Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Thermodynamic Modeling for Combined ORC (Organic Rankine Cycle) and Single-Flash Geothermal Power Plants

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Keywords: ORC, Single Flash, Geothermal.

ABSTRACT

There are two kinds of basic geothermal power plants. Organic Ranking Cycle (ORC) and Single Flash power plant are very famous in geothermal power plants. Producing more electricity and more thermal energy are the main aims from the geothermal power plants. For these aims, the best way is combining these two kinds of power plants. These power plants can combine together in serial and parallel condition. The aim of this report is make a module for these power plants and compare them. The results and curves shows that, ORC with parallel single flash gets more electricity and thermal energy than the ORC with serial single flash geothermal power plant.

1. INTRODUCTION

Thermodynamical design is necessary for the calculation of all parameters in a power plant. Make models for each power plant can be started before design of a power plant. The producing electricity and thermal energy from geothermal power plants are greatly dependent on the characteristic of the natural resource. The enthalpy, pressure, chemistry and mass flow are all site, time and resource dependent.

There are also many type of power plants such as Single Flash power plant, Organic Ranking Cycle (ORC) power plant, Binary power plant, Kalina power plant and also combination of some of these power plants. In this report, thermodynamical design has been done for combining single flash and ORC power plants.

Single Flash and Organic Ranking Cycle power plant (ORC) can combine parallel and serial. With this method it will be possible to get more electricity and also more thermal energy. The hot water can be used for direct use applications. The aims of this report are making a module for determining the parameters of the geothermal fluid in each points and also calculate the supply power from the turbine (MWe) and the supply thermal energy (MWt) from condensers and heat exchangers and compare these two kinds of geothermal power plants.

For calculations of the thermodynamical parameters of the geothermal power plants EES (Engineering Equation Solver) has been used in this report.

2. SINGLE FLASH AND ORC GEOTHERMAL POWER PLANTS

Single flash steam technology is used where the hydrothermal resources are in liquid form, the fluid goes into a separator which is held at a lower pressure than the fluid, causing it to vaporize (or flash) rapidly to steam. The steam is then passed through a turbine coupled to a generator as for dry steam power plants.

Organic Ranking Cycle (ORC) power plants are used where the geothermal resource is insufficiently hot to efficiently produce steam for a single flash power plants or where the resource contains too many chemical impurities to allow flashing. The fluid brine coming from the separator of a single flash power plant can be utilized in a binary power plant as well as the fluid coming directly from the geothermal well (Astralian renewable energy, 2003)

Organic Ranking Cycle (ORC) power plants can achieve higher efficiencies than single flash power plants and they allow the utilization of resources of lower temperature.

In addition, corrosion problems are avoided. However, ORC power plants are more expensive and large pumps are required which consume a significant percentage of the power output of the plants.

Working fluids in ORC power plants should have a low boiling point to change easily to vapor with heat transfer from the geothermal fluids in heat exchanger. In most ORC power plant, Isopentane or other similar Organic Ranking fluids are used as the working fluid.

3. ORC WITH SERIAL SINGLE FLASH

In ORC with serial single flash power plants (Figure 1) the geothermal fluid goes into a separator which is held at a lower pressure than the fluid, causing it to vaporize (or flash) rapidly to steam. The steam is then passed through a turbine coupled to a generator as for dry steam power plants. With a valve after separator in brine line, the pressure of the geothermal water goes down and it should be as the same as the pressure of fluid after turbine. These two fluids mixed together and there is little seam in mixed fluid because with the valve the pressure of the water decrease and the fluid changes to two phase, steam and water. Then the geothermal fluid goes to the heat exchanger for change the working fluid (Isopentane) from liquid form to vapor form and the geothermal fluid injected to injection well or it can be used for direct uses. When the working fluid in close loop has been change to vaporize form, it goes to the turbine and with the generator the electricity will be produce. Then the working fluid goes to the condenser and after the condenser the working fluid should be in liquid form, because the fluid before the pump should be liquid. With the pump in close loop the pressure of the working fluid goes high and it goes to heat exchanger again. The module of this two geothermal power plants have been done in section 3.1 and the results and the curves have been collected in section 3.2.

3.1 Module of the ORC with Serial Single Flash

3.1.1 Parameters of the separator

For calculations, the mass flow and at least two other parameters of the fluid need to be known. Here we assume that the enthalpy and pressure are known. With these parameters all the others parameters of the fluid such as entropy and temperature can be determined.

