Analysis and Optimization of Geothermal Organic Rankine Cycle (ORC) for Electricity Generation

Abouelyazed M. Kulaib, Mohammad S. Albannaq, Rafik M. El Shiaty

Abstract— **This study directly investigates the ability of applying organic Rankine cycle (ORC) based on the geothermal energy. ORC technology is considered an effective process that can be adapted for use in different industries and applications in Kuwait. The geothermic heat sources can be used to save energy in some applications such as warming building in winter, to operate absorption air conditioning systems and operating ORC. Organic Rankine cycle (ORC) is considered a method of power generation depending upon medium and low heating sources is currently best solution of using waste energy in steam/ gas turbine power plants. The geothermal is used now to operate low-temperature small scale organic Rankine cycle power plants. The study was carried out theoretically and analytically.**

Keywords: Geothermal, Organic Rankine Cycle, performance, electricity

Symbols
A : Surface areas of tubes, m^2
d : outside diameter of the tube, m
L : Tube length, m
h : Heat transfer coefficient the tubes, kJ/kg K
g : Acceleration of gravity (9.81 m/s^2)
k : Thermal conductivity of the tube's material.
T : Temperature, ^oC
v_1 : Specific volume at inlet of pump. m^3/kg
m : Mass flow rate, kg/s
P : Power required, W
p : Pressure, Pa
W: Work, kJ/s
Q : flow rate, m^3/s
μ : dynamic viscosity, Pa.s
ρ : Fluid density, kg/m^3
η : Efficiency of the pump

I. INTRODUCTION

The Organic Rankine Cycle (ORC) is a cycle which can uses organic substance such as refrigerants, Hydrocarbons HCs, NG, methane, Butane, etc as a working fluid. Generally, the working medium should be suitable for casing of using geothermal energy as a heating source for purpose of generation electricity [Khennich, 2012]. In total, the world's installed capacity of geothermal power is about 48,493 MWt. The top countries with the biggest installed capacity are China, USA, Turkey, and Japan, [2]. The power generated from the ORC unit is not high may be from few kW to few MW for a single unit. In order to increase the utilization of the thermal resources of low to medium temperature sources, binary technology has been developed, Franco, 2011, [3]. The fluid properties as critical temperature, pressure, latent heat, mass weight should be relevant. The former uses hydrocarbons while the latter uses ammonia, [Matsuda, (2013)]. Organic Rankine Cycle parameter should have been defined accurately. So, by using suitable working fluid, proper geothermal heating source, the cost may be effective. Also, using suitable condition of Organic Rankine thermodynam,ic 22cycle is very important, [Villani, M., 2008].

The basic of operation of the organic Rankine cycle is like that of the Rankine cycle whereas the working fluid (organic) is pumped to a boiler at low pressure then, heat is added from geothermal hot water source, then the liquid organic is evaporated directly, and then discharged with low pressure to low pressure turbine, which is expended and the fluid temperature is decreased, finally re-condensed in the condenser, [Imran et al, 2015]. The cycle can be improved by the use of a regenerator, this only can be applied in the case of dry refrigerant whereas, the organic has not reached the two-phase state at the end of the expansion, [Mendrinos, et al, 2006]. The Organic Rankine cycle uses the heat storage in hot water (geothermal to make boiling of the organic fluid which have very low boiling point. If refrigerant vapor may be wetness from exit of turbine, it is required to use regenerative cycle or use a single pass system. So, the refrigerant mass flow rate depends on the mass flow rate of geothermal water, turbine performance, vapor dryness factor, etc. Generally, the control system in topping circuit used the data from fluid after turbine. So, the low flow fraction of refrigerant from boiler outlet should be throttled to condenser inlet, [Brasz et al, 2005].
The geothermal temperature is varying from 50^{o}C - 350°C. The ORC power plant unit is perfectly adapted for this kind of applications. However, it is important to put in the account that the low-temperature geothermal sources (less than 100°C), (Stephan et al, 2010). The specification of hot water well is affecting on the binary cycle performance especially, power output, thermal efficiency, condensation performance; pump power needed, etc, Ronald DiPippo (2007). This process of using geothermal energy in ORC power plant should be designed to reduce the different losses such as friction, irreversibility, exergy, turbine loss, compression loss, flow loss, etc. These losses occur through the process during the transferring heat across different components of ORC such as heat exchanger (evaporator), condenser (cooling system). The losses are reduced by maintaining a closer match between the cooling fluids curve and the working fluid heating curve (Ronald DiPippo, 2008). The return geothermal cooled water is backed to the ground (DiPippo, 2008). JingHan et al, (2020) investigated and analyzed the thermodynamic of ORC based on the geothermal energy. This work proposes a conceptual

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analysis and optimization of an organic Rankine cycle for power generation. The results showed that, the maximum energetic efficiency of the combined Butene/Parane configuration is 18.96%, also the highest exergy efficiency is recorded by the combination of Butene/Pentane. The system performance of an organic Rankine cycle system using HFC-245fa was analyzed. The ORC system efficiency and net power of the system are also studied by Donghong et al 2007. It has been suggested that the optimum usage of exhaust heat should be maximized to improve the system's efficiency and minimize system drain.

Agustín et al (210) presented an expanded theoretical study on the thermal energy requirements of a solar ORC. It includes an analysis of the various technologies involved in the production of solar energy. The information presented in this study can be used for various applications related to the solar ORC. A paper by Wang et al, (2012) focused on the selection and optimization of a working fluid for a heat recovery system. The parameters considered included the evaporation and condensation pressure, working fluid viscosity, and the heat recovery efficiency. The multi-objective programming approach is used to analyze the overall performance of different conventional and organic Rankine cycle plant layouts. The program is performed using different working fluids and the temperature difference between the two by Xiaomin Liu et al, (2017). Although the increase in the temperature may cause the overall performance of a specific fluid to improve, the optimal system design for that specific application still remains the same. This study showed that the superheated cycle with R152A is the most suitable for minimizing work output and exergy efficiency.

Shahram et al, (2017) performed **c**omparative study of the profitability of different types of geothermal electricity production. The amount of boundary conditions that constitute of the heat source inlet temperature, the heat sink inlet pressure, and the heat source mass flow rate are indicated below. Among the various parameters considered in optimizing operations, the degree of superheat ranges between 0 and 20. The thermo-economic performance of various subcritical and transcritical power plants is studied by Jian Song et al, (2018). This study focuses on the utilization of superheated and/or recuperation materials in the context of conventional and renewable energy sources. The optimization is carried out to maximize the efficiency of a given system's power and/or fuel use. The influence of various configurations on system performance is also evaluated. These systems are more energy-efficient and can reduce cooling water consumption. With the increasing number of geothermal plants globally, the total installed capacity of these facilities is expected to reach over 21,400 MW by 2020, (Moya et al., 2018; EXERGY, 2019).

