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# Potential development of organic Rankine cycle (ORC) power generation system by utilizing heat from natural hot-spring in Malaysia

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**Abstract**. Organic Rankine Cycle (ORC) is widely used because of its ability to work with low and medium-grade heat resources. ORC basically operate by using organic working fluid which allows the application of Rankine Cycle to be operate at various range of heat resources depend on the properties of working fluid. This allows wide application of ORC power cycle at temperature below 370 °C where the steam-based Rankine Cycle are no longer efficient. This present paper discusses the potential development of micro power generation based on the ORC concept by utilizing heat from natural hot spring in Malaysia. The performance of the systems is analysed based on three different working fluids which are R134a, R410a and R245-fa. The comparison was done by the variation of hot water inlet temperatures in the range of 50 °C to 75 °C at the evaporator and 25 °C of ambient water at the condenser. The results indicates that R245-fa had 9 % thermal efficiency when the hot water inlet temperature is 75 °C which is the highest among the other working fluids in the similar condition. Meanwhile, the ideal power output of turbine is also analysed. The R410 can generate 2.38 kW power output when the input temperature of hot water is 75 °C which is the highest as compared to other working fluid at similar condition. Therefore, it can conclude that the micro-scale power generation systems can be developed based on ORC power cycle by utilizing heat resources by natural hot spring in Malaysia.

## 1. Introduction

The depletion of fossil fuels and environmental problems have led to the research and development of energy conversion systems through the utilization of renewable energy resources. Therefore, Organic Rankine Cycle (ORC) is widely being used because of its ability to work with low and medium-grade heat resources. As a result, new resources from renewable energy such as solar heat, biomass, geothermal and waste heat from industries with a temperature range between 50 °C to 200 °C can be exploited to become an alternative in generating electricity [1] [2]. ORC basically operates by using organic working fluid which allows the application of Rankine Cycle to operate at various ranges of heat resources depend on the properties of the working fluid. This allows wide application of ORC power cycle at temperature below 370 °C where the steam-based Rankine Cycle are no longer efficient [3].

In Malaysia, the natural hot spring has a such potential to be utilized as the heat resources in the ORC power generating system. There are about 60 hot springs that have been discovered in peninsular of

Malaysia where 75% of them are in easy access area, most of them are developed for recreational and tourism purposes [4] [5]. Table 1 shows the Range of surface temperature and flow rate of hot springs in the Peninsular Malaysia where the temperature was observed to be below 100°C where it varies between 27°C to 98°C and the range of flowrate from 0 – 20 l/s with the average of 2.03 l/s [6].

**Table 1.** Elevation, Temperature and flowrates of thermal hot springs in the Peninsular Malaysia [4].

| Parameter | **Minimum** | **Maximum** |
|---|---|---|
| Elevation (above sea level) (m) | 3 | 420 |
| Temperature (°C) | 27 | 98 |
| Flowrate (l/s) | 0 | 20 |

Figure 1 shows several locations of the thermal hot spring located in the Peninsular Malaysia [7]. Typically, most thermal water exists in small pools and puddles, with sizes in the range of 1-5 $m^2$. Meanwhile, Figure 2 shows the temperature and flowrate distribution of natural thermal springs in the Peninsular Malaysia. The surface water temperature of most hot spring in Malaysia is in the range of 40°C to 75°C.