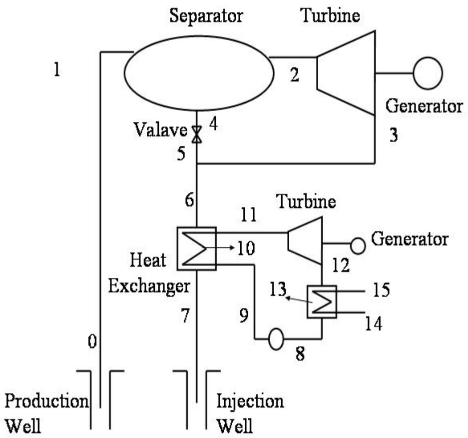

Figure 1: ORC with serial geothermal power plant

The fluid goes to the separator to separate steam and liquid because only steam should enter the turbine. With enthalpy and pressure, the quality of the fluid can be calculated and then the mass flow of steam and brine by the following equations, the numbers refer to Figure 3 and variables are defined in Nomenclature:

$$M2 = X*M1 \quad (1)$$

$$M5 = (1- X)*M1 \quad (2)$$

Thermal equilibrium gives:

$$X = (h1- h5)/(h2-h5) \quad (3)$$

Where X is the steam fraction of the geothermal fluid in the separator ,X=0 means that the fluid is saturated water, but X=1 that the fluid is pure dry steam.

The temperature of steam and brine are the same as that of the geothermal fluid that enters the separator, or:

$$T5= T1-Ts \quad (4)$$

$$T2=T1-Ts$$

The pressure of the steam and brine are also the same as the pressure of the geothermal fluid that comes into the separator, or:

$$P2 = P1 \quad (5)$$

$$P5 = P1 \quad (6)$$

The enthalpy of the steam is determined as saturated steam enthalpy at pressure $P2$. Similarly, the enthalpy of the brine as saturated water enthalpy at $P5$. The entropy of the steam and the brine can be calculated from temperature and enthalpy, so all the parameters of the fluid are known in the separator.

3.1.2 Parameters of the turbine

Ideally, the entropy of the fluid after the turbine is the same as the entropy of the fluid before the turbine (as shown in Figure 3), i.e.:

$$S3 = S2 \quad (7)$$

With a fixed pressure after the turbine and S3 known, the enthalpy of the fluid after the turbine can be calculated with the EES software. Thus, the power of the turbine can be calculated as:

$$W\_t = (h2-h3)*M2* \eta t \quad (8)$$

Where ηt is the isentropic efficiency of the turbine.

The mass flow after the turbine equals the mass flow before the turbine so:

$$M3 = M2 \quad (9)$$

After the turbine, with the entropy and the pressure of the fluid, the temperature can calculate by the EES software.

3.1.3 Parameters of the valve

After the separator, a control valve is used for controlling the pressure of the liquid fluid (brine), because the pressure after the valve should be the same as that after the condenser and also after the turbine. It is also possible to use a pump on the condensate.

$$P5 = P3 \quad (17)$$

In the separator, all the parameters of the liquid fluid (brine) can be calculated. The mass flow after the valve is the same as the mass flow before the valve, i.e:.

$$M5= M4 \quad (18)$$

The enthalpy is also the same before and after the valve:

$$h5= h4 \quad (19)$$

The liquid fluid after the valve mixes with the condensate that comes from the condenser and flows to the reinjection well. However, if this fluid has temperature that is high enough, it can be used for direct use applications such as space heating, swimming pools, greenhouses or snow melting. The mass flow of the injected fluid is determined by Equation 20:

$$M6= M5+M3 \quad (20)$$

The enthalpy of the injection fluid is determined by Equation 21:

$$h6 = (M3*h3+M5*h5)/M6 \quad (21)$$

The pressure of the injection fluid is the same as the pressure of the fluid after the valve:

$$P6= P5 \quad (22)$$

With the enthalpy and pressure known, all other parameters can be determined.

3.1.4 Parameters of the pump in ORC

If the pressure in a closed loop before the pump is known other parameters can be determined, because the quality of the working fluid should be zero. With these two parameters, other parameters before the pump are known. Hence, from the power of the pump and the efficiency of the pump, the pressure after the pump can be calculated. Also, entropy of fluid after the pump and before it are the same, so:

$$P9 = (v8*P8*M8+Wp*\eta\, p)/ (v8*M8) \quad (25)$$

$S9 = S8$ (26)

With $P9$ and $S9$ known, other parameters in a closed loop after the pump can be calculated.

