The United Nations University

GEOTHERMAL TRAINING PROGRAMME
Orkustofnun, Grensásvegur 9,
IS-108 Reykjavík, Iceland

Reports 2003
Number 20

CONCEPTUAL MODELLING OF A POWER PLANT FOR THE SABALAN GEOTHERMAL AREA, IRAN

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ABSTRACT

In this report, conceptual models of two types of power plants are presented for a geothermal project on the western slopes of Mt. Sabalan, approximately 16 km south east of Meshkin Shahr City, in the province of Ardabil in NW-Iran. Geothermal exploration activity in this geothermal field is on-going with the drilling of 3 deep exploration wells for determining the parameters of the reservoir. If the characteristics of the reservoir are acceptable, the project will continue. Thermodynamical design is one of the best ways for making a model of a geothermal power plant and the Engineering Equation Solver (EES) software is very useful for calculating the thermodynamical parameters of the equipment in the geothermal power plant. Here it is used for modelling single flash and ORC power plants for the Meshkin Shahr area. As the first well had not yet been tested in September 2004, general values based on known geothermal fields and wells were used for testing the models.

1. INTRODUCTION

Iran is a country that is blessed with an abundance of fossil fuel in the form of oil and gas. It has the second largest gas reservoirs and also huge oil reservoirs. However, Iran has also a good potential for renewable energy such as geothermal, wind and solar, that it wants to use for the benefit of its people. The main benefits for Iran in using its renewable energy are:

1. Better overall utilization of its energy sources;
2. Saving fossil fuel for export to other countries or for future generations;
3. These are environmentally benign energy sources, with a low CO_2 emission.

Generally, geothermal energy is a clean energy source. Some instances of geothermal applications are: for electricity generation, space heating, swimming pools, greenhouses and snow melting. At several locations in Iran there is good potential for geothermal energy. Its utilization until now has been limited to bathing and balneology, but the first exploration project to use geothermal for an electrical power production plant is now under way.

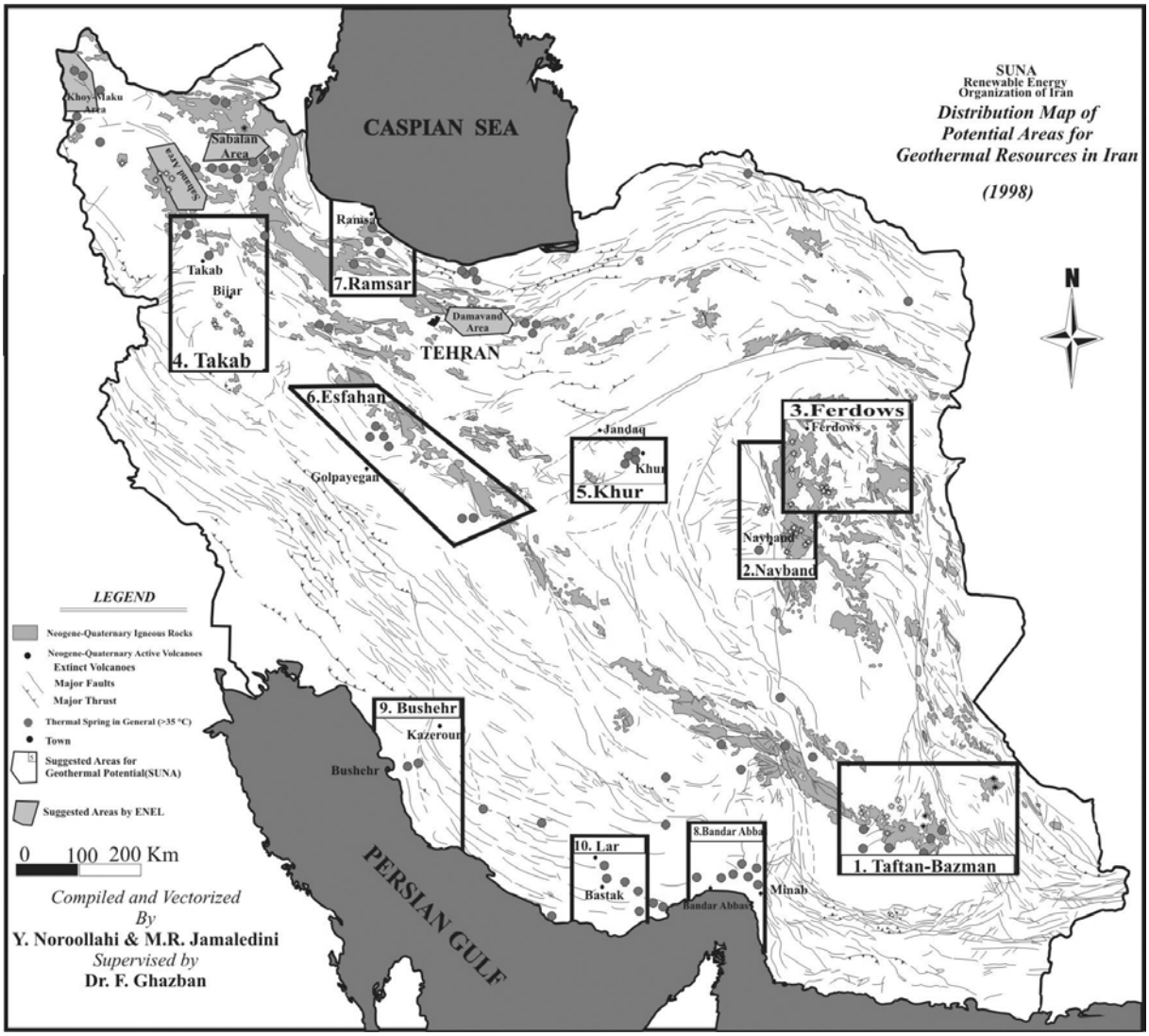

FIGURE 1: Map showing potential areas of geothermal resources in Iran
(potential high-enthalpy fields shown as boxes shaded in gray) (Fotouhi and Noorollahi, 2000)