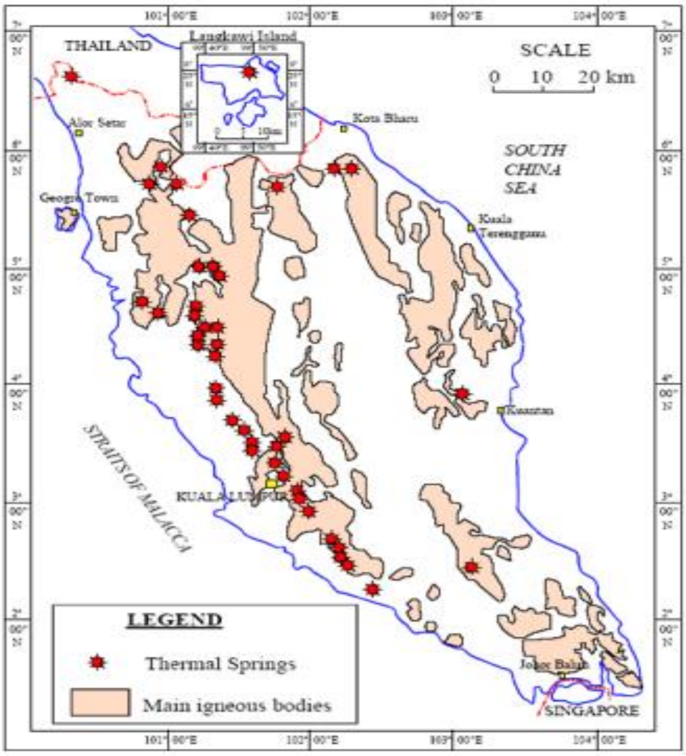


**Figure 1.** Thermal spring locations in Peninsular Malaysia [7].

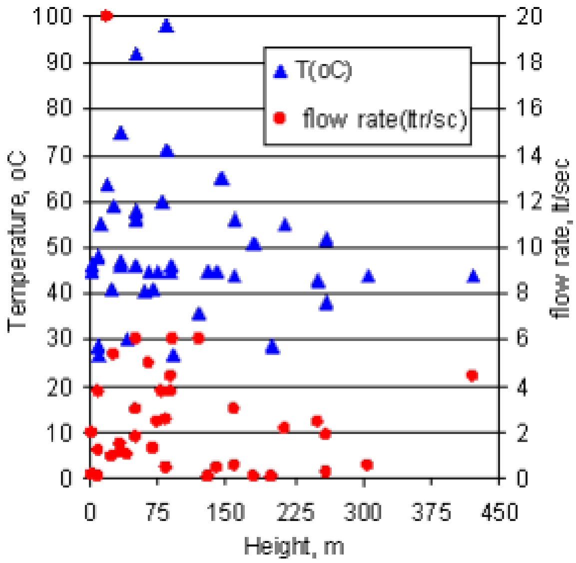


**Figure 2.** Temperature and flow rate distribution of natural thermal springs in the Peninsular Malaysia [4].

Therefore, previous data shows that most of the natural hot springs in Malaysia can be exploited for micro-scale power generation systems by using ORC. Recently, the ORC power cycle has received a lot of attention for low-temperature applications, and researchers continuously enhance cycle efficiency to take advantage of low-heat resources like renewable energy or waste heat [8]. Park et al. [9] review experimental studies of ORCs where 15 of the 58 experimental tests analyses had heat input temperatures under 100 °C, and two of them are under 70 °C. Therefore, ORC power generation for low-grade heat resources needs further study before the system can be developed and widely used due to its low cycle efficiency.

## 2. Organic Rankine Cycle (ORC) Working Principal

Similar to conventional Rankine Cycle, ORC operated by four basic main components which are the evaporator, condenser, pump and turbine. However, ORC utilized organic substances as a working fluid such as hydrocarbons and refrigerants instead of water steam [10-11]. This gives advantages towards the cycle where the working fluid used has lower condensation and boiling point than water which is commonly used in the conventional Rankine cycle. As a result, low and medium grade-heat resources can be exploited to generate the cycle. Figure 3 shows the general schematic diagram of the ORC configuration for power generation system and Figure 4 is shown in the T-s diagram for an ORC thermodynamics cycle that has been proposed in this study.