3.1.5 Parameters of the heat exchanger in ORC

The enthalpy of the geothermal fluid before the heat exchanger) $h6$) and the enthalpy of the working fluid after the pump ($h9$) are known. After the heat exchanger, the quality of the working fluid is equal to one (X=1). Knowing this and the pressure of the working fluid after the heat exchanger ($P9$), the entropy of the working fluid after the heat exchanger ($S9$) is known too. Hence, all parameters of the working fluid after the heat exchanger are known. Using the heat balance equation, the enthalpy of the geothermal fluid after the heat exchanger can be calculated, according to:

$h7 = (h6*M6-(h11-h9)*M9)/M6$ (27)

The mass flow after the pump in the power plant and the mass flow before the pump are the same, so:

$M9 = \mathrm{M8}$ (28)

The pressure of the geothermal fluid before the heat exchanger and its pressure after the heat exchanger are almost the same. With Ph used for the pressure loss, this is described by:

$P7 = P6-Ph$ (29)

With this pressure and $h7$, all parameters of the geothermal fluid in point 7 are known. The heat transfer from the geothermal fluid to the working fluid can therefore be calculated by Equations 30 and 31:

$Qhh = M6*(h6-h7)$ (30)

$Qch = M9*(h11-h9)$ (31)

3.1.6 Parameters of the turbine in ORC

The entropy of the working fluid after the turbine is the same as the entropy of the working fluid before the turbine. Also, the pressure of the working fluid after the turbine is almost the same as the pressure of the working fluid before the pump because pressure loss in the condenser is low, hence:

$S12 = S11$ (32)

$P12 = P8+Pc$ (33)

All the parameters of the working fluid after the turbine are known with $P12$ and $S12$, hence the enthalpy of the working fluid can be calculated. Based on the enthalpy and the efficiency of the turbine, the power of the turbine can be calculated as:

$W\_t=(h4-h5)*M4*\eta t$ (34)

The mass flow of the working fluid after the heat exchanger is the same as the mass flow of the working fluid after the pump, hence:

$M11 = M9$ (35)

3.1.7 Parameters of the condenser in ORC

The pressure loss of the cooling fluid in the condenser is not high .Pc is used to represent this, hence:

$P15 = P14-Pc$ (36)

Also the mass flows for the two fluids are constant, so:

$M14 = M15$ (37)

$M12 = M8$ (38)

To calculate the parameters of the condenser, the enthalpy of the cooling fluid (outlet) must be known. This can be determined from the heat balance equation, giving:

$h14 = (M14*h15-M12*(h12-h8))/M14$ (39)

With $h14$ and $P14$ known, all the others parameters for the condenser can be calculated.

3.2 Results and Curves for ORC with Serial Single Flash

For calculations, the variables listed here below were chosen. In our calculations, it is assumed that the geothermal fluid is pure steam and the cooling fluid is water. Therefore, the chosen values for input for the various parameters reflect characteristic values from production wells in other geothermal fields in the world. Due to the lack of data, this is the only option open to do some calculations. The selected values are:

P1=1200 kPa	h1 =1500 kJ/kg	c=4.18
P3=250 kPa	η_t 1= η_t 2=0.85	P8=500 kPa
m8=80 kg/s	P9=1000 kPa	η_p=0.8
P14=200 kPa	T14=15`C	m14=100 kg/s
T_{out}=30`C		

The efficiency of the turbines ranges between 0.6 and 0.9 (Geir Thorolfsson, personal communication).

One of the important parameters in power plants is mass flow that effected the power of the turbine and also the thermal energy of the hot water

Figure 2 shows the amounts of MWe and MWt vs. mass flow in ORC with serial single flash.

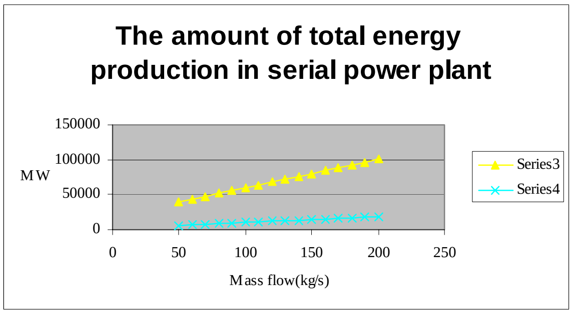

Figure 2: The amount of energy production by ORC with serial single flash power plants.

4. ORC WITH PARALLEL SINGLE FLASH

Most of the parts ORC with parallel single flash are as the same as ORC with serial single flash, but only in single flash part, after the turbine the geothermal fluid goes to the condenser for getting more efficiency from turbine and also getting more hot water. (Figure 2)

The module of ORC with serial single flash geothermal power plant, have been done in section 4.1 and the results and the curves have been collected in section 4.2.