The geothermal exploration in Iran was started by the Ministry of Energy of Iran (MOEI) in 1975. Research and surveys indicated that Iran had substantial geothermal potential, especially in the Sabalan, Sahand (Azarbaijan) and Damavand regions that were believed to be considerable prospects for direct use and possibly for electric power generation. In 1975, a contract between the Ministry of Energy of Iran (MOEI) and Ente Nazionale per L´Energy Electrica of Italy (ENEL), was signed for geothermal exploration in North Iran (Azarbaijan and Damavand regions). According to the final ENEL reports, there was good potential for geothermal energy in Sabalan, Damavand, Khoy-Maku and Sahand area regions (see Figure 1). This was not pursued due to the Islamic revolution in 1978 and later the war with Iraq, which led to a break in geothermal exploration for more than 10 years.

This changed in the beginning of the nineties, when the Electric Power Research Center (EPRC) and the Renewable Energy Organization of Iran (SUNA) were established. They were given the authority to confirm the geothermal potential of the above mentioned region, and demonstrate their possible utilization. As a result, the Meshkin Shahr and Sarein fields in the Sabalan area were proposed for development with regard to electric and direct use, respectively (1993-1996). In Sarein, baths and swimming pools have been built that allow its inhabitants to enjoy some of the benefits of the geothermal resources.

2. GEOLOGY OF THE MESHKIN SHAHR AREA AND THE GEOTHERMAL ACTIVITY

2.1 Main geological structures

Mt. Sabalan is a large stratovolcano, consisting of an extensive central edifice built on a probable tectonic horst of underlying intrusive and effusive volcanic rocks. Enormous amounts of discharged magma caused the formation of a collapsed caldera about 12 km in diameter, and a depression of about 400 m. The lava flows in the Sabalan are mostly trachy andesite and dacite with alternating explosive phases. The schematic geological map of the Meshkin Shahr area (Figure 2) shows the volcanic formations from Eocene to Quaternary (Noorollahi and Yousefi, 2003).

2.2 Geothermal activity in the Meshkin Shahr area

In the Meshkin Shahr geothermal area, there are several hot springs with a temperature in the range of 25-85°C, originating from Mt. Sabalan. These springs in the Meshkin Shahr prospect issue mainly from the gravels of the Dizu formation. In Table 1, temperatures, elevations above sea level, mass flows and pH of hot springs have been listed (Noorollahi et al., 2003).