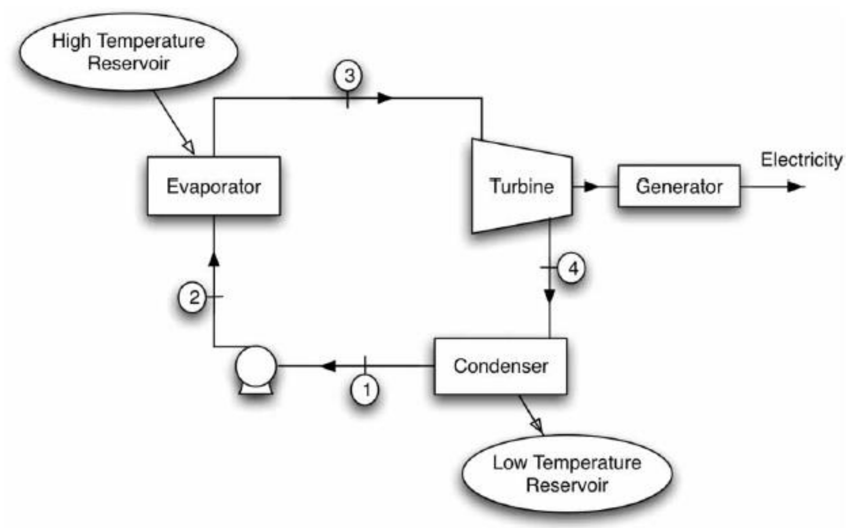


**Figure 3.** ORC energy conversion schematic diagram [12].

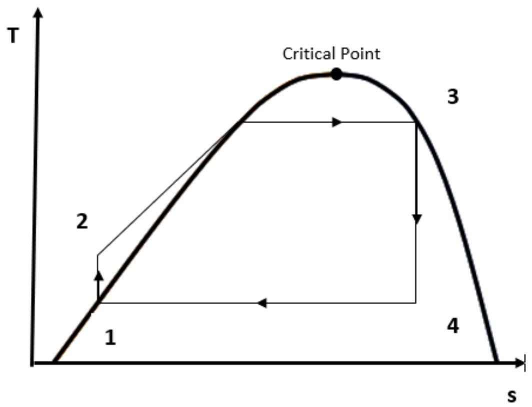


**Figure 4.** T-s diagram of ORC thermodynamics cycle.

From the figures, working fluid such as refrigerant is pumped from point 1 to point 2 to feed the working fluid which is in liquid form into the evaporator. This process will increase the pressure as well. The fluid is then heated from point 2 into saturated vapor at point 3. The high-pressure vapor is then expanded towards the turbine from point 3 to low pressure vapor mixture at point 4. At this stage the thermal energy is converted to mechanical energy through the shaft for generating electricity. The working fluid is then condensed in the condenser from saturated mixture at point 4 into the saturated liquid at point 1. The working fluid is then pumped back into the evaporator to repeat the cycle [13-14].

### *2.1. Working Fluid Selection.*

In ORC there is a wide selection of working fluids. The working fluid selection must consider the basis of safety such as low toxicity, flammability and fouling characteristics [15]. With the increase of awareness towards global environmental issues, the selection of working fluid must have low global warming potential (GWP) and ozone depletion potential (ODP) [16]. Therefore, refrigerants such as R134a, R410a and R245fa are commonly used as the working fluid in ORC power cycles due to the low-toxicity characteristics [17]. The R134a, R410a and R245fa are common refrigerants that being used in air conditioning and refrigerator systems. They are all the new generation refrigerants made of

Hydrofluorocarbon (HFCs) in order to replace the chlorofluorocarbon (CFCs) refrigerants where the present of chlorine content contribute to the depletion of ozone layer. R134a, also known as 1,1,1,2-Tetrafluoroethene and chemical formula of $CH_2FCF_3$, have the molecular weight of 102.03 g/mol and boiling point of -26.06°C at atmospheric pressure. Meanwhile, the R410a is a mixture of Pentafluoroethane and Difluoromethane by 50/50 % of weight. The chemical formula of R410a is $CH_2F_2/CHF_2CF_3$ with the molecular weight of 72.58 g/mol and boiling point of -51.58 °C at atmospheric pressure. The R245fa on the other hand also known as 1,1,1,3,3- Pentafluoropropane have the chemical formula of $CF_3CH_2CHF_2$. The molecular weight and boiling point at atmospheric pressure are 134.05 g/mol and 15.13 °C.

Table 2 shows refrigerants' GWP and ODP that are used in this study [18-19]. This is due to the availability of data and commonly found in references [20-21].

**Table 2.** Critical Temperature, GWP and ODP of selected refrigerants

| Refrigerants | **Critical Temperature (°C)** | **GWP** | **ODP** |
|---|---|---|---|
| R134a | 101.1 | 1160 | 0 |
| R410a | 72.8 | 1890 | 0 |
| R245fa | 154.01 | 950 | 0 |

In addition to safety considerations, choosing the right working fluid is essential to optimize heat extraction from the hot stream and achieving high cycle thermal efficiency. Two thermodynamic properties that are commonly used during the pre-selection of working fluid which are the slope of the saturated vapor curve and the critical temperature. The saturated vapor curve is characterized based on their slope of saturation vapor in the T-s diagram as dry, isentropic and wet fluids. The slope of a dry fluid is positive, while the slope of wet fluid is negative, and the slope of isentropic fluid has infinite large slopes. In application, because they do not condense after passing through the turbine, dry and isentropic fluids are preferable as a working fluid for an ORC. [10,22]. The working fluid on the other hand must exhibit a critical temperature value larger than the heat source's inlet temperature in order to evolve in a saturated cycle [11]. Therefore, this present paper highlights the comparison of three refrigerants which have variation of temperature different between its critical temperature and maximum heat source temperature.

