PROCEEDINGS, 42nd Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 13-15, 2017
SGP-TR-212

Direct Applications of Geothermal Energy; Economic and Environmental Assessment: Meshkin-Shahr, Iran

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Keywords: *District Heating System, Direct use, Geothermal Energy, Meshkin-Shahr, Iran*

Abstract

The city of Meshkin-Shahr is located in Northwestern of Iran, in a region with significant geothermal energy potential. 11 wells (consist of 7 production, 1 reinjection and 3 monitoring wells) have been drilled in the field since 2002. This work evaluates the potential use of separated brine to supply the thermal power demand for the local district heating and industrial use. Separated liquid with 120 °C temperature and 150 kg/s flow rate will be utilized for direct use of geothermal energy. Food processing, district heating, greenhouse, geothermal tourist center and fish farm are the main consumers of this geothermal heating system. Energy and exergy analysis were performed to model the potential direct use. The Economic and environmental analysis was also performed to demonstrate the commercial viability of the project and reduced greenhouse gasses emissions.

1. INTRODUCTION

Geothermal energy is one of the renewable energy resources witnessing increasing interest. Geothermal energy can supply energy demand in two different forms. It could be used indirectly for geothermal power generation or be utilized directly for heating purposes such as greenhouses, district heating, fish farming and others (Lund and Boyd, 2015).

82 countries around the world have reported installed direct use geothermal applications. Some of these countries have a long history in the research and development of direct geothermal energy use. Amongst these countries are: the US, Iceland, New Zealand. In the case of the US, the direct utilization of geothermal energy includes heating of swimming pools and spas, aquaculture and greenhouses, district heating, industrial applications and ground-source heat pumps. The largest application is ground-source heat pumps accounting for 88% of the annual energy use. In summary, when considering direct-use without geothermal heat pumps, the distribution of annual energy use is as follows: 34% for fish farming, 28% for bathing and swimming, 15% of individual space heating, 9% for greenhouse heating, 9% for district heating, and the rest is for agricultural drying, industrial process heating, cooling, and snow melting. The current installed capacity and annual energy use for district heating is 81.55 MWth and 839.6 TJ/yr (Lund and Boyd 2015).

Utilization of geothermal energy has played a major role in the energy supply of the Iceland for many years. The share of geothermal energy in the primary energy source in Iceland is about 68%. Space heating is by far the most important direct utilization, covering more than 90% of all energy used for house heating in the country. About 30 separate geothermal district heating systems are operated in towns and villages in the country and additionally some 200 small systems in rural areas. The Reykjavik district heating system is the largest in the country, serving a population of over 200,000 people. There are about 175 swimming pools in the country of which 150 are heated using geothermal energy. Geothermal snow melting covers a total area of around 1,200,000 m^2, mostly in the capital Reykjavik. Fish farming produces about 7,000 tons annually on 70 fish farms, mainly producing arctic char and salmon. Some of the direct-use applications capacity and annual energy use are district heating of 1,515 MWth (29,400 TJ/yr); snow melting of 195 MWth and 1,900 TJ/yr; bathing and swimming of 90 MWth (1,600 TJ/yr) (Ragnarsson 2015).

In recent decades New Zealand has faced significant growth in geothermal energy harvesting. Several New Zealand companies have invested significantly in large scale industrial direct geothermal energy applications in the last five years including; Ngati Tuwharetoa Geothermal Assets Limited supplying the Svenska Cellulosa Aktiebolaget tissue mill at Kawerau, and Tuaropaki trust supplying clean steam generated from geothermal energy to the milk powder processing plant at Mokai. Despite these new developments, there has been a reduction in geothermal direct use overall since 2010, primarily a consequence of Norske Skog Tasman closing one of the paper production lines at its Kawerau facility in January 2013 (Carey, Dunstall et al. 2015). The installed capacity and energy use of the various applications stands at: 31 MWth (289 TJ/yr) for district heating; 24 MWth (366 TJ/yr) for greenhouse heating; 17 MWth and 196 TJ/yr for fish farming; 0.13 MWth and 2 TJ/yr for animal farming; 284 MWth and 5,043 TJ/yr for industrial processing; 58 MWth and 1,375 TJ/yr for bathing and swimming; and 33 MWth (992 TJ/yr) (Carey, Dunstall et al. 2015).

Iran has high geothermal energy potential(Noorollahi, Yousefi et al. 2009, Porkhial and Yousefi 2015). The country geothermal gradient range varies from 2°C/100m in the Zagros belt to 13 °C/100m around the Damavand volcano in the north. Most geothermal energy studies in Iran have focused on electricity production, while, research on the direct use of geothermal energy have received less attention.