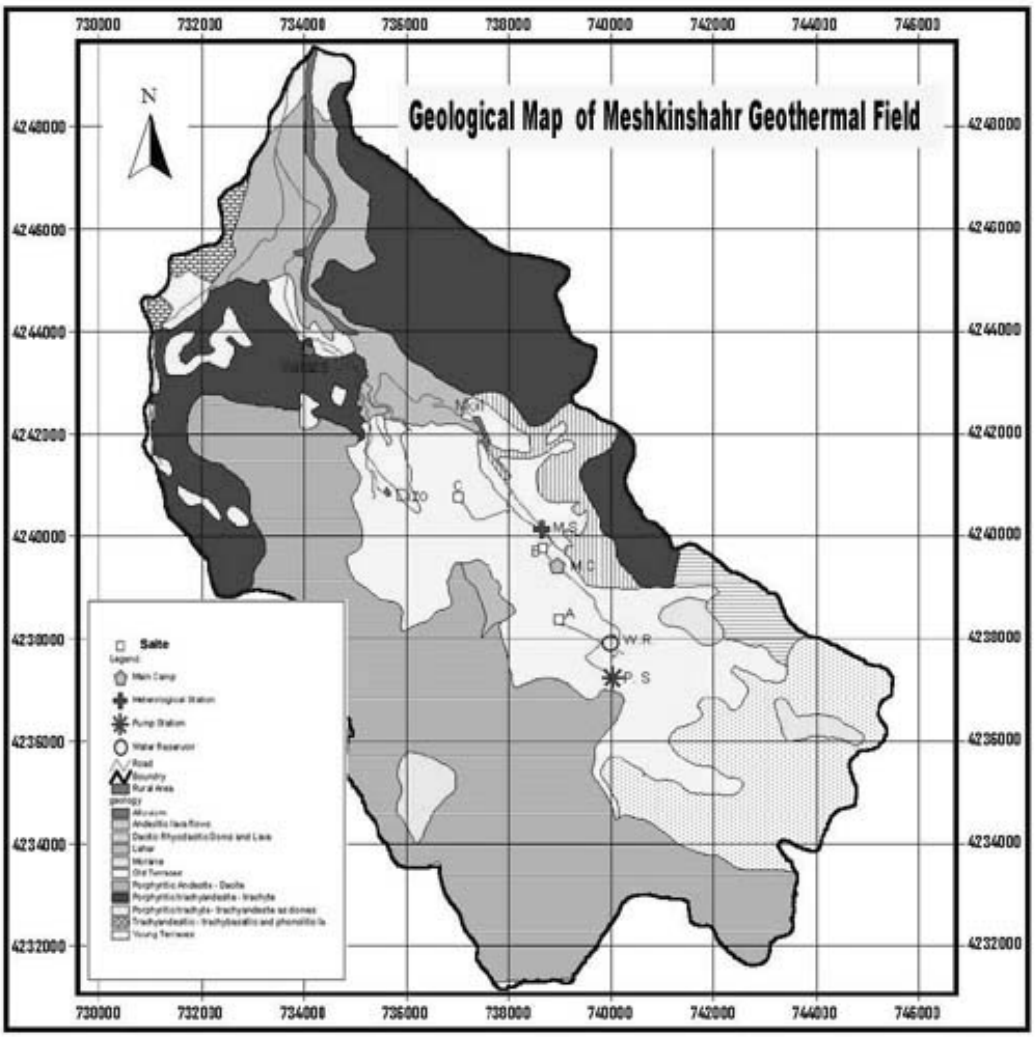

FIGURE 2: Schematic geological map of the Meshkin Shahr area (Noorollahi and Yousefi, 2003)

TABLE 1: Charactersistics of hot springs in the Meshkin Shahr area (Noorollahi et al., 2003)

Location	Temperature (°C)	Elevations (m)	Mass flow (l/s)	pH
Moil	45	2200	1.5	5
Gheynarge	83	2120	7	7
Ilando	34	2010	4	6
Ghatour-su	29	2200	10	3
Aghsu	32	2500	0.3	3
Malek-su	45	2250	2	6
Khosraw-su	64	2140	0.2	6
Yel-su	41	1980	4	5
Do-do	51	1990	1	5

2.3 Geophysical exploration of the Sabalan area

In 1998, Kingston Morrison Ltd (KML) on behalf of SUNA completed a resistivity survey, consisting of DC, TEM and MT measurements in the Meshkin Shahr area. In this area, locations of three exploration wells were proposed. In addition, the Sabalan region was recommended for a Transient Electro-Magnetic (TEM) survey. The findings were approved by MOEI and Renewable Energy Organization of Iran (SUNA). SUNA is committed to developing the Meshkin Shahr area.

Exploration for geothermal resources in the Mt. Sabalan area, undertaken in the summer of 1998, identified several low-resistivity anomalies around the flanks of the volcanic complex. Interpretation of the 212 magnetotelluric soundings was assisted by the use of additional TEM and shallow DC resistivity measurements. Large areas (>50 km^2) of relatively low resistivity (<5 ohm-m) were found in the Meshkin shahr area, in the vicinity of the mixed chloride-sulphate-bicarbonate hot springs at Gheynarge (to the northwest) and at Sarein (in southeast). Other significant areas with low resistivity were found near Dollar Spring, along an inferred southern outflow path towards the Bouchli higher-chloride spring, and near the acid-sulphate spring at Ghatour Su, which is near the northern rim of an inferred caldera collapse structure. Also, close to the northern caldera margin, between Tous Goali and Houshang Meidani. Here, there are relatively young trachydacite/rhyolite lava domes and flows and some surface evidence of hydrothermal alteration, but no active thermal features. On the north-eastern side of the volcanic complex, a thick layer (1-1.5 km) of moderately low resistivity (7-15 ohm-m) is associated with surface exposures of relic alteration. This layer overlies a dome-shaped resistive basement in an area of high Bouguer gravity values, which supports an inferred structural model of a dense intrusive mantled by conductive clays. Evidence of structural control on the location of some of the low-resistivity anomalies is also noted. Conceptual hydrological models, based on layered resistivity sounding interpretations, support the geochemical evidence from springs, of fluid mixing processes in the uppermost few hundred metres. Rising chloride fluids tend to discharge in valleys where the layer of lowest resistivity is closest to the surface, while mixed and steam-heated waters discharge from overlying layers of intermediate resistivity, and cold groundwater springs occur within an uppermost high resistivity layer (Bromley et al., 2000).

2.4 The development of the Sabalan field

When detailed surface geothermal exploration (geological, geophysical and geochemical) in the Sabalan regions had been completed, the Meshkin Shahr area was targeted for further development. Sites of three deep exploration wells were proposed. In addition, the Sabalan region was recommended for further TEM surveys. These findings were approved by MOEI and SUNA. At present, SUNA is committed to developing the Meshkin Shahr area. For that, SUNA built an 8 km long road into the area and prepared 3 large drill sites for deep exploration wells together with other necessary civil work.

The National Iranian Drilling Company (NIDC) was contracted by SUNA to do the drilling in the area. The drilling of the first exploration well started in late 2002, and was finished in the spring of 2003. Presently (autumn 2003), NIDC is drilling the second well, and drilling of the third well is planned in the near future.

The first exploration well was finished at about 3.2 km depth, with temperatures at this depth believed to be near 250°C. A shallow well was also drilled near the exploration well to a depth of almost 600 m, to use for injection of the geothermal fluid into the earth during testing activities and hopefully also later during production. The second well is being drilling in Sept. 2004. The first well has not been tested at the time of writing, so information about the results and the geothermal parameters is still at a minimum.

3. MODELLING OF POWER PLANTS

Thermodynamical design is necessary for the calculation of all parameters in a power plant and for making models for each power plant before design of a power plant can be started. The production of geothermal electricity and the design of a geothermal power plant are greatly dependent on the characteristics of the natural resource. The enthalpy, pressure, chemistry and mass flow are all site, time, and resource dependent.

There are also many types of power plants such as: single flash power plant, organic Rankine cycle power plant (ORC), binary power plant, Kalina power plant, and also combinations of some of these plants. In this report, thermodynamical design has been done for a single flash power plant, and organic Rankine cycle with isopentane as the working fluid. As mentioned above, results from drilling are still very limited and therefore assumptions have to be made on the various parameters. Parameters of the wells are assumed to take values that are common from other geothermal fields in the world.

