram of a working fluid, as follows.

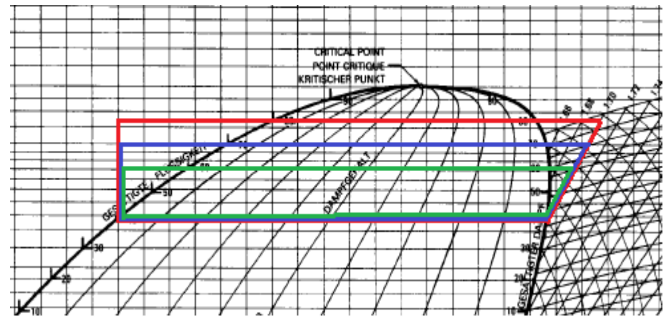

Fig. 6.P-h diagram of R22 application for Organic Rankine Cycle. [11],[12]

-Red line using heat source attemperatures 90°C

-Blue line using heat source attemperatures 80°C

-Green line using heat source attemperatures 70°C

4.2.1 RESULTS (TESLA TURBINE)

Organic Rankine Cycle system, using heat source attemperatures 90°C, result the working fluid through turbine at pressure and temperature inlet state 37 bar and 80 °C respectively, at pressure and temperature outlet state 15 bar and 40 °C respectively, output power 15.4 kJ/kg and The thermal efficiency equal 8.5%.

Organic Rankine Cycle system, using heat source attemperatures 80°C, result the working fluid through turbine at pressure and temperature inlet state 29 bar and 70 C respectively, at pressure and temperature outlet state 15 bar and 40 °C respectively, output power 9.1 kJ/kg and The thermal efficiency equal 5.0 %.

Organic Rankine Cycle system, using heat source attemperatures 70°C, result the working fluid through turbine at pressure and temperature inlet state 15 bar and 60 °C respectively, at pressure and temperature outlet state 15 bar and 40 °C respectively, output power 4.2 kJ/kg and The thermal efficiency equal 2.3 %.

4.2.2 RESULTS (CENTRIFUGAL TURBINE)

Organic Rankine Cycle system, using heat source at temperatures 90 °C, result the working fluid through turbine at pressure and temperature inlet state 6 bar and 80 °C respectively, at pressure and temperature outlet state 1 bar and 30 °C respectively, output power 20 kJ/kg and The thermal efficiency equals 12 %.

Organic Rankine Cycle system, using heat source at temperatures 80 °C, result the working fluid through turbine at pressure and temperature inlet state 5 bar and 70 C respectively, at pressure and temperature outlet state 1 bar and 30 °C respectively, output power 11.8 kJ/kg and The thermal efficiency equals 7.1 %.

Organic Rankine Cycle system, using heat source at temperatures 70 °C, result the working fluid through turbine at pressure and temperature inlet state 4 bar and 60 °C respectively, at pressure and temperature outlet state 1 bar and 30 °C respectively, output power 6 kJ/kg and The thermal efficiency equals 5.5 %.