The result of (Noorollahi Younes , Itoi Ryuichi et al. 2007) indicated that 8.8% of land area in Iran has geothermal potential with 18 promising high-temperature geothermal fields. These eighteen prospected areas have been recommended for detailed geological, geochemical and geophysical investigations. The most investigated field in Iran is the Sabalan geothermal prospect. Sabalan lies in the Moeil valley on the western slopes of Mt. Sabalan, approximately 16 km southeast of the Meshkin-Shahr city (Noorollahi, Yousefi et al. 2009). Eleven wells including 7 productions, 1 reinjection, 3 monitoring wells have been drilled in Sabalan, which is recognized as a potential for geothermal power generation. Specifications of these wells are provided in Table 1.

Table 1. Specifications of drilled wells in Sabalan geothermal field.

Name	Depth (mMD[1])	Location			Max measured Temperature[°C]	Flash-point Pressure[kPa]
		Elevation[m.a.s.l[2]]	Easting[m.E[3]]	Northing[m.N[4]]		
NWS-1	3197	2632	739108	4238580.0	243	300
NWS-2	638	2632	--	--	--	--
NWS-3	3160	2487	737028	4240784.0	149	--
NWS-4	2255	2487	73712	4239833.0	237	380
NWS-5D	1901	2487	738414	4239824.0	240	410
NWS-6D	2377	2742.55	739855	4237769	239	550
NWS-7D	2705	2742.55	739842	4237780	224	NA
NWS-8D	2413.5	2884	740582.1	4236276.9	200	--
NWS-9D	2700	2884	740573.1	4236272.6	232	580
NWS-10D	2300	2742.55	739817	4237817	228	618
NWS-11RD	2813	2478	737042.97	4240789.82	175	--

The geothermal power development at Sabalan considered a single flash power plant. The flow rate and temperature of the geothermal fluid exiting from power plant is150 kg/s at 120℃ (Taghaddosi and Porkhial 2015).

The chemical composition of the geothermal fluid varies in different geothermal wells that are drilled in Sabalan area also composition changes during one year of discharge testing. The chemical composition for well NSW-1 is provided in Table 2 (MOUSAVI, JALILINASRABADY et al. 2015).

Table 2. The chemical composition of the well NSW-1 fluid.

Chemical Composition	pH	Cl [mg/kg]	Na^+ [mg/kg]	SO_4^{2-} [mg/kg]	SiO_2 [mg/kg]	Ca^{2+} [mg/kg]	K^+ [mg/kg]	B [mg/kg]	CO_2 [Gas] [mg/kg]
	6.6	975	690	437	129	127.2	109.5	8.21	358

Table 2 shows that well NSW-1 produced fluid is a near neutral acid sulphate-chlorides water with relatively low silica content indicating mixing of the deep geothermal water with some shallow steam heated water, unfortunately, the bicarbonate concentration was not measured, possibly bellow detection limits. The fluid chemistry indicates a low potential for mineral scaling in the heat exchanger (Figure 1).

Meshkin-Shahr city is located in the Ardabil province which is situated in northwestern part of Iran. It has a population of 40,000 and covers an area of 18 km^2. The first geothermal power plant in Iran was established near that area and the field development was started

[1] Meters Measured Depth(mMD)
[2] Meters Above Sea Level(m.a.s.l)
[3] Measured Eastward(m.E)
[4] Measured Northward(m.N)

in 2001. Due to geographical setting of the city (located in a mountainous area), the need for home heating is essential the whole year round. Heating is normally provided through burning fossil fuels.

This research aim is to demonstrate the ability of mentioned flow to supply some heat demands of Meshkin-Shahr. In order to achieve this different heat demand, sectors were introduced in the following section and the energy and exergy evaluations for this system will be conducted. Finally, supply heat system efficiency is calculated.

2. HEATING SYSTEM DESIGN

As discussed earlier, the geothermal direct use system is anticipated to service several consumers as shown in Figure 1.