A paper by (Doaa , 2017) describes the design of a binary cycle power plant that uses one of the low temperature geothermal resource of 92^{o}C at Bir Nabi well. The performance of the power plant is analyzed using three operation parameters namely, reinjection temperature, geothermal flow rate. The various parameters of an ORC binary cycle power plant are discussed. The temperature ranges from 90 to 130^{o}C and the mass flow rate ranges from 10 to 50 kg/s. Hijriawan et at, (2019) studied theoretically the organic Rankine cycle based on the geothermal energy. They discussed that the plant consists of two different loops, heating fluid loop (geothermal) and the organic loop. These plants can extract heat at different ranges of temperature such as (100°C - 200°C for geothermal wells). Also, the study provided that, the utilization of lower geothermal wells of about 70 – 100 °C can be use in small Organic Rankine cycle. To achieve effective and efficient geothermal heat exchangers, it should be minimized the heat losses. Little temperature difference of less than 10 °C between forward and return lines in low temperature wells necessitates large heat exchangers area and high mass flow rates, [Spadacini et al, 2017].

In recent years, multi-component or ORC power plant of working medium were used. The working medium may be composed of two or more fluids which is evaporating and condensing at suitable have been considered, [Alshammari et al, 2018]. From the analyses reviewed in the literatures, it is difficult to identify general criteria for the optimum study the thermal podium design of geothermal binary plants. Also, there are a lot of variables and factors that affect on the operation and performance of binary cycle power plant. So it need to study and investigate some of these variables as geothermal water temperature, hot water flow rate, evaporator pressure, etc on the performance of geothermal power plant. This study aims to generate power from low temperature geothermal resources using ORC plant technology. It is also compare the efficiency and output power of plant at different working fluids and operating parameters such geothermal temperature, mass flow rate, cycle highest pressure. The study is treated using the steady-state theoretical and empirical models.

II. METHODOLOGY

Using geothermal energy for operating the ORC power plant performance was investigated. The study was carried out theoretically and analytically. It was used several data from previous literatures and actual power plant installed in Kuwait. The necessary data is collected from actual plants and site visits. The calculation of power output from ORC is listed and its effect on the plant thermal efficiency is included. Also operating temperature ranges, pressure ranges, and mass flux for heating fluid is investigated. Also, the effect of properties of organic fluid (R-134A) on the performance of binary cycle power plant is studied. Theoretical models were carried out on the binary cycle with different operating conditions. The calculated data has been sorted and classified. A comparison between different operating conditions for binary cycle was performed. The effect of selecting topping cycle working medium on the performance of cycle was explained. So, the degree of superheat, working mediums minimum, maximum temperatures, pressures and flow rate are investigated and listed in results. A computer model for thermal efficiencies, heat transfer factor and coefficient is built. The outputs give information on cycle performance. The effect of selecting evaporator with different characteristics has been studied.

III. THEORETICAL ANALYSIS

Thermal analysis and simulating of ORC power plants require a numerical and theoretical solver system. Whereas, in this modeling, the theoretical equations of following are required: mass and energy balance, heat transfer rate, pressure drops through heat exchanger, mechanical losses in pumps and turbine, leakages, etc. On the other hand dynamic analysis is required for calculating the energy and mass accumulation in the different parts of the plant. The dynamic models analysis is useful for implementing and simulating control purpose particular during transient, during start & stop conditions. The organic cycle included four processes: first: the working fluid is pumped from low to high pressure by a circulating small liquid pump which consumed power. Second: The liquid of high pressure of working fluid enters evaporator where it is boiled and evaporated at a constant pressure by an external heat source as geothermal energy to become superheated vapor. Third: the superheated vapor expands through a turbine to generate power output. Fourth: the organic superheat vapor is entered a condenser and then it cooled saturated liquid. Then the pump is delivered the liquid to the evaporator and the cycle repeated again. In order to modeling the Rankine cycle of a typical geothermal binary plant, the following equations can be used as shown in Figures 1:

Turbine theoretical work,

$$W_T = m_R(h_3-h_4), \qquad \text{Eqn. 1}$$

Refrigerant circulating pump theoretical work,

$$W_P = m_R(h_2-h_1) = v_1(p_2-p_1) \qquad \text{Eqn. 2}$$

The maximization cycle overall net thermal efficiency of the plant can be evaluated from the following Eqn.

$$\eta_{cycle} = \frac{W_T - W_P}{Q_{in/R}} = \frac{W_{net}}{Q_{in/R}} = \frac{\dot{m}_R(h_3-h_4)-W_P}{\dot{m}_R(h_3-h_2)} \qquad \text{Eqn.3}$$

The heat input in the topping part of binary cycle (refrigerant cycle) is calculated by the following Eqn:

$$Q_{in/R} = m_R(h_3-h_2) \qquad \text{Eqn.4}$$

The total heat input from hot water source can be calculated from the following equation:

$$Q_{in/geo} = m_w\, Cp\, (T_{w,in} - T_{w,out}) \qquad \text{Eqn.5}$$

So, it is considered that the cycle efficiency is more affected by the geothermal source and ambient temperatures. Assuming, reversible and isentropic process, the efficiency of cycle can be calculated using the following equation:

$$\eta_{cycle} = 1 - \frac{T_{amb}}{\dfrac{(T_{geo,in} - T_{geo,out})}{Ln(\dfrac{T_{geo,in}}{T_{geo,out}})}} \qquad \text{Eqn.6}$$