For calculation of the parameters of power plants, the Engineering Equation Solver (EES) has been used in this project (F-Chart Software, 2003). The basic function provided by EES is the solution of a set of algebraic equations and the formulae for all equipments grouped in modules. EES can also solve differential equations, equations with complex variables, do optimization, provide linear and non-linear regression and generate publication-quality plots. EES automatically identifies and groups equations which must be solved simultaneously. This feature simplifies the process for the user and ensures that the solver will always operate at optimum efficiency. EES provides many built-in mathematical and thermophysical property functions useful for engineering calculations. Also with EES it is easy to draw the thermodynamical diagrams and schematics of each mechanical system. For testing the programs, some examples from the report 'Binary power generation from waste heat' by M. Sagun (1992) were used.

4. SINGLE FLASH POWER PLANT

Single flash steam technology is used where the hydrothermal resources are in liquid form (see Figure 3). The fluid goes into a separator, which is held at a lower pressure than the fluid, causing it to vaporise (or flash) rapidly to steam. The steam is then passed through a turbine coupled to a generator as for dry steam power plants.

The majority of the geothermal fluid does not flash, and this liquid is reinjected into the reservoir or used in a local direct heat application. Alternatively, if the liquid from the separator has sufficiently high temperature, it can be passed into a second separator, where a pressure drop induces further flashing to steam. This steam, together with the exhaust from the principal turbine, is used to drive a second turbine or the second stage of the principal turbine to generate additional electricity. Typically, a 20-25% increase in power output is achieved, with a 5% increase in plant costs (Australian Renewable Energy, 2003).

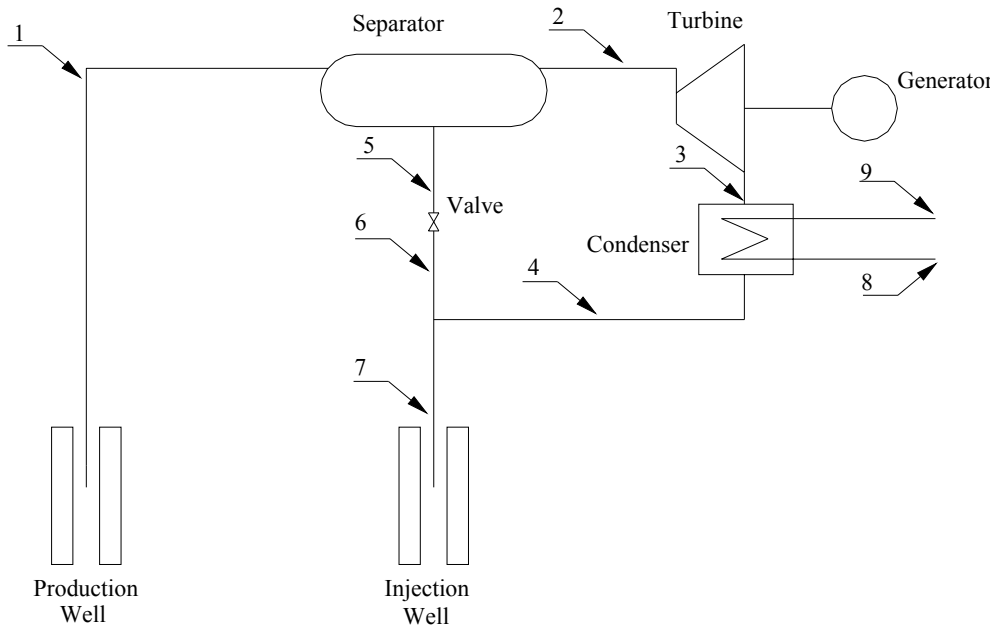

FIGURE 3: Schematic of a single flash power plant (Valdimarsson, 2003)

Flash steam plant generators range in size from 10 to 55 MW, but a standard size of 20 MW is used in some countries, including the Philippines and Mexico (Australian Renewable Energy, 2003). The run-off fluid (at point 7 in Figure 3) can be used for direct use applications.

4.1 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.

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 the of 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:

$$T2 = T1= T5 \quad (4)$$

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.

4.2 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:

$$W\_t = (h2\text{-}h3)*M2*\eta_t \quad (8)$$

where η_t 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 known, the temperature can be calculated by the EES software.

4.3 Parameters of the condenser

The condenser is used for getting more power from the turbine (by lowering h3 in Equation 8). Output steam from the turbine is usually condensed in a direct contact condenser or a surface type condenser. For calculating all the parameters of the geothermal fluid after the condenser, mass flow, enthalpy and pressure of cooling fluid should be known. Heat transfer from the steam to the cooling fluid is calculated by Equation 10:

$$\dot{Q}_h = M3*(h3\text{-}h4) \quad (10)$$

The cooling fluid receives this heat and according to Equation 11 it is calculated as:

$$\dot{Q}_c = M8*(h9\text{-}h8) \quad (11)$$

The heat transfer over the condenser $\dot{Q}_h$ and $\dot{Q}_c$ should balance out, hence:

$$\dot{Q}_h = \dot{Q}_c \quad (12)$$

Equation 12 is called the heat balance equation.