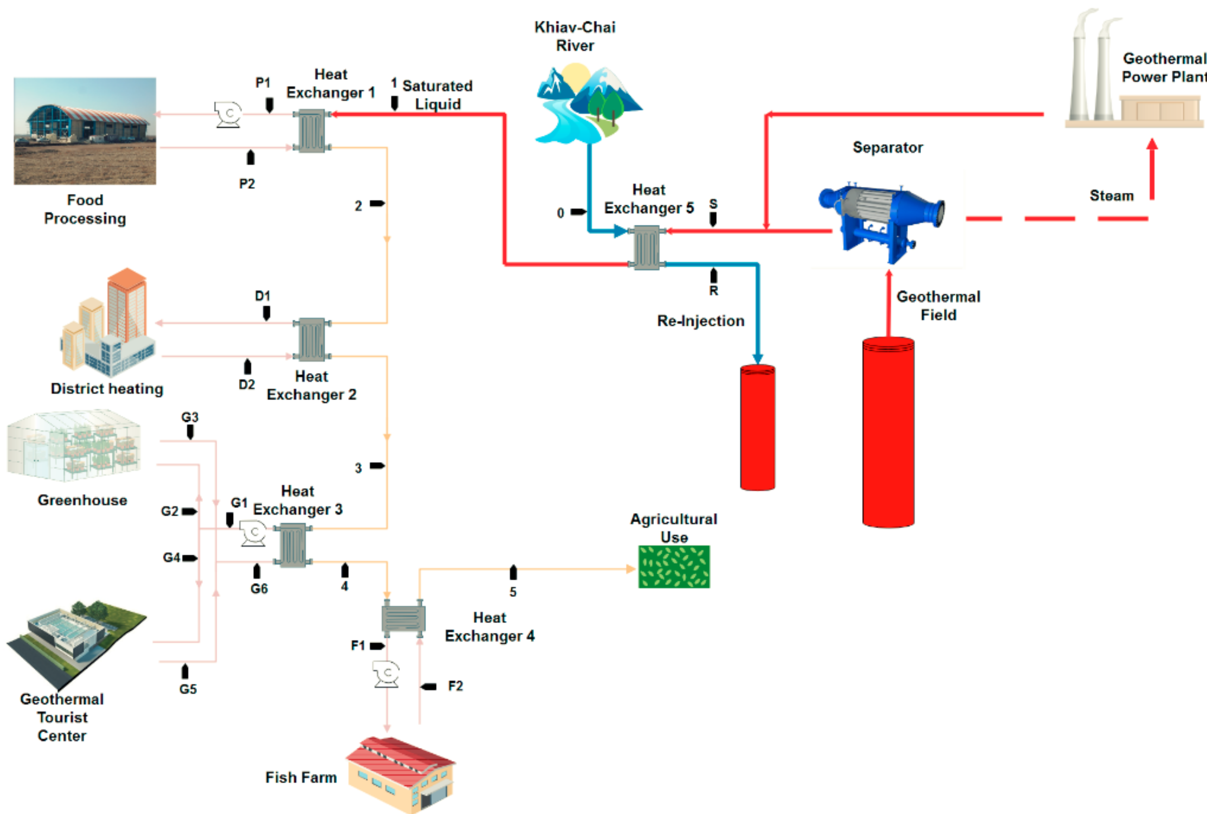

Figure 1. The proposed cascading geothermal heating system

Figure 1 shows that the circulation of geothermal fluid is an open cascading system. After the separation of the geothermal fluid into steam and hot water, steam is sent to the geothermal power plant and hot water (brain) runs through the heat exchanger 5 along with the steam condensate from the cooling towers blow down. The hot water mass flow and temperature entering the heat exchanger 5 are 150kg/s and 120°C, respectively (Taghaddosi and Porkhial 2015). In the heat exchanger 5, the hot geothermal fluid heats up cold fresh water from the Khiav-Chai river. The secondary hot fluid is sent to several tertiary systems near Meshkin-Shahr city including food processing facility first (heat exchanger no. 1) then it cascades down to the district heating system (heat exchanger no. 2). Heat exchangers no. 3 serves both the greenhouse and geothermal tourist center. While heat exchanger no. 4 supply the fish farm and the fluid is used then for soil warming and irrigation.

2.1. Food Processing

Geothermal energy has been used in different industries such as, bottling of water and carbonated drinks in Bulgaria, Serbia, Turkey and the United States, milk pasteurization in Romania and New Zealand, leather industry in Serbia and Slovenia, chemical extraction in Bulgaria and Poland also in Russia, CO_2 extraction in Iceland and Turkey, pulp and paper processing in New Zealand, iodine and salt extraction in Vietnam, and acid production in Italy. These industries require high temperature, have high energy consumption and often operate all year-round (Lund and Boyd 2015).