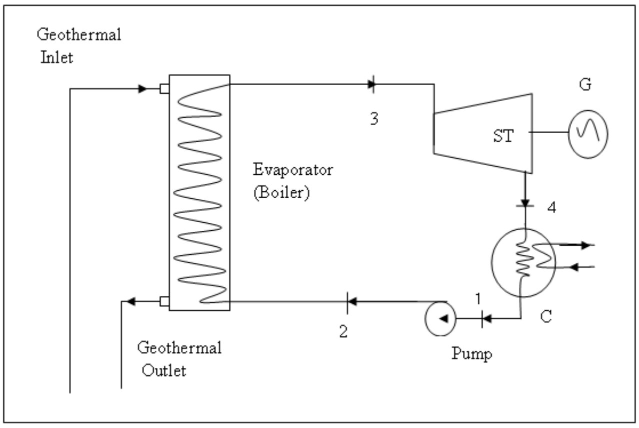

Figure 1: flow chart of simple binary cycle power plant

Where: T_{amb}: ambient temperature, °C, η_{cycle}: cycle effciency

However, the actual electrical power output = (turbine power – pump power) -auxiliaries power consumption used in cycle, so the net power can be increased with decreasing pumping work. The pumping work can be decreased as decreased the evaporator pressure (p_2), so it preferred to select low pressure pump to circulated refrigerant the of the cycle. Also increasing the turbine refrigerant inlet temperature is very required to increase the power output from turbine. However, increasing the refrigerant superheat degree will lead to increase the enthalpy of refrigerant gas inlet to the turbine, and then turbine work is increased, finally the power out will be increased. It is shown that, there are a lot of operating variables or parameters should be taken in account during design the binary ORC plants. From these parameters evaporator pressures, hot fluid maximum temperature, physical properties of the geothermal fluid, the return geothermal fluid temperature, the ambient temperature and the maximum rate of heat transfer and extracted by secondary working fluid. This entire factor affects directly on the size, cost, and power rate of the binary cycle power plants, [23]. In a real Organic Rankine Cycle, the compression by the pump and the expansion in the turbine are not isentropic

$$Wp = \frac{h_{2s} - h_1}{\eta_p},\ W_T = \eta_T(h_3 - h_4) \qquad \text{Eqn.7}$$

Where, η_P, η_T are the isentropic efficiencies of pump and turbine. In most geothermal binary power plants, the shell and tube heat exchanger is used in boiler (evaporator) and in condenser. The outside overall heat-transfer coefficient for the condenser is given by equation (3-8):

$$U_o = \frac{1}{\dfrac{A_o}{A_i}\dfrac{1}{h_i} + \dfrac{A_o Ln\left(r_o/r_i\right)}{2\pi kL} + \dfrac{1}{h_o}} \qquad \text{Eqn.8}$$

Where:

A_o and A_i are outer & inner surface areas of tubes, L is inner tube length, h_i is inside convective heat transfer coefficient the tubes, h_o is the outside convective heat transfer coefficient of the tubes, k is the thermal conductivity of the tube's material. Also, Eqn. 8 can be used to calculate the heat transfer coefficient outside the evaporator tubes:

$$h_o = 0.725\left[\frac{\rho_l(\rho_l - \rho_v) g h_{fg} k^3}{\mu d(T_g - T_w)}\right]^{1/4} \qquad \text{Eqn.9}$$

Where

ρ_l, ρ_v are the density of liquid and vapor of working fluid, h_{fg} :latent heat, μ : dynamic viscosity, k: thermal conductivity, d:outside diameter of the tube, T_g: saturation temperature of the fluid condensed, T_w : wall tube temperature. In case of turbulent flow, the heat transfer coefficient inside the tubes can be estimated by the following formulas:

$$h_i = \frac{Nu * k}{d_i} \qquad \text{Eqn.10}$$

The Nusselt number, $Nu = 0.023\, Re^{0.805} Pr^{0.4}$ Eqn.11

$$Re = \frac{\rho V d}{\mu} \qquad \text{Eqn.12}$$

Where: d is outside diameter of the tube, k is thermal conductivity of working medium, Nu is the Nusselt number, Pr is Prantl number, and Re is the Reynolds number calculated for the ρ, μ working medium properties inside the tube. In most, binary power plant cycle, the evaporator is selected as multi-paths shell and tube heat exchanger or plate heat exchanger with parallel plates and baffles which are attached together and fitted into the outside casing. These plates could have a corrugation angle of ‘‘β’’ to with the main direction of geothermal hot water flow (counter flow). The plate type heat exchangers are preferred to shell and tube heat exchanger, especially in case of geothermal heat transfer, because there are particles or ions which are dissolved in geothermal water such as (silica SiO_2 or calcium carbonate $CaCO_3$). These materials deposited on the surfaces and cause fouling of the heat exchanger, so selecting plate shell and tube exchanger is proper for geothermal power plant due to easier cleaning mechanically or chemically from these materials. The overall heat-transfer coefficient, [24]:

$$U_o = \frac{1}{\frac{1}{h_o} + \frac{\Delta x}{k} + \frac{1}{h_i}} \qquad \text{Eqn.13}$$

Where: Δx is the thickness of the plate, for very thin wall tube,

$$U_o = \frac{1}{\frac{1}{h_o} + \frac{1}{h_i}} \qquad \text{Eqn.14}$$

IV. RESULTS & DISCUSSIONS

The specific consumption of the organic working fluid (refrigerants) in case of geothermal binary plants is often higher than 50 kg/s per MW produced. Generally, the power loss in binary cycle is very large by comparison with other types of steam power plants because the refrigerant comes from turbine in superheated state. Also, the circulation pumps or cooling tower fans consume a considerable part of the generated power from the plants. It is known that, the power required to run the binary plants pumps is relatively fixed and is generally between 2 and 10% of the gross plant output which is depending on the working fluid operating pressure.

A. Geothermal water temperature effect

The effect of geothermal water temperature on the power output in the case of operating evaporator pressure, 4 bar, and fixed outlet water temperature of 70°C is shown in the Fig. 2. It is shown that as increasing the geothermal water inlet temperature to the evaporator, the heat added to refrigerant is increased, the main Equation of heat input is:

$$Q_h = m_w \times Cp \times (T_{w,in} - T_{w,out}) = m_w \times (h_{w,in} - h_{w,out}) \qquad \text{Eqn. 15}$$

Where: m_w is mass flow rate of hot water, kg/s, Cp is mean specific heat of water, kJ/kg °C, $T_{w,in}$ hot water inlet temperature, °C, $T_{w,out}$ hot water inlet temperature, °C, $h_{w,in}$, $h_{w,out}$: enthalpies of hot water at inlet and outlet kJ/kg.

As shown with increasing the heat input to cycle by increasing the hot water inlet temperature, the work net from cycle is increased also, where as the work net from cycle is calculated by Eq. 16

$$W_{net} = W_T - W_P = Q_{in} - Q_{out} \qquad \text{Eq. 16}$$

Where: Wnet net work from cycle, kJ/s, W_T, turbine work done, kJ/s , Wp pump work, kJ/s, Q_{in} is heat input to refrigerant, kJ/s, Q_{out} is heat reject from cycle in the condenser, kJ/s. Figure 4 shows the effect of increase geothermal water inlet temperature on the working medium of topping part of cycle. With increase the hot water inlet temperature, the rate of evaporation of refrigerant is increased. So, the heat input to refrigerant is increased also. In this figure the evaporator pressure is fixed at 4 bar. From the heat balance in the evaporator, the heat lost from water should be equals the heat input to the refrigerant, with neglecting evaporator loss, environmental loss, material loss. But actually in the real cycle theses losses should be taken in the account. It is consumed that the overall loss in the evaporator may by about 2% from total heat extracted on the evaporator. So, heat lost from water = heat extracted by refrigerant, so:

$$m_w \times Cp \times \Delta Tw = m_R \times Cp \times \Delta T_R \qquad \text{Eq. 17}$$

Where: m_R is refrigerant mass flow rate, kg/s, ΔT_w is water temperature difference, °C and ΔT_R refrigerant temperature difference, °C.