## 3. Case Study Analysis

This present paper conducted performance analysis of the simple ORC power generation system by using average heat resources from natural hot spring in Malaysia. Three different commonly used refrigerants in ORC were introduced which are R134a, R410a and R245fa with the objectives of studying the difference in thermal efficiency of the systems and the ideal power output at the turbine. The heat resources for evaporator which were in this case is the hot water from the hot spring were set from 50°C to 70°C while the condenser cooling resource was considered to be fixed at the ambient water temperature, that is 25°C. The mass flow rate of water for both evaporator and condenser were constant at 1 kg/s. The assigned condition for hot water at the evaporator heat exchanger and cold water at condenser heat exchanger are presented in table 3.

**Table 3.** Assign condition for temperature and mass flow rate at inlet of evaporator and condenser.

| Parameter | **Value** |
|---|---|
| Hot water inlet temperature (°C) | 50 - 75 |
| Cold water inlet temperature (°C) | 25 |
| Mass flow rate of hot water (kg/s) | 1 |
| Mass flow rate of cold water (kg/s) | 1 |

The working fluid of ORC were assumed to be saturated vapor at the outlet of the evaporator before entering the turbine inlet. While at condenser outlet is assumed to be saturated liquid before entering the pump. For both evaporator and condenser, a fixed temperature difference of 5°C is imposed at pinch point temperature [22]. The pinch point temperature is fixed to simplify the calculation of the working fluid's temperature of the heat exchanger without precise geometry design or any computation of the heat exchanger. The pinch point temperature corelation are present in equation (1) where $T_{hwp}$ is the temperature of hot water at pinch point condition under condition of saturated liquid of the working fluid. The $T_{orcP}$ is the temperature of working fluid at the saturated liquid, and $\Delta T_{pp}$ is the pinch point temperature which are the difference of temperature between hot water stream and working fluid stream where 5°C is used in this study.

$$T_{hwp} = T_{orcP} + \Delta T_{pp} \tag{1}$$

Meanwhile, the working fluid mass flowrate was determined by assuming the heat transfer from the hot water to the refrigerant saturated liquid temperature is 11 kW [13]. The heat transfer from the cold water to the condenser pinch point is assumed to be 11 kW as well. The working fluid mass flowrate and the heat transfer in heat exchanger are given in equation (2) and (3). The $\dot{m}_{orc}$ and $\dot{m}_{hw}$ are the mass flow rate for working fluid and hot water, while $h_{hwi}$, $h_{hwp}$ and $h_{orcsl}$ are the enthalpy for hot water inlet, hot water at pinch point and working fluid at saturated liquid condition. $Q_{evaP}$ is the heat transfer from the inlet of the hot water to the pinch point temperature of hot water.

$$\dot{m}_{orc} = \frac{\dot{m}_{hw}\,(h_{hw\dot{\iota}} + h_{hwp})}{h_{orcp}(T_{orcP})} \tag{2}$$

$$Q_{evaP} = \dot{m}_{hw}\,(h_{hwi} - h_{hwP}) \tag{3}$$

In this study, analysis is done by the assumption of the flow is in steady state condition and all the pressure drop in the evaporator, condenser and pipes are neglected. The isentropic expansion and compression process are also assumed to occur at turbine and pump. The ORC thermal efficiency, $\eta_{th}$ is defined in equation (4) while the ideal power of the turbine output is defined in equation (5). In equation (4) $Q_{out}$ is defined as the heat transfer rate at the condenser while $Qin$ is the heat transfer rate at the evaporator. In equation (5), the $h_{i,t}$ and $h_{o,t}$ are the turbine inlet and outlet enthalpy while $\dot{m}_{orc}$ is defined as the mass flowrate of the working fluid. The overall research methodology flowchart is present in Figure 5.