Another direct use of geothermal energy in food processing could be in conserved and canned foods industry, which is assessed in this research. Geothermal energy could be a clean alternative to fossil fuels like natural gas, diesel fuel and coal. In the presented model, data for a conserved and canned food company is used. The annual food production of this factory is provided in Table 3.

Table 3. Annual food productions.

Product	Production amount[ton]
Tomato paste	1153
Compote	249
Ketchup	670
Jam	855

Current diesel and natural gas consumption in order to supply the energy needed for this food processing facility are shown in Table 4. In addition, according to National Iranian Oil Products Distribution Company (NIOPDC), heat value of mentioned fossil fuels are provided in Table 4.

Table 4. Fuel consumptions and heating values.

Fuel	Consumption	Heat Value	Annual Energy Consumption
Diesel	1,440 $[lit]$	37.7921 $[MJ/lit]$	54,420.6 $[MJ]$
Natural Gas	463,788 $[m^3]$	33.93 $[MJ/m^3]$	15,736,326.84 $[MJ]$
Total	________	________	15,790,747.4 $[MJ]$

It is assumed that daily working time is 16 hours and additionally there are 330 working days each year considering Iranian nation holidays. Therefore daily energy consumption can be calculated as follows:

$$Q_{F.P} = 15{,}790{,}747.4 \left(\frac{MJ}{year}\right) \times \frac{1}{330}\left(\frac{year}{day}\right) \times \frac{1}{16}\left(\frac{day}{hour}\right) = 2658.4 \ \left(\frac{MJ}{hour}\right) \qquad (1)$$

$Q_{F.P} =$ Food Processing Hourly Energy Demand

From the optimization of industrial unit processes, diesel and natural gas boilers normally have 85 percent efficiency for heating purposes, (Liptak 1998). Hence required power will be:

$$\dot{Q}_{F.P} = 2{,}658.4 \ \times 0.85 = 2{,}259.64 \ \left(\frac{MJ}{hour}\right) = 627.6 \ (kW_{th}) \qquad (2)$$

$\dot{Q}_{F.P} =$ Food Processing Required Power

2.2. District Heating

In order to evaluate the needed energy for district heating, it is necessary to consider the total heating demand of Meshkin-Shahr city. Meshkin-Shahr region is situated in Ardabil province. Unfortunately, Natural Gas (main fuel source) consumption data of this region is not available. In order to estimate the fuel consumption per capita, data from Ardabil was considered. According to 2014 energy balance, the amount of natural gas consumed in Ardabil was 811 million cubic meters.

Based on the last Iranian census taken place in 2011, the population of Ardabil and Meshkin-Shahr are 1’248’000 and 40’000, respectively. In proportion, the amount of natural gas consumption in Meshkin-Shahr is estimated to be about 26 million cubic meters per year as shown in equation 3.

$$GC_M = GC_A \times \frac{P_M}{P_A} = 811 \times 10^6 \times \frac{40{,}000}{1{,}248{,}000} = 25.99 \times 10^6 \ (m^3) \quad (3)$$

GC_M =Gas Consumption in Meshkin-Shahr GC_A =Gas Consumption in Ardabil

P_M =Population of Meshkin-Shahr P_A = Population of Ardabil

The Iranian natural gas heating value is 36,120 kJ per cubic meter and efficiency of central heating systems (CHS), which is the most common heating system in buildings of this area, is 55 percent(Yousefi, Roumi et al. 2016).

$$Q_{\text{chs}} = GC_M \times \frac{HV_{NG}}{1\ m^3} \times \mathcal{E}_{\text{chs}} = 25.99 \times 10^6 \times \frac{36120\ kJ}{1\ m^3} \times 0.55 = 516388.6 \times 10^6\ (kJ) \quad (4)$$

Q_{chs} = Central Heating Systems Energy Demand HV_{NG} =Heat Value of Natural Gas

$\mathcal{E}_{\text{chs}}$ =Central Heating Systems Efficiency

Generally, 71 percent of energy consumption is related to heating and cooling which can be provided by geothermal energy(Yousefi, Roumi et al. 2016).

$$Q_{H\&C} = Q_{\text{chs}} \times P_{H\&C} = 516388.6 \times 10^6 \times 0.71 = 366635.94 \times 10^6\ (kJ) \quad (5)$$

$Q_{H\&C}$ = Heating and cooling energy Consumption $P_{H\&C}$ = Percentage of energy Consumption for Heating and cooling

To calculate the heating power that is needed for supplying district heating demand purpose will be:

$$\dot{Q}_{D.H} = Q_{H\&C} \times \frac{1\ year}{365\ days} \times \frac{1\ day}{24\ hours \times 3600\ sec} = 11625.94\ (kW_{th}) \quad (6)$$

$\dot{Q}_{D.H}$ = District Heating Required Power

In addition, it is assumed that the intensity of consumed energy in winters is twice as much as the mean energy consumption. Thus thermal power needed for district heating of Meshkin-Shahr city in winter is approximately 23251.88 kWth (23.25 MWth).