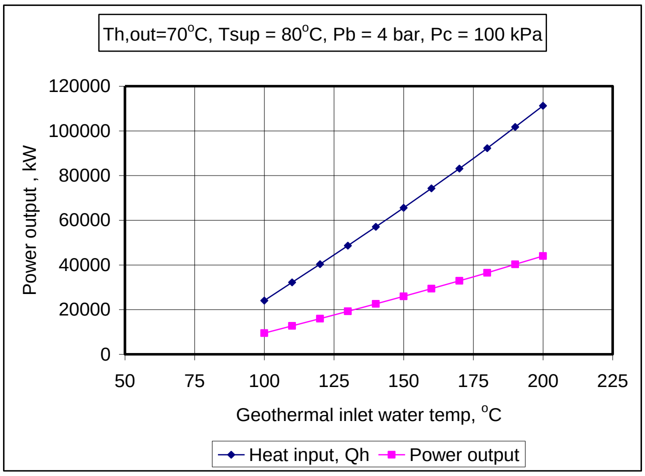

Figure 2: shows the power & heat output with geothermal water temperature

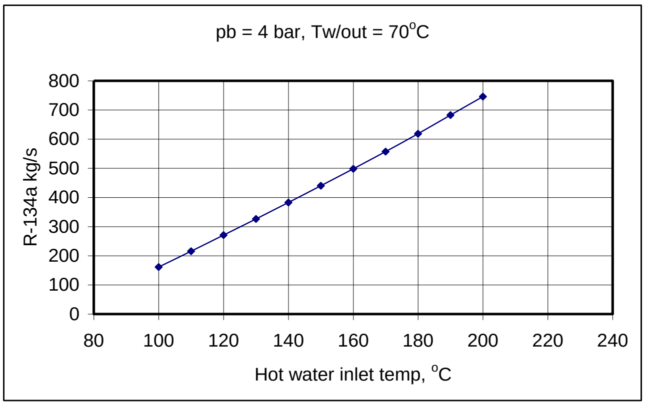

Figure 3: shows the effect of hot water temperature on the refrigerant mass flow rate

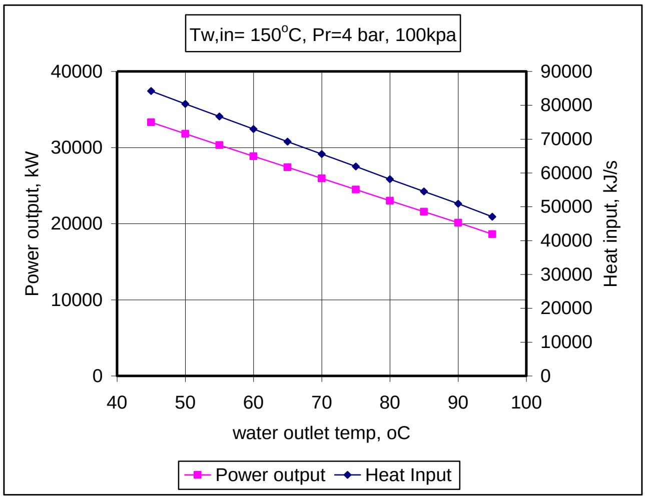

Figure 4: shows the effect of outlet hot water temperature on the power output from cycle.

As shown in Fig. 6, with increase the hot water temperature out from evaporator, the heat input to refrigerant is decreased, so the power output from cycle is decreased directly. So, the power out from the binary cycle is proportional directly with hot water inlet temperature, and inversely proportional with outlet temperature.

B. Effect of superheating on ORC performance

In this part of modeling, the effect of superheat amount of refrigerant is investigated. It is known that if increase the inlet turbine temperature; it means more cycle power output and then increasing the efficiency. The study was investigated in four case of evaporator refrigerant pressure, 10, 8, 6, 4 bar. It is shown that, the increase the pressure of refrigerant in the evaporator, the power output from cycle is decreased. Also, the thermal efficiency is decreased as increasing the operating pressure of refrigerant in the boiler. This is shown in Figure 4, 5.

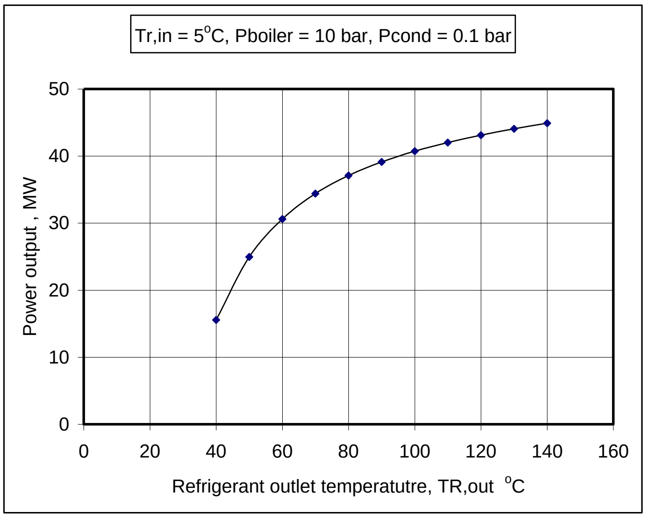

Figure 5: shows the power output with refrigerant superheat temperature.

C. Refrigerant Mass Flow Rate

In binary cycle, each pump has special performance. Theses performance of pump depends on the head of geothermal water, also the refrigerant boiler pressure and ambient condition around condenser. The specific relation between The energy usage in a pumping of working fluid in binary cycle is based on flow rate, the pressure head needed; tube friction which depends on the material of pipeline used. However the mechanical efficiency and volume/mass flow rates has very important effect on the refrigerant circulating pump power.