The enthalpy of the condensate after the condenser is determined at P4 and the quality of the fluid (X) is

equal to zero. The enthalpy of the cooling fluid after the condenser is determined by substituting Equations 10 and 11 into Equation 12:

$$M3*(h3-h4) = M8*(h9-h8) \quad (13)$$
$$h9 = ((h3-h4)*M3+h8*M8)/M8 \quad (14)$$

The pressure of the steam before the condenser and condensate after the condenser is almost the same, hence:

$$P4 = P3 \quad (15)$$

Similarly, the mass flow of the geothermal fluid after the condenser is the same as the mass flow before the turbine, so:

$$M4 = M3 \quad (16)$$

With h4 and P4 known, other parameters can be calculated.

4.4 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.

$$P6 = P4 \quad (17)$$

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.:

$$M6 = M5 \quad (18)$$

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

$$h6 = h5 \quad (19)$$

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:

$$M7 = M6+M4 \quad (20)$$

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

$$h7 = (M4*h4+M6*h6)/M7 \quad (21)$$

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

$$P7 = P6 \quad (22)$$

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

4.5 Results

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. As mentioned before, the wells in the Meshkin Shahr field in Iran have still not been tested. 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:

$M1$ = 50 kg/s	$h1$ = 1100 kJ/kg	$P1$ = 1200 kPa
η_t = 0.85	$P3$ = 11.3 kPa	$M8$ = 300 kg/s
$P8$ = 200 kPa	$h8$ = 50 kJ/kg	

The efficiency of steam turbines ranges between 0.6 and 0.9 (Geir Thórólfsson, personal communication). In Table 2, all calculated numbers for the different parameters are shown. The T-S diagram of steam (water) is shown in Figure 4, and the P-h diagram of steam (water) is shown in Figure 5.

TABLE 2: Calculated parameters for a single flash power plant

Point no.	*H* (kJ/kg)	*M* (kg/s)	*P* (kPa)	*S* (kJ/kg˚C)	*T* (˚C)
1	1100	50	1200	2.87	188
2	2784	7.589	1200	6.523	188
3	2079	7.589	11.3	6.523	48.2
4	201.8	7.589	11.3	0.6804	48.2
5	798.6	42.41	1200	2.216	188
6	798.6	42.41	11.3	0.6804	48.2
7	708	50	11.3	0.6804	48.2
8	50	300	200	0.1785	11.87
9	97.49	300	200	0.3419	23.22

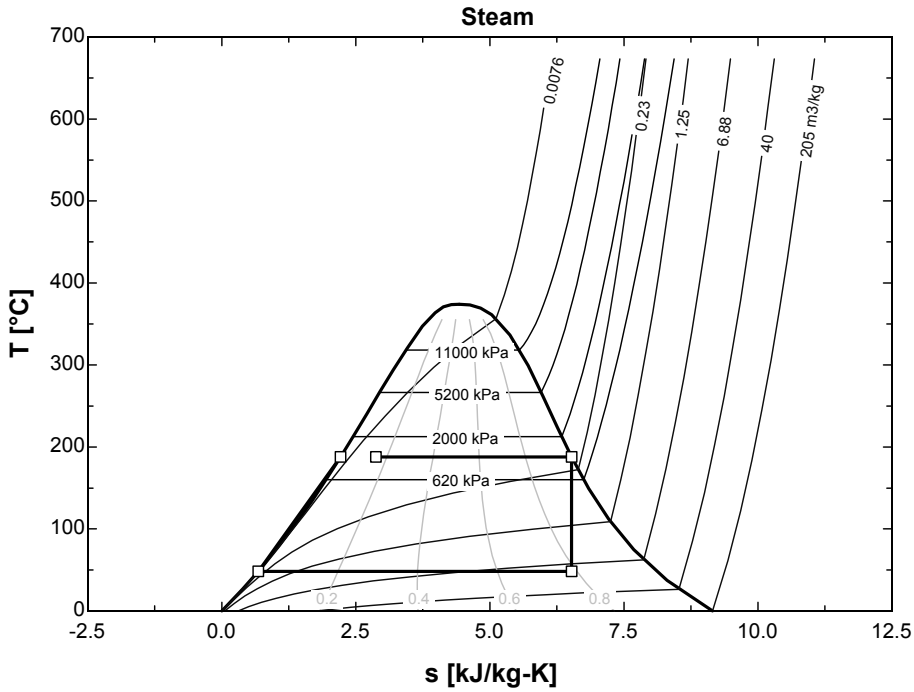

FIGURE 4: T-S diagram of steam (water) in a single flash power plant

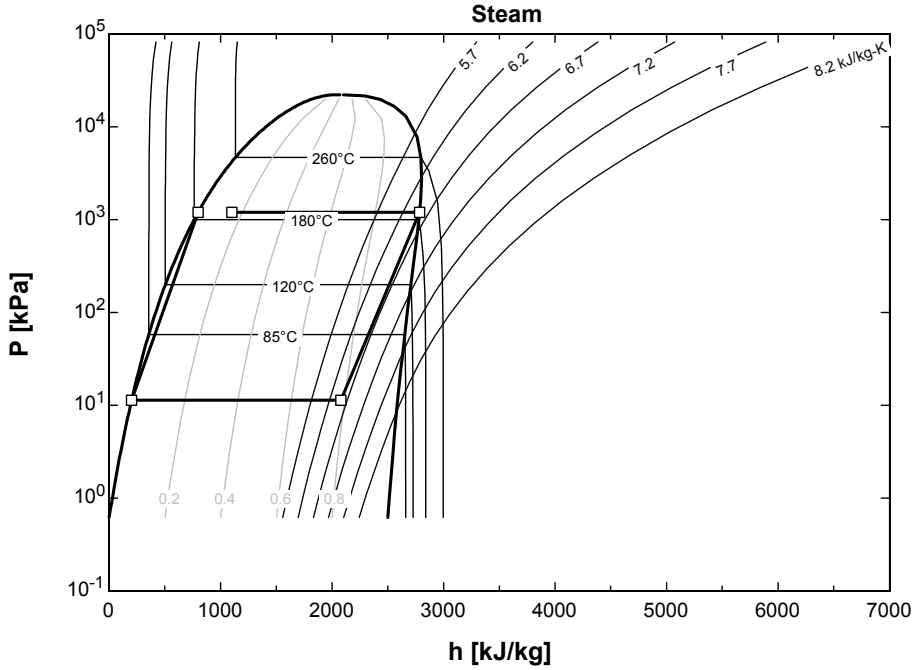

FIGURE 5: P-h diagram of steam (water) in a single flash power plant

With Equation 8, the power of the turbine is calculated as:

$$W\_t = 4{,}548 \text{ kW}$$

And the heat transfers in the condenser are calculated by Equations 10 and 11 as:

$$\dot{Q}_c = \dot{Q}_h = 14{,}248 \text{ kW}$$

5. ORGANIC RANKINE CYCLE (ORC) POWER PLANT

Organic Rankine cycle power plants (see Figure 6) are used where the geothermal resource is insufficiently hot to efficiently produce steam for a single flash power plant, 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 (Australian Renewable Energy, 2003).

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 vapour with heat transfer from the geothermal fluids. In most ORC power plants, isopentane or other similar organic fluids are used as the working fluid.

The advantages and disadvantages can be summarized as follows (Wilbur, 1985):

Advantages
- More suited to low-temperature hydrothermal resources;
- Smaller turbine size for given output;
- Less expensive turbine for given output;
- High-pressure operation throughout, eliminating vacuum operation;

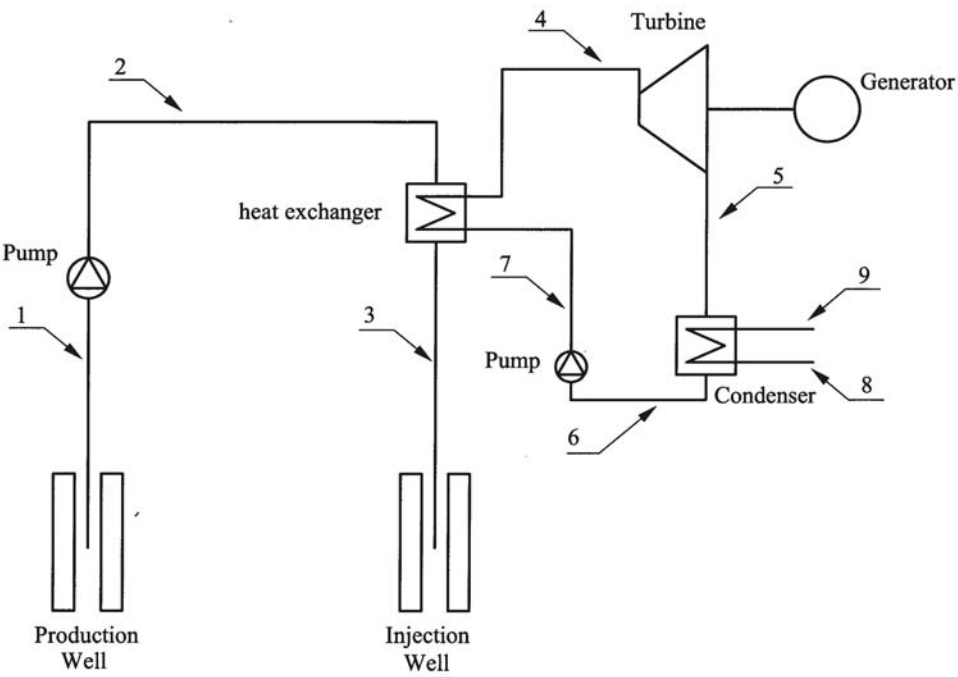

FIGURE 6: ORC power plant (Valdimarsson, 2003)

- Less problems of air in-leakage;
- Non-corrosive working fluid in turbines;
- Higher isentropic turbine efficiencies;
- Complete dry expansion, eliminating erosion problems;
- Condensing temperature can be lower for better cycle efficiency.

Disadvantages
- Secondary fluid cost;
- No leaks permissible;
- Heat exchangers costly;
- Huge brine flow rates needed for a reasonable-size plant, leading to disposal problems;
- Flammability of hydrocarbon work fluid requires fire protection design;
- Complex control system.

Some factors to be considered in the design and operation of binary power plants are discussed below.

5.1 Parameters of a pump on the wellhead

Often the fluid comes up from the well in free flow, but it is also possible that the water level in the well is below the surface level. Hence, a pump may be needed at the top of the wellhead.

The enthalpy, pressure and mass flow of the geothermal fluid are known so it is easy to determine the others parameters. With the power and efficiency of the pump known, the pressure after the wellhead pump is calculated. Entropy of the fluid after the pump and entropy of the fluid before the pump are the same, hence:

$$P2 = (v1*P1*M1+Wp1*\eta_p1)/\ (v1*M1) \quad (23)$$

$$S2 = S1 \quad (24)$$

With $P2$ and $S2$ known, other parameters can be calculated.

5.2 Parameters of the pump in the power plant

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:

$$P7 = (v6*P6*M6+Wp2*\eta_p2)/ (v6*M6) \quad (25)$$

$$S7 = S6 \quad (26)$$

With $P7$ and $S7$ known, other parameters in a closed loop after the pump can be calculated.