$$\eta_{th} = \frac{w_{net}}{q_{in}} \tag{4}$$

$$\dot{W}_{out} = \dot{m}_{orc}(h_{i,t} - h_{o,t}) \tag{5}$$

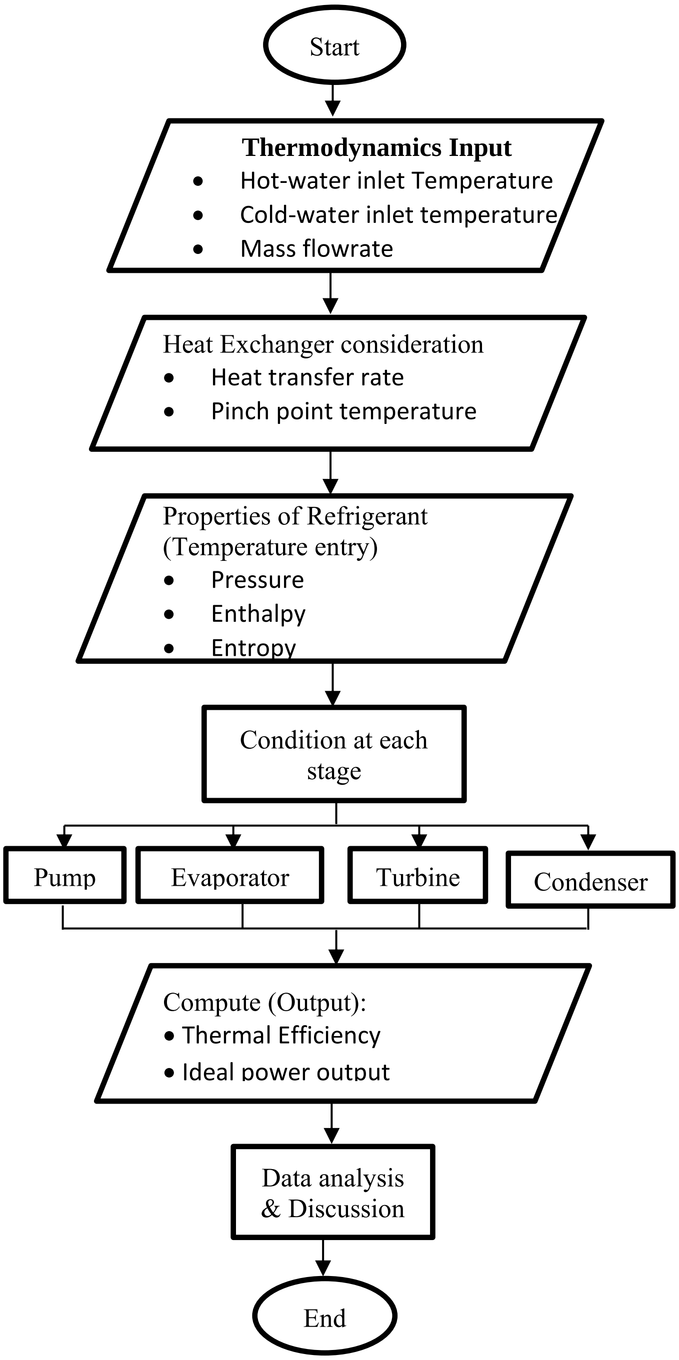


**Figure 5.** Methodology Flowchart.

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## 4. Result and Discussion

There are two main analyses discussed in this part, which is the thermal efficiency of ORC and ideal power output of the system. For the purposes of those studies, three organic refrigerants were employed which are R410a, R134a and R245fa. The results of those working fluids were compared with similar operating conditions.

### *4.1. Thermal Efficiency of the systems.*

The thermal efficiency of the system can be described as the fraction of the amount of heat input that is converted to net work output [21]. Figure 6 shows the results of the thermal efficiency of the refrigerants on the different temperature of the hot water inlet. The results indicates that the thermal efficiency increased as the hot water inlet temperature increased. Based on the results, R245fa has the higher thermal efficiency when the hot water inlet temperature is at 75 °C which is 1.9% more than R134a and 11% more than R410a. This is because of the high enthalpy difference between the saturated liquid and saturated vapor of R245fa at 75 °C as compared to others refrigerant. This can be seen in the graph shown in Figure 7. The graph indicates the amount of heat being transferred at the evaporator as a function of the hot water inlet temperature. From the graph, the heat transfer at the evaporator increases as the hot water inlet temperature increases for both R245fa and R134a. Meanwhile, for R410a, the heat transfer at the evaporator decreases as the hot water inlet temperature increases. This is because as the hot water inlet temperature increases, the refrigerant state of condition is approaching the critical temperature, where the difference of enthalpy and entropy values decreases as the temperature increases. This is difference with R134a and R245fa where their critical temperatures are larger than the maximum hot water inlet temperature. However, as the hot water inlet temperature decreases, the thermal efficiency becomes almost equal for all three types of refrigerants.