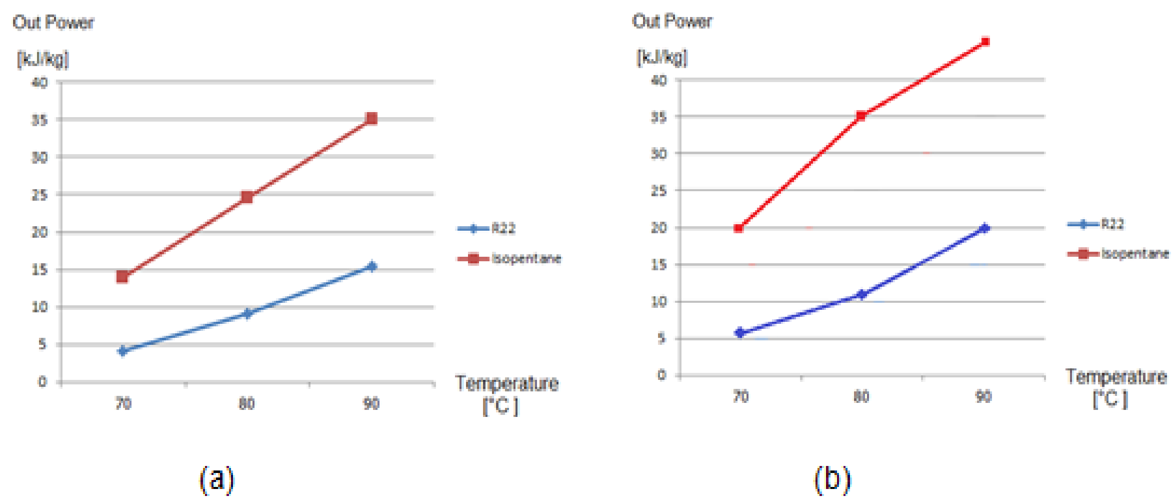

Fig. 7. Result of comparison on (a) isopentane and Refrigerant 22(Tesla Turbine)

Result of comparison on (b) isopentane and Refrigerant 22 (Centrifugal Turbine)

Result of experiment and calculation of ORC using Isopentane efficiency is 30% better than R22 estimate. Result experiment and calculate ORC Machine using centrifugal Turbine efficiency is better than Tesla turbine 28% The Tesla Turbine is cheaper and easily structure than other turbines which can be applicable on Organic Rankine Cycle Machine.

The study reveals that, low-temperature sources have low power output also. If we use low-temperature sources for suitable, it will appropriate make the interesting development, it is produced from various natural and renewable sources such as geothermal energy, waste heat, solar-thermal energy etc.The suitability of high pressure pump for working fluid has result on the efficiency of work. In addition, Thermodynamics theory on P-h diagram also presented the effect of heat sources' temperature and flow rate on any work. Thus, the study and design on ORC machine has to concern mainly on pressure pump, flow rate and optimized temperature. Further study on the machine can be developed throughout the county due to its low cost and efficiency.

5. CONCLUSIONS

From the experiment based on calculation theory, Organic Rankine Cycle using Isopentane and Refrigerant 22 (R22) as working fluid expanding through Turbine that has heat source attemperatures 90, 80 and 70 °C, result of Isopentane as working fluid through Turbine at pressure and temperature inlet state 6, 5 and 4 bar and 80, 70 and 60 °C respectively, at pressure and temperature outlet state 1, bar and 30 °C respectively, (Tesla Turbine)output power 35, 24.5 and 14 kJ/kg respectively, and The thermal efficiency equal 8.3, 6.2 and 3.6%,(Centrifugal Turbine)output power 50, 35 and 20 kJ/kg respectively, and the thermal efficiency equal 11.9, 8.6 and 5.1%,respectively. Result of R22 as working fluid through Turbine at pressure and temperature inlet state 37, 29 and 15 bar and 80, 70 and 60 °C respectively, at pressure and temperature outlet state 15 bar and 40 °C respectively, (Tesla Turbine)output power 19.9, 8.6 and 5.1 kJ/kg respectively, and The thermal efficiency equal 8.5, 5.0 and 2.3 %respectively. %,(Centrifugal Turbine)output power 20, 11.8 and 6 kJ/kg respectively, and the thermal efficiency equal 12, 7.1 and 5.5%,respectively. Result of experiment and calculation of ORC using Isopentane efficiency is 30% better than R22 estimate. Result experiment and calculate ORC Machine using centrifugal Turbine efficiency better than Tesla turbine 28%. The Tesla Turbine is cheaper and easily structure than other turbines which can be applicable on Organic Rankine Cycle Machine. The study reveals that low-temperature sources have also low power output. If we use suitable low-temperature sources, it can be made interesting development.Generally, it is produced from various natural and renewable sources such as geothermal energy, waste heat, solar-thermal energy etc. Thus, the study and design on ORC machine has to concern mainly on pressure pump, flow rate and optimized temperature. Further study on the machine can be developed throughout the county due to its low cost and efficiency.

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