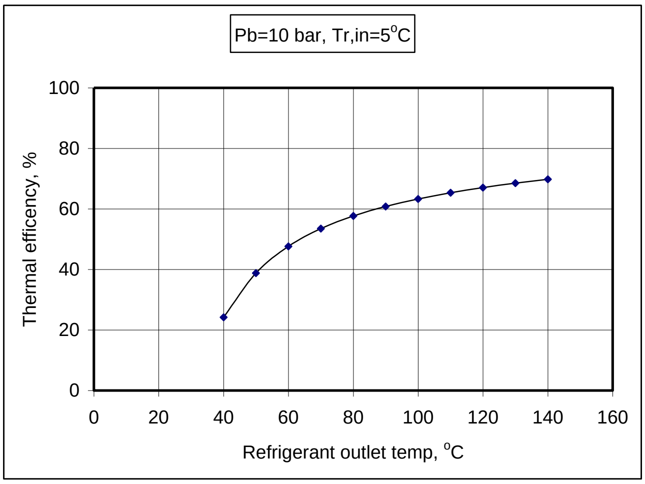

Figure 6: thermal efficient vs. superheat refrigerant temperature

The effect of evaporator pressure on the performance of binary cycle is shown in Fig. 7, 8. With increasing the superheat refrigerant temperature, the power out put is increased in all operating pressures.

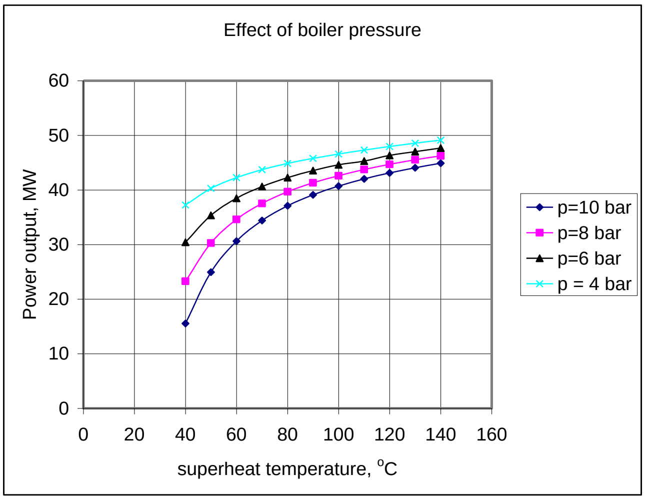

Figure 7: shows the power output with refrigerant superheat temperature with different operating pressures.

In some cycles with wet fluid, super heating is essential in order to keep the expansion in vapor phase and to prevent wet expansion and erosion in turbine. Since most ORCs use dry fluids, having excessive superheating is proven to have negative effect on maximum working pressure, saturation temperature and performance of the cycle. This figures indicates that excessive superheating with increasing pressure have negative effect on total efficiency and power output from binary organic cycle. The reason of decreasing power output or thermal efficiency from cycle is results from decreasing the rate of condensation at same heat input to cycle by geothermal water. So it is indicated that not good to select high operating pressure for evaporator.

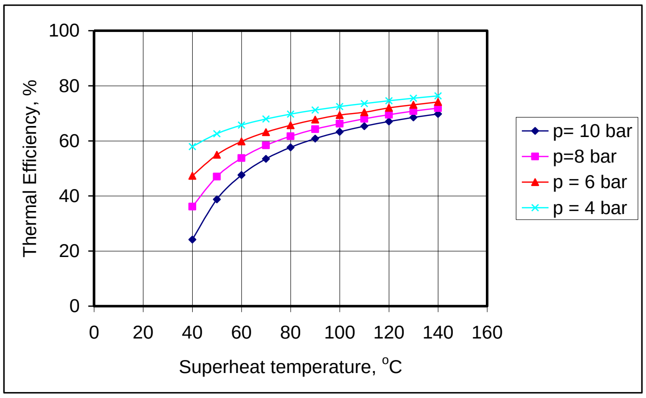

Figure 8: thermal efficiency Vs. superheat refrigerant temperature with different operating pressures

So, the power required to drive a pumps (P_i), is defined simple following Eq. 18:

$$P_i = \frac{\rho g H Q}{\eta} \qquad \text{Eq. 18}$$

Where: ρ is the fluid density (kg/m^3), H is the energy Head added to the flow (m), Q is the flow rate (m^3/s), η is the efficiency of the pump plant as a decimal

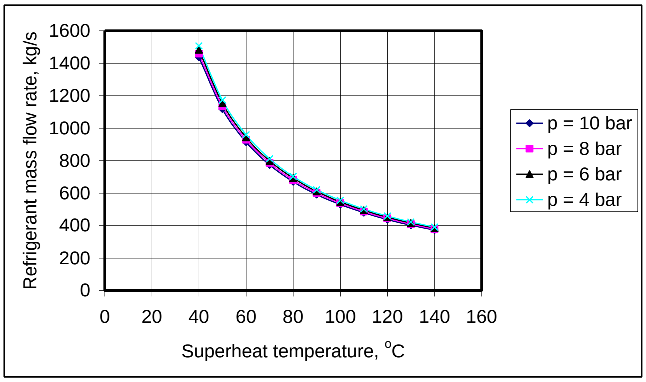

Figure 9. The effect of refrigerant superheat temperature on the refrigerant mass flow rate.

As shown in Eq. 18, the pump power depends upon the properties of fluid, flow rate, working head. If the working head is increased, the at same pump capacity, the pump power consumption should be increased. Figure 9, shows the effect of superheated refrigerant amount on the mass flow rate of refrigerant in the topping circuit. It is known that the pressure head needed by the pump (H) is equals the static lift, the head loss due to friction and any minor losses due to fitting parts. The pump work done can be calculated from thermodynamic Rankine cycle as following:

$$W_{pump} = h_2 - h_1 = v_1\,(p_2 - p_1) \qquad \text{Eq. 19}$$

Where, h_1, h_2 are enthalpies at inlet and outlet from pump, kJ/kg, p_1, p_2 are the pressure at inlet and outlet from pump, kPa, v_1 is specific volume at inlet of pump. m^3/kg. As shown in Fig. 10, increase the superheat amount of refrigerant lead to decrease the amount of refrigerant mass flow rate. So, the increasing of refrigerant superheats temperature, need to increase the amount of heat added to cycle to get same power output.

D. Refrigerant superheated effect at fixed Flow rate

Since using waste heat of binary power plant cycle from condenser is more effective in organic upper circuit (refrigerant). Because that working medium is operates at very low temperature. On the other hand, more superheat temperature will give more potential for connection of a heat pump to an ORC condenser and to produce additional heat. As a result, it is an important issue to check if added condenser heat capacity can is enough to make complete condensation of refrigerant.. As, increase of temperature of refrigerant leaving boiler, the power output is increased from cycle. Because increase the refrigerant temperature inlet the turbine lead to increase the work of turbine, (Figures 11, 12). So, the net power from the power plant will be improved directly, with increasing refrigerant superheat at fixing mass flow rate through topping part of organic binary circuit.