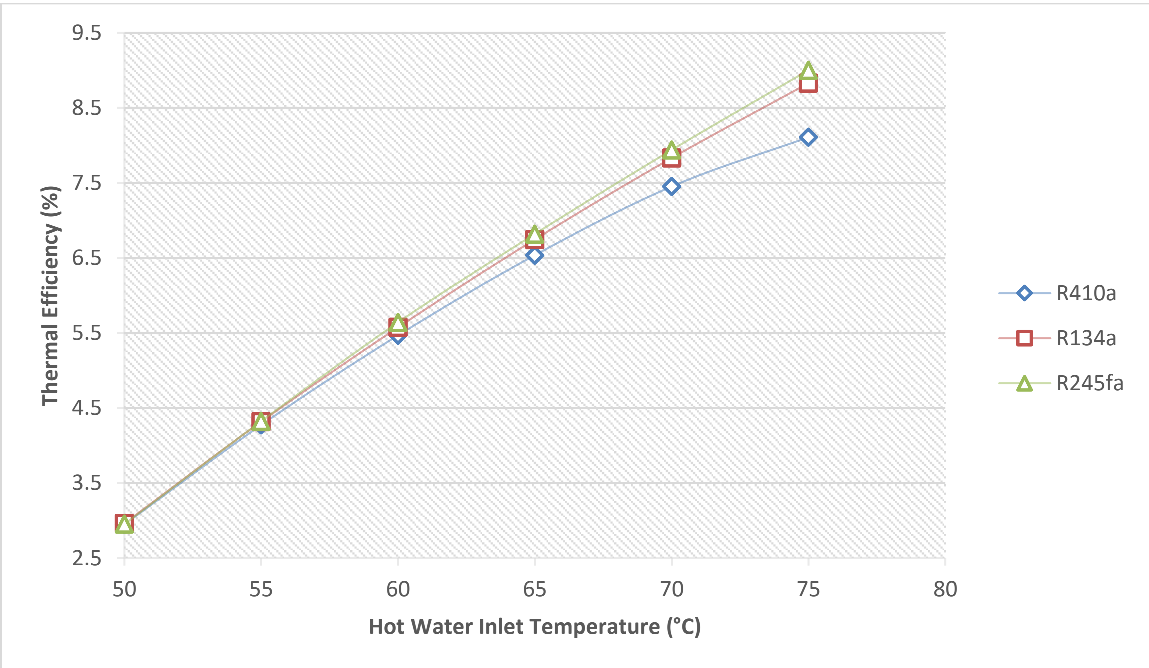


**Figure 6.** Thermal Efficiency vs Hot Water Inlet Temperature.

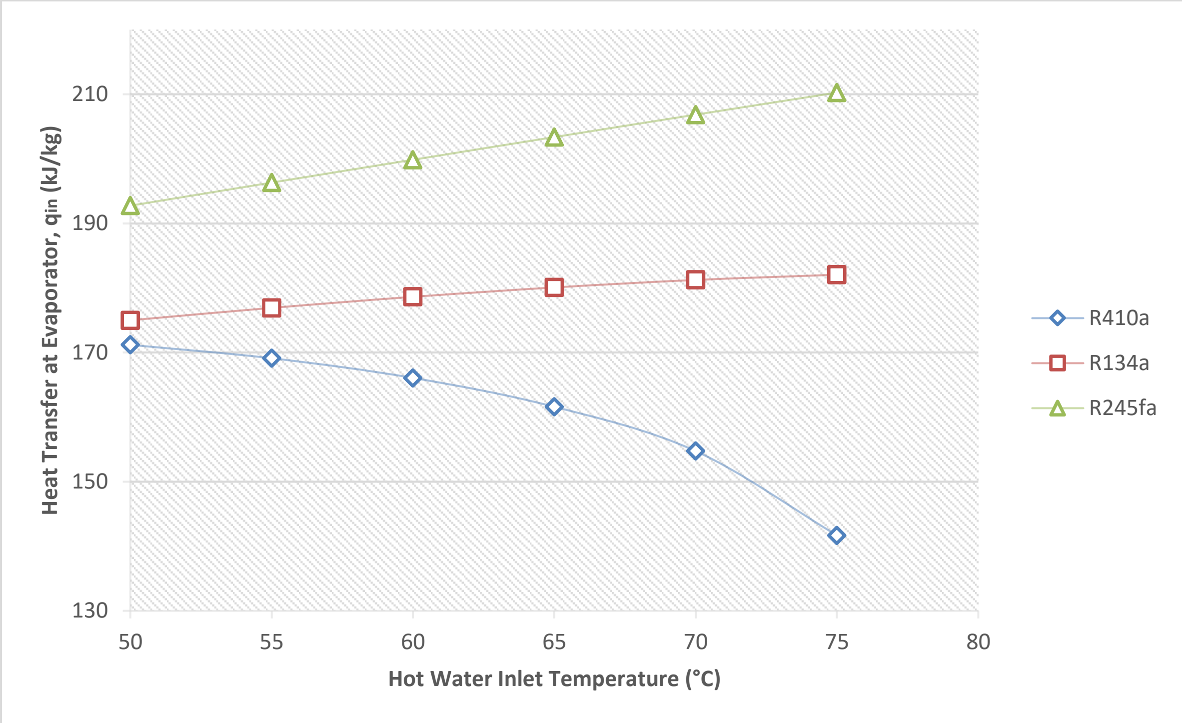


**Figure 7.** Heat Transfer at Evaporator vs Hot Water Inlet Temperature.

*4.2. Ideal Power Output of the system.*

The ideal power output of the system is described as the amount of enthalpy difference at the turbine inlet and outlet of the turbine times with the mass flowrate of the working fluids. Figure 8 shows the ideal power output of the refrigerants on the different temperature of the hot water inlet. The results show that R410a had the highest power output as compared to others working fluids. The result also shows that a potential of 2.38 kW can be extracted from the systems with the 75 °C hot water inlet temperature with R410a as the working fluids. Based on the graph, the power output increased as the hot water temperature increased with R410a having the highest ideal power output as compared to R134a and R245fa. This is because R410 has the lowest critical temperature and the least difference between critical temperature to the heat input temperature at 75 °C. From the T-s diagram in Figure 4, the evaporation process of point 2- point 3, as the input temperature increase approaching to critical temperature the entropy difference between saturated liquid and saturated vapor become smaller which allowed more refrigerant being transferred from saturated liquid to saturated vapor in R410a systems. This can be seen in Figure 9 where the graph indicates the mass flowrates of the working fluids in each of differences hot water inlet temperature.