5.3 Parameters of the heat exchanger

The enthalpy of the geothermal fluid before the heat exchanger ($h2$) and the enthalpy of the working fluid after the pump ($h7$) 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 ($P7$), the entropy of the working fluid after the heat exchanger ($S7$) 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:

$$h3 = (h2*M2-(h4-h7)*M7)/M2 \quad (27)$$

The mass flow after the pump on the wellhead is the same as mass flow before the pump, or:

$$M2 = M1 \quad (28)$$

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

$$M7 = \mathrm{M6} \quad (29)$$

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

$$P3 = P2-P_h \quad (30)$$

With this pressure and $h3$, all parameters of the geothermal fluid in point 3 are known. The heat transfer from the geothermal fluid to the working fluid can therefore be calculated by Equations 31 and 32:

$$\dot{Q}_{hh} = M2*(h2-h3) \quad (31)$$

$$\dot{Q}_{ch} = M7*(h4-h7) \quad (32)$$

5.4 Parameters of the turbine

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:

$$S5 = S4 \quad (33)$$

$$P5 = P6+P_c \quad (34)$$

All the parameters of the working fluid after the turbine are known with $P5$ and $S5$, 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:

$$W\_t = (h4\text{-}h5)*M4*\eta_t \tag{35}$$

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:

$$M4 = M7 \tag{36}$$

5.5 Parameters of the condenser

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

$$P9 = P8\text{-}P_c \tag{37}$$

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

$$M8 = M9 \tag{38}$$
$$M6 = M5 \tag{39}$$

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:

$$h8 = (M8*h9\text{-}M5*(h5\text{-}h6))/M8 \tag{40}$$

With $h8$ and $P8$ known, all the others parameters for the condenser can be calculated.

5.6 Results

For calculations, input variables for the power plant (see Figure 6) are chosen as the following:

$M1$ = 50 kg/s	$h1$ = 1100 kJ/kg	$P1$ = 4000 kPa
$Wp1$ = 287 kW	$\eta_p 1$ = 0.8	$M6$ = 91 kg/s
$P6$ = 100 kPa	$Wp2$ = 480 kW	$\eta_p 2$= 0.8
P_h = 100 kPa	η_t = 0.85	$M8$ = 600 kg/s
$P8$ = 200 kPa	$h9$ = 150 kJ/kg	P_c = 100 kPa

In Table 3, known and calculated parameters at all points in Figure 6 are shown.

TABLE 3: Results of all parameters in an ORC power plant with isopentane

Point no.	h (kJ/kg)	M (kg/s)	P (kPa)	S (kJ/kg˚C)	T (˚C)
1	1100	50	4000	2.821	250
2	1100	50	4000	2.821	250
3	122.1	50	3900	0.4118	28.29
4	196.6	91	2360	-02869	164.3
5	104.1	91	200	-0.2869	86.76
6	-344.4	91	100	-1.671	27.48
7	-340.7	91	2360	-1.671	28.28
8	81.97	600	200	0.2892	19.51
9	150	600	100	0.5157	35.8

In Figure 7, the T-S diagram of isopentane is presented and in Figure 8, the P-h diagram of isopentane.