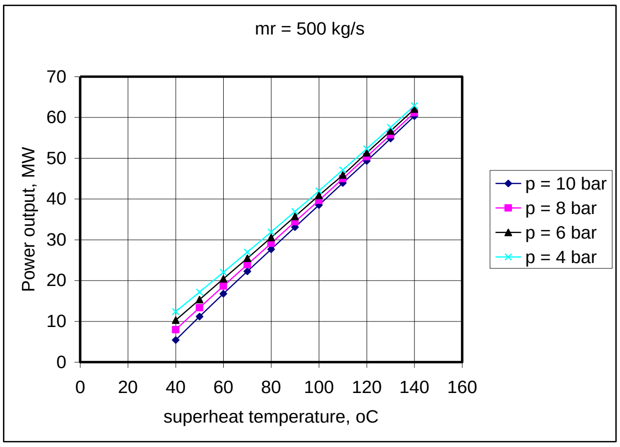

Figure: 10 effect of refrigerant temperature on the power output at (m_R= 500 kg/s)

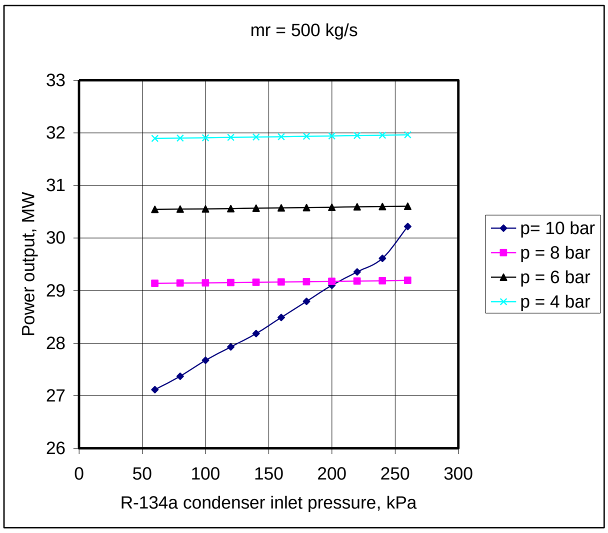

Figure 11 shows the effect of inlet pressure of refrigerant to condenser on the power output

Figures. 13, 14 show the effect of condenser pressure on the cycle efficiency. As increasing the refrigerant pressure leaves the boiler, the power output is decreased, also the rate of change is semi horizontally, expect for case of 10 bar, the change is linearly and very high. The increase of refrigerant inlet pressure to evaporator is not effective on the power output from the cycle. This is applied on the thermal efficiency of cycle too, so the decreasing the pressure of refrigerant inlet to the turbine is proper in ORCs plants. As a result the variation of fluid mass flow in ORC performance is not significant in case of high boiler pressure of refrigerant. So, the case of 4 bar boiler pressure is preferred in the study the performance of ORC plant. The geothermal water temperature is fixed at 150°C, the outlet water is 70°C. Only the exit temperature of refrigerant is changed directly to different operating values. The rate of increase thermal efficiency is higher than the rate of increase the power output from the binary cycle. Increasing the refrigerant temperature output from evaporator lead to increase the turbine work done, and then the net work is increased, so the power output is increased, Figures 14 to 23.

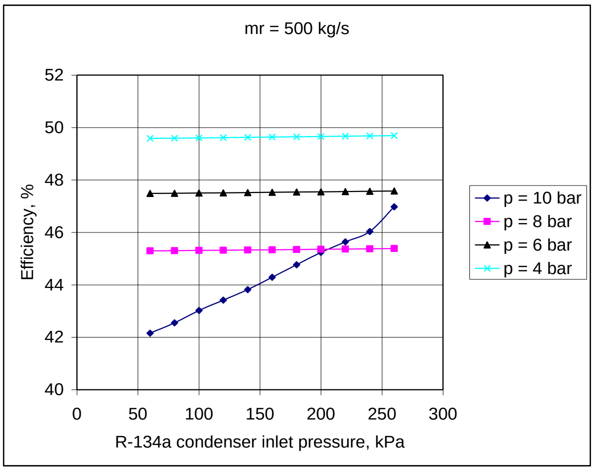

Figure 12 shows the effect of inlet pressure of refrigerant to condenser on the efficiency of cycle

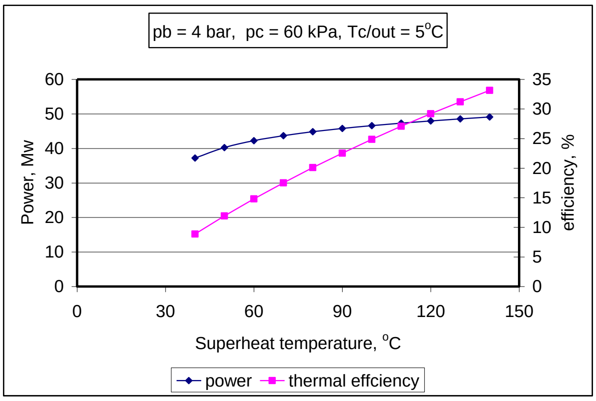

Fig. 13: power output and efficiency vis refrigerant temperature leaves boiler at (4 bar)

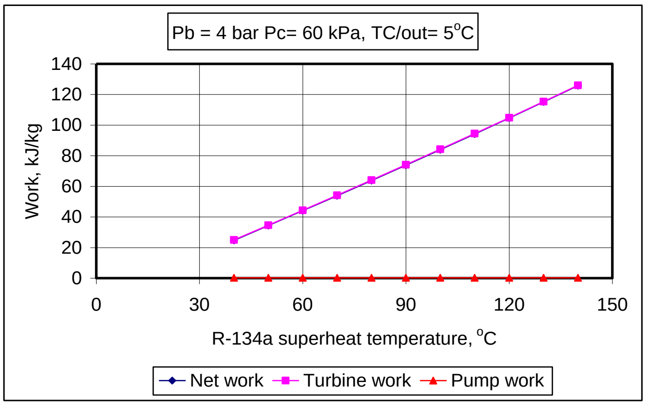

Fig. 14: pump, turbine, Net work of ORC vis refrigerant temperature leaves boiler at (4 bar)

Figure 15, 16 show the cycle performance, power output, refrigerant mass flow rate, thermal efficiency with fixed operation condenser pressure, (60 kPa, 4 bar). As shown with increase the refrigerant temperature leaved the boiler, the power output increased, but the mass flow rate decreased. So, this is important during the operation of plant, which will need to adjust feed water pump speed to meet the required mass flow rate. So, the refrigerant mass flow rate depends on the mass flow rate of geothermal water, turbine performance, vapor dryness factor, etc. The low flow fraction of refrigerant from boiler outlet should be throttled to condenser inlet.