4.1 Module of the ORC with Parallel Single Flash

All of the equations in the ORC with Parallel Single Flash (Figure 3) geothermal power plant are as the same as the equations in ORC with serial single flash. Just in the ORC with Parallel Single Flash, after the first turbine, the condenser have been used for getting more power from the first turbine and also it should be a pipe line for send the geothermal fluid to the injection well.+

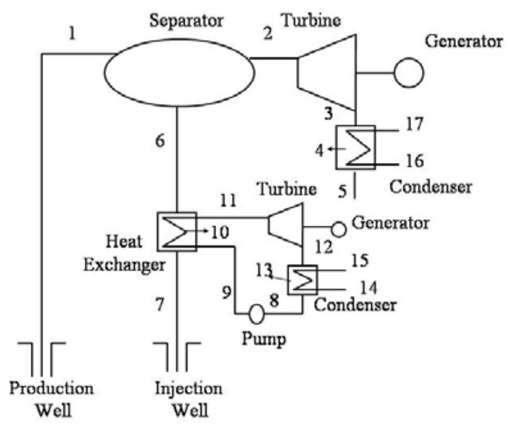

Figure 3: ORC with parallel single flash

4.2 Results and Curves for ORC with Parallel Single Flash

For calculation of the parameters in ORC with parallel single flash geothermal power plant, all of the input variables are the same as ORC with serial single flash, but only the pressure of the geothermal fluid after the turbine is different. Because with the condenser after the turbine in ORC with parallel single flash the pressure goes down, so:

$$P3=100\text{ kPa}$$

Figure 4 shows the amounts of MWe and MWt vs. mass flow in ORC with parallel single flash.

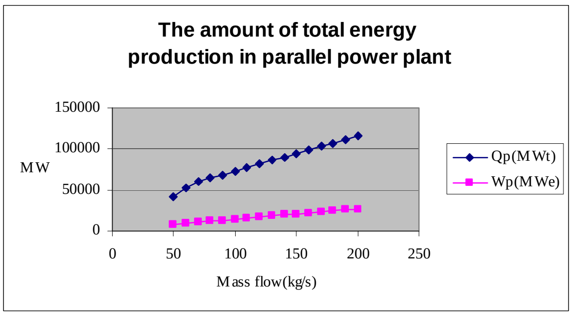

Figure 4: The amount of energy production by ORC with parallel single flash power plants.

5. CONCLUSIONS

Producing the electricity and the thermal energy from the hot water are the final aims in the geothermal power plants. For getting more electricity and thermal energy combining organic ranking cycle and single slash power plants have been proposed. These tow types of the power plants can combine serial and parallel. The main difference between these two types of geothermal power plants are using a condenser in ORC with parallel geothermal power plant and using a pump in ORC with serial single flash power plant. Figure 3 and the results from this report show that, from the ORC with parallel single flash power plant more electricity and thermal energy can produced than the ORC with serial single flash power plant, because with the condenser after the first turbine, the pressure of the geothermal fluid will decrease, so getting more electricity will be possible and also with this condenser getting more hot water will be possible too.

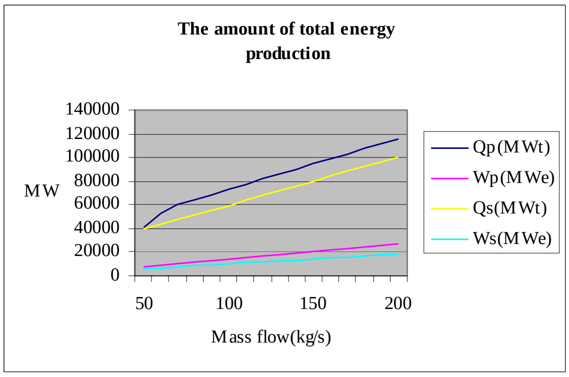

Figure 5: The effects of mass flow in the geothermal power plants.

Conceptual modeling of the power plants with EES is very useful. It is easy to change the input variables and calculate the output variables and also to compare the output variables.

Conceptual modeling of the different types of geothermal power plants with the main features of the geothermal system known allows assessment of which type of geothermal power plants has the highest output hot water from condensers and heat exchangers. This gives information on which type of geothermal power plants produces the highest hot water 0mass flow for direct uses and which type is the most effective one in producing hot water, vital knowledge for taking the right decisions.

NOMENCLATURE

h Enthalpy(kJ/kg)**;**

M Mass flow rate(kg/s);

P Pressure (kpa)

Pc Pressure loss in condenser (kPa);

P_h Pressure loss in heat exchanger (kPa);

Qch Heat transfer in heat exchanger on the cold side;

Qhh Heat transfer in heat exchanger on the hot side;

S Entropy (kJ/kg`C);

T Temperature (`C);

X Quality of fluid, i.e fraction of steam in fluid;

Wp Power of pump (kW);

Wt Power of turbine (kW);

η_t Efficiency of turbine

η_p Efficiency of pump

v Specific volume (m^3/kg)

Ts Temperature loss in separator

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