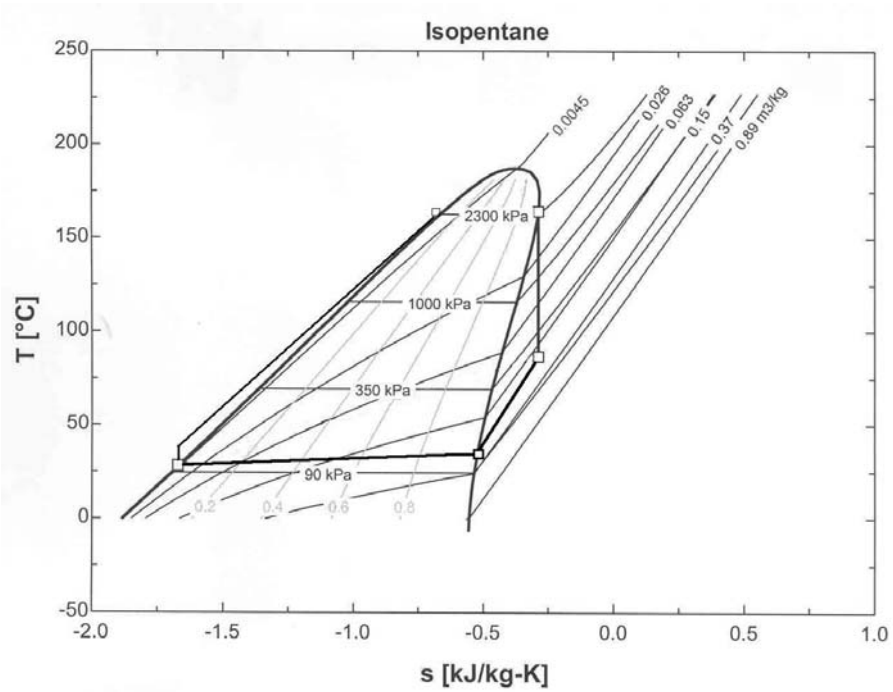

FIGURE 7: The T-S diagram for isopentane in an ORC power plant

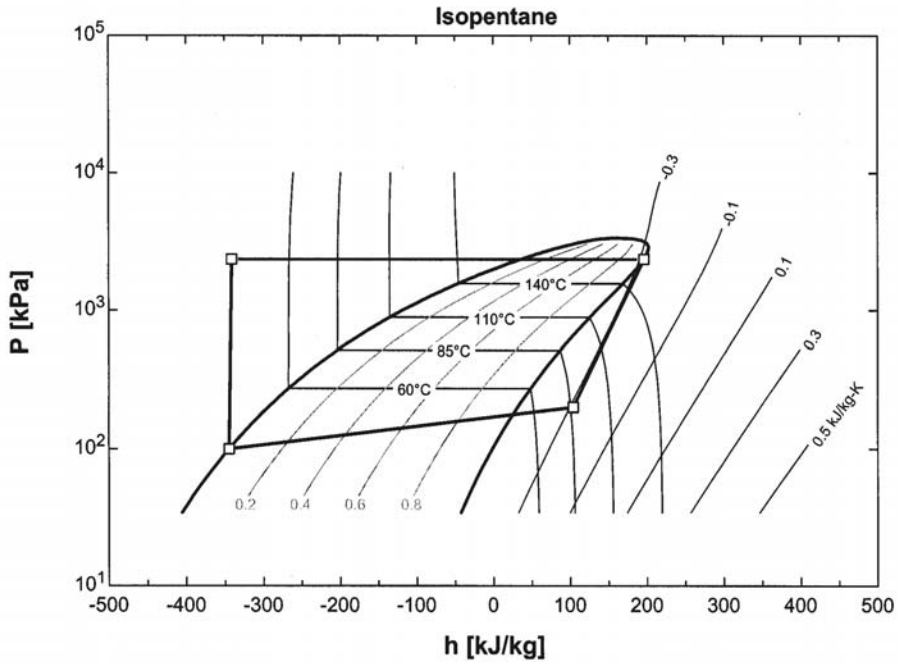

FIGURE 8: the P-h diagram of isopentane in an ORC power plant

The power of the turbine can be calculated by Equation 35, as:

$$W\_t = 7{,}151 \quad \text{kW}$$

And finally, the heat transfer in the heat exchanger can be determined by Equations 31 and 32, as:

$$\dot{Q}_{hh} = \dot{Q}_{ch} = 48{,}895 \text{ kW}$$

6. CONCLUSIONS

The calculated power output of the turbines for the two geothermal power plants discussed is:

Single flash power plant (steam): W_t = 4.6 MW
ORC power plant (isopentane): W_t = 7.2 MW

The main difference between the two types of power plants is the use of a heat exchanger in the ORC power plant, and the necessity to use a separator in the single flash power plant to separate the steam from the water. The power of the turbine in the ORC power plant is higher than the power of the turbine in the single flash power plant. It has though to be mentioned here that somewhat higher power can be obtained from a single flash plant by optimizing the separator pressure.

The enthalpy of the geothermal fluid that leaves the ORC power plant is, generally, lower than the enthalpy of the run-off geothermal fluid from the single flash power plant. This means that with ORC power plants it is possible to utilize the energy better. However, an alternative for the single flash power plant is to utilize the run-off geothermal fluid in direct use applications, such as heating or bathing. The famous bathing resort, the Blue Lagoon in Svartsengi, SW-Iceland, is a good example of this.

Some calculations were also done using ammonia as the working fluid in the ORC power plant, but the results were not realistic. It is difficult to use ammonia for this, as it needs, for example, a big heat exchanger or a very big condenser for the very special conditions.

Conceptual modelling of 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. There are many kinds of power plants, one of the most recent types is the Kalina power plant, that uses a mixture of ammonia and water as working fluid. Time did not allow to do calculations on it, but it is recommended that similar calculations should be done for that. Another type of plant, which time did not allow for modelling, is the combined flash steam and ORC cycle like the one which is used in the Svartsengi power plant.

Conceptual modelling of different types of power plants with the main features of the geothermal system known, allows assessment of which type of power plant has the highest output power from the turbine, which is the cheapest, which power plant is economical, etc. This gives information on which type of power plant produces the cheapest electricity and which type is the most effective one in producing electricity, vital knowledge for taking the right decisions.

NOMENCLATURE

A	Area (m^2);
h	Enthalpy (kJ/kg);
M	Mass flow rate (kg/s);
P	Pressure (kPa);
P_c	Pressure loss in condenser (kPa);
P_h	Pressure loss in heat exchanger (kPa);
$\dot{Q}_c$	Heat transfer in condenser (kW);
$\dot{Q}_h$	Heat transfer in heat exchanger (kW);
$\dot{Q}_{cc}$	Heat transfer in condenser on the cold side (kW);
$\dot{Q}_{ch}$	Heat transfer in condenser in hot side (kW);
S	Entropy Meshkin S(kJ/kg˚C);
T	Temperature (˚C);

X	Quality of fluid, i.e fraction of steam in fluid;
Wp	Power of pump (kW);
W_t	Power of turbine (kW);
η_t	Efficiency of turbine;
η_p	Efficiency of pump;
v	Specific volume (m^3/kg).

ACKNOWLEDGEMENTS

I would like to express my gratitude to Dr. Ingvar B. Fridleifsson director and Mr. Lúdvík S. Georgsson deputy director of the UNU Geothermal Training Programme for giving me the opportunity to participate in this special course and for their endless support, and similarly to Mrs. Gudrún Bjarnadóttir for her help and kindness during the training course. Great thanks to Dr. Páll Valdimarsson, Mr. Sverrir Thórhallsson, Mr. Geir Thórólfsson and Mrs. Agnieszka Rogowska for their help during the training and the preparation of this report and to Mrs. Maria-Victoria Gunnarsson for editing my report. Finally, I would like to express my thanks to my supervisors Ms. Fjóla Jónsdóttir and Mr. Jón Ágúst Thorsteinsson and also all lecturers and staff members of Orkustofnun and ÍSOR, and all the others who showed their willingness to share their knowledge and experience.

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