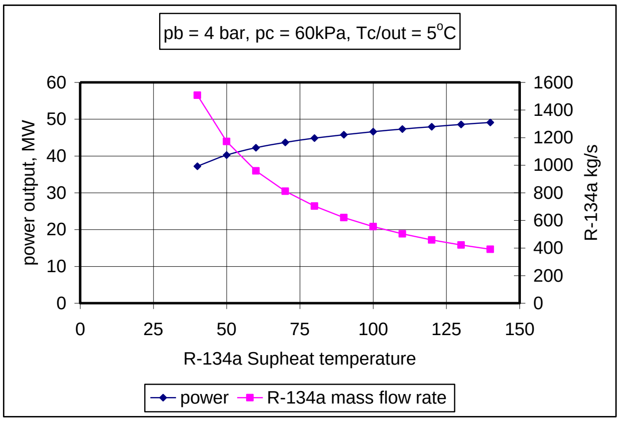

Fig. 15: Power, mass flow rate vis refrigerant temperature leaves boiler at (4 bar)

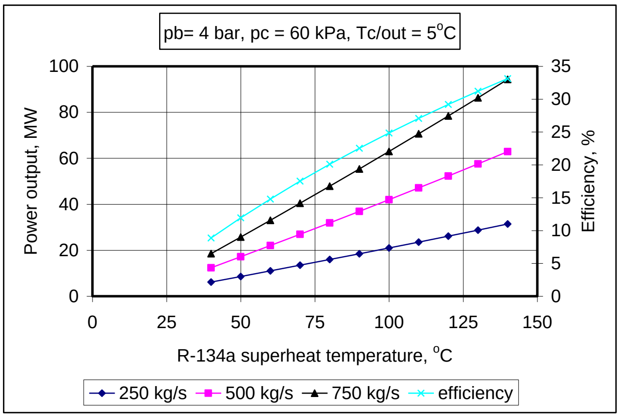

Fig. 16: ORC performance with different operating refrigerant mass flow rate in fixed (pb = 4 bar)

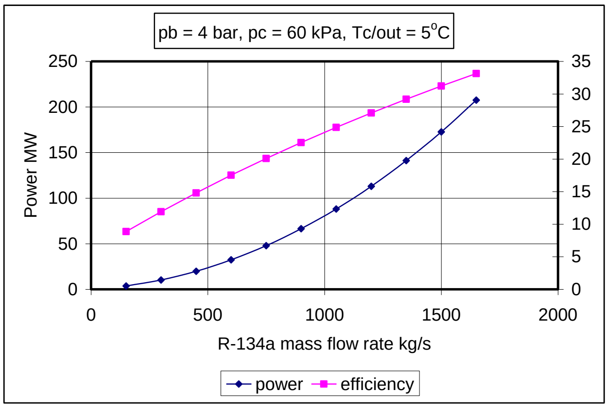

Fig. 17: effect of refrigerant mass flow rate on the power output and efficiency

So, it required to operate the boiler at lower evaporation and condensation pressure. Whereas, at lower pressure, the enthalpies of refrigerant at same superheat temperature is higher than high pressure. With in increase, the superheat refrigerant temperature exit from boiler, the power output is increase, and the efficiency is increased linearly (Figure 17).

E. Effect of Evaporator Refrigerant inlet Temperature

Figures 18, 19 show the effect of refrigerant inlet temperature to evaporator (boiler) on the performance of ORC. When, the temperature of refrigerant exit from turbine is increased, the power output is decreased. Also, with increase the exit of refrigerant temperature, the thermal efficiency of plant is decreased too. The reason of decreasing power with increasing temperature of refrigerant exit from turbine is decreasing the energy extracted from by turbine. Also, the condensation power is increased with increase refrigerant temperature.

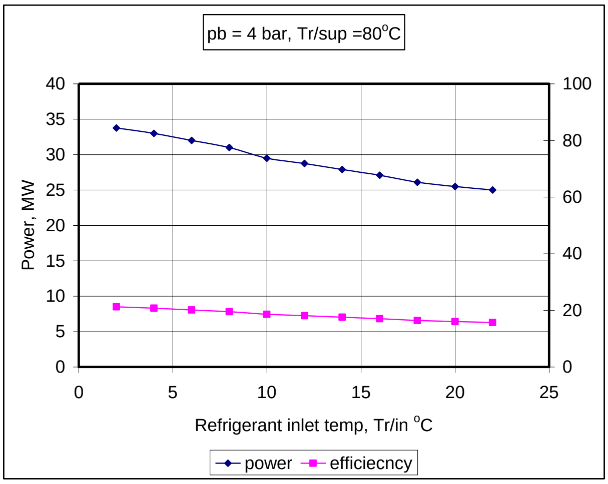

Fig. 18: effect of inlet temperature of refrigerant to boiler on the power output

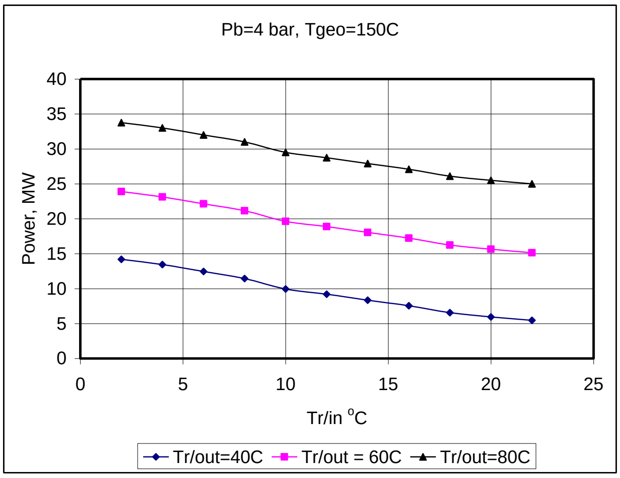

Fig. 19: effect of inlet refrigerant temperature to boiler on the power output in three different cases of superheated temperature

G. Effect of Exit water temperature

Figures 20 to 23 show the effect on variation water exit evaporator on the performance of binary cycle. To improve the power output from the cycle, the heat added should is large. But at increase the water exit temperature, the heat input is decreased. The increase of water temperature outlet from boiler (return water) is not good because the performance of cycle is poor. With increase the return water temperature, the input to cycle will be decreased, and then the power output from cycle is decreased too.