2.3. Greenhouse

Geothermal energy is commonly used for greenhouse heating in many countries such as Iceland, China, and the USA. Greenhouse size, location, and roof material have important control on energy loss and the amount of heat demand.

A greenhouse producing lettuce for the local market is to be located at about 15 km from the production wells. Inter-V type is chosen among different types of greenhouses. The reason for this choice is the cold and snowy weather of Meshkin-Shahr and the Inter-V type roof ability to avoid the accumulation of snow on the roof, which is also used for rainwater collection.

Based on Iranian regulations, minimum dimensions of a greenhouse are 11 meters length 6 meters width. Crop type, cultivation method, and construction cost these dimensions can increase. The side walls of the greenhouse have multi layers extruded polystyrene insulation. This material is chosen to prevent heat loss and reduce infiltration of the greenhouse.

Different types of materials that can be used for the roof of the greenhouse are glass, plastic films, and fiberglass. According to Meshkin-Shahr special climate and the importance of light transmission ability, double glazed glass is a suitable choice to use as the ceiling of the greenhouse(Panagiotou 1996).

In order to ensure even distribution of heating which is necessary for greenhouses, “Pipes on the floor between the plots” is selected. The main advantage of this method is providing a proper temperature in all greenhouse area causing growth in cultivation. Winter heat loss consists of two components:

$$\dot{Q}_G = \dot{Q}_T + \dot{Q}_I \tag{7}$$

$\dot{Q}_G$ =Greenhouse Required Power

$\dot{Q}_T$ =Heat Loss Through Roof and Wall

$\dot{Q}_I$ =Infiltration/ventilation

$\dot{Q}_T$ is the heat loss by conduction of transparent roof and walls of the greenhouse. For this heat loss it is necessary to separately evaluate the heat transfer area of transparent roof and walls.

$$\dot{Q}_T = \dot{Q}_{Cover} + \dot{Q}_{Wall} \tag{8}$$

$\dot{Q}_{Cover}$ =Heat Loss Through Roof

$\dot{Q}_{Wall}$ =Heat Loss Through Wall

$$\dot{Q}_{Cover} = \frac{A_{Cover}}{R_{Cover}} * (T_i - T_o) \tag{9}$$

A_{Cover} =Skylight Area

R_{Cover} =Cover Heat Resistance

T_i =Inside Temperature

T_o = Outside Temperature

A_{Cover} is the skylight area which have the most energy loss. Based on mentioned greenhouse dimensions, A_{Cover} is 88 m^2. R_{Cover} consists of three components. $R_{i,Cover}$ and $R_{O,Cover}$ are caused by inner and outer thermal convection, respectively. $R_{\lambda,Coverr}$ is stand for thermal conduction in windows.

$$R_{Cover} = R_{i,Cover} + R_{\lambda,Cover} + R_{O,Cover} \tag{10}$$

$R_{i,Cover}$ =Inner Convectional Thermal Resistance

$R_{\lambda,Cover}$ =Windows Conductional Thermal Resistance

$R_{O,Cover}$ =Outer Convectional Thermal Resistance

As discussed before, “pipes on the floor between plots” is chosen as the heating system and considering DIN 4701 standard, $R_{i,Cover}$ is 0.12.

Due to the greenhouse design, double glass in steel frame with 15 mm space in the middle was considered for the skylight, which gives an $R_{\lambda,Cover}$equal to 0.14 according to DIN 4701 standard. Unlike two other factors, $R_{O,Cover}$ is totally dependent to the climate. Wind speed in Meshkin-Shahr at about 4m/s according to Iran Meteorogical Organization report, therefore $R_{O,Cover}$ is 0.0455 (DIN 4701). Hence R_{Cover} can be calculated using equation 10 giving:

$$R_{Cover} = 0.12 + 0.14 + 0.0455 = 0.3055 \left(\frac{m^{2\circ}C}{W}\right)$$

From the management and programming organization (MPO) of Iran magazine, winter design temperature (T_o