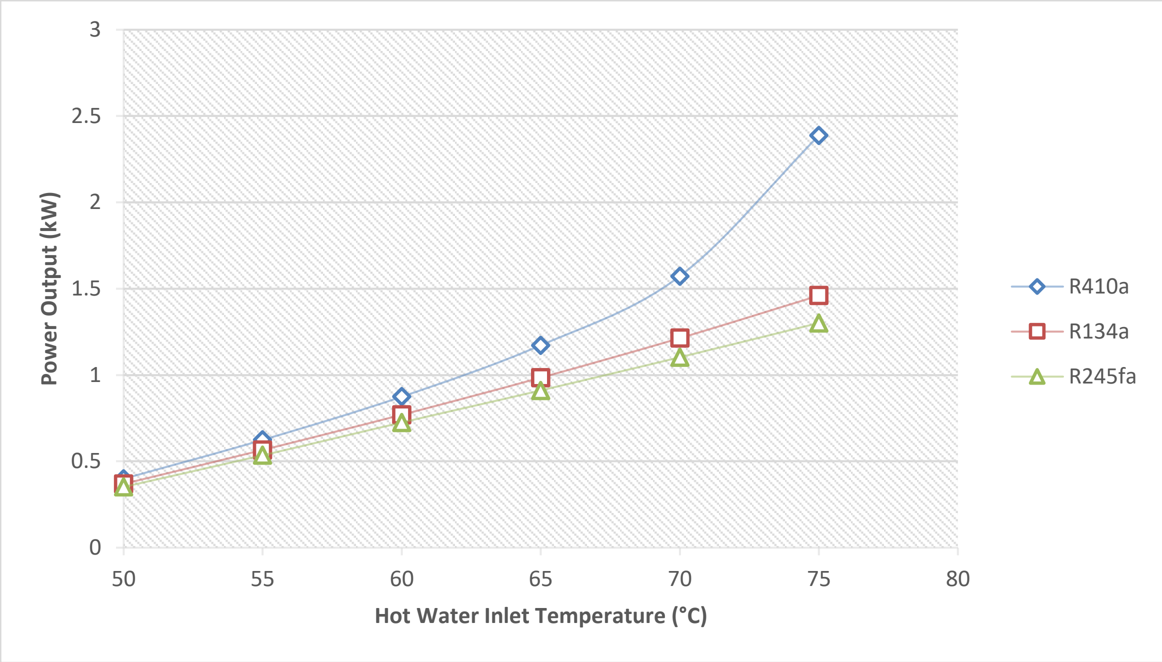


**Figure 8.** Ideal Turbine Power Output vs Hot Water Inlet Temperature.

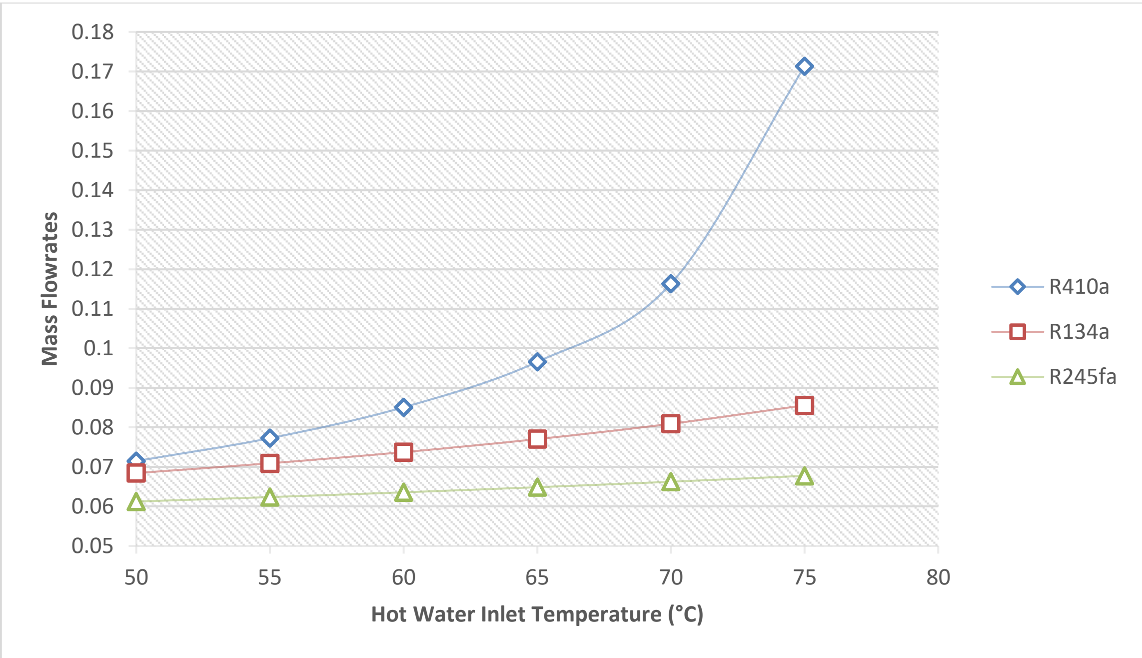


**Figure 9.** Mass Flowrate of Working Fluids vs Hot Water Inlet Temperature.

## 5. Conclusion

This paper highlights the potential development of ORC power generation system by utilizing heat from natural hot spring in Malaysia. The analysis was conducted by comparing three different working fluids which are R410a, R134a and R245fa. The comparison was done by the variation of hot water inlet temperatures in the range of 50 °C to 75 °C at the evaporator and 25 °C of ambient water at the condenser. From the calculation analysis, R245fa has the highest thermal efficiency as compared to R134a and R410a with the variation of temperature assigned. The highest efficiency was at 75 °C where the thermal efficiency of R245fa was 9 % while R134a and R410a have the efficiency of 8.8 % and 8.1 % respectively. The results also indicate that thermal efficiency increases as the hot water temperature increases. The influence of hot water resources temperature on the ideal turbine power output was determined. The results show that more power can be generated by using R410a as the working fluids with the highest power output is 2.38 kW at hot water temperature of 75 °C. Meanwhile, the R134a and R245fa have a power output of 1.4 kW and 1.3 kW respectively in similar working conditions. Therefore, it can be concluded that the examined working fluids could be used to generate power using low-heat resources from the hot-spring in Malaysia.

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