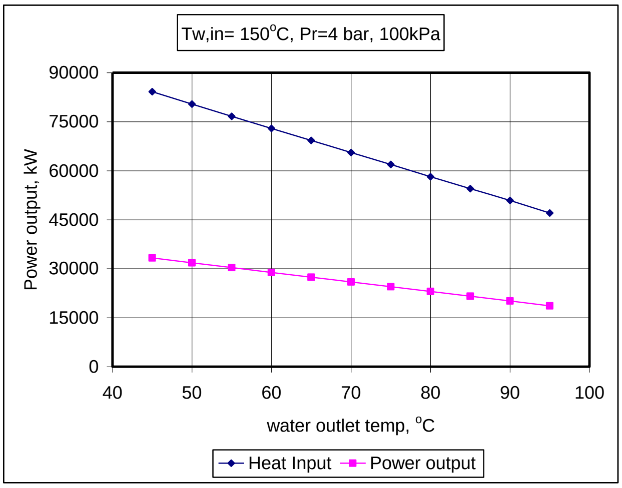

Fig. 20: effect of outlet water temperature from boiler on the power output

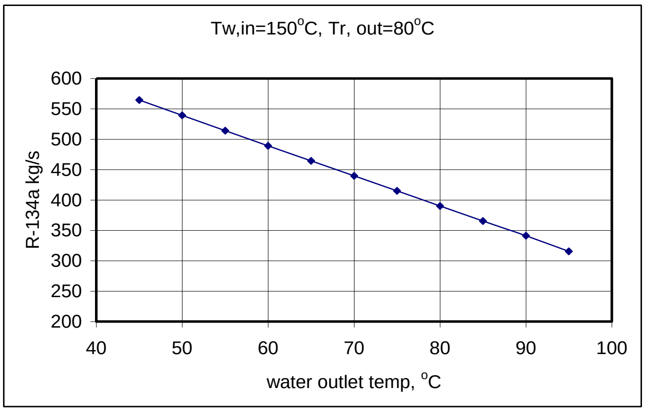

Fig. 21: effect of outlet water variation temperature on refrigerant mass flow rate

F. Water Mass Flow Rate Variation

Table 4-9 shows the results of variation mass flow rate of hot water on the performance of ORC plant.

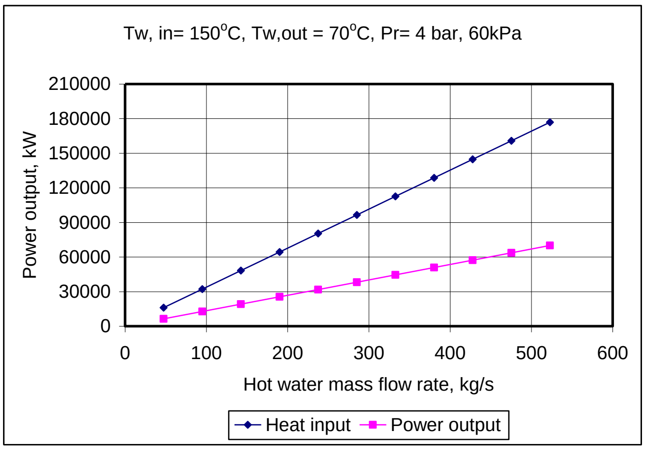

Figure 22: shows the effect of variation hot water mass flow rate on the power output from binary cycle

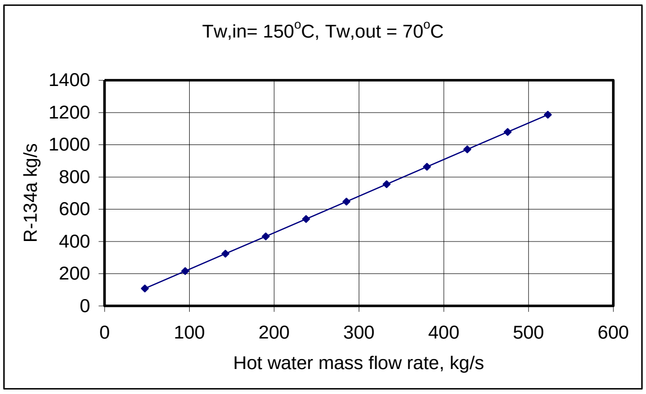

Figure 23: shows the effect of variation hot water mass flow rate on refrigerant mass flow rate

Increasing the hot water mass flow rate lead to increase the rate of heat transfer to refrigerant. This is occurred due to increase the heat input (Qin) to cycle. Also, increasing the water mass flow rate, lead to increase the refrigerant mass flow rate too, due to increase the rate of evaporation of refrigerant. However, as water mass flow rate increase, the heat input is increased, then heat transfer to refrigerant increased then the mass of flow rate of refrigerant is increased. On the other hand, the refrigerant evaporator temperature should be increased above critical temperature of ORC working refrigerant. Moreover, it is noted that pinch point is considered as heat source and evaporator temperature difference. So, it is important, at designing evaporator, the evaporator temperature and pressure cannot increase after certain values. Also, it is known that the pump efficiency will be decreased, when the mass flow rate is increased.

V. CONCLUSION & RECOMMENDATION

The organic Rankine cycle is an attractive unit for generating electricity from low-grade sources such as geothermal energy. The binary gothermal power plant uses two maion loops, one loop is called primary working fluid cycle, the second is known by the secondary working meduim loop. In the first loop the working meduim is usually hot water, the other is hydriocarbons fluids. The main feature of secondary fluid is lowest boiling temperature. The effect of operating parameters on the geothermal ORC such as, feed water temperature, refrigerant boiler temperature, evaporator pressures, fluid mass flow rates on the performance of ORC performance was investigated analytically. The cycle effciency depends on the ambient temperature and hot water source of well used. Generally, the thermal effciency of cycle is low but it can imporoved by using increaing superheat amount, decreasing evaporator pressure. The refrigerant mass flow rate plays very important effect on the performance of power cycle. The organic mass flow rate depends on the geothermal mass flow rate, temperature difference on the hot water from down well. The geothermal power plants are considered hydrothermal systems because it used two fluids hot water or brine and organic fluid as refrigerant. The geothermal ORC can work with different operating temperature for geofluid. The common range of hot water used is (150°C to 400°C). Geothermal ORC depends on the available heating source temperature, and pumping flow rate. The heat input from geofluid is increased by increase the hot water temperature inlet to boiler and the water flow rate. The low temperature which can be used to operate small-ORC cycle is 57°C. The selection of ORC affects on the performance and cost of plants because the power output is depending on the properties of organic fluid in binary cycle. The geothermal binary power plant is very effective for using low boiling working fluid in power section as refrigerant R-134a at low pressure. The lower pressure of evaporator can gives a bigger amount of superheat in vapor refrigerant which gives a very high work done by turbine, which leads to increase the power output by the ORC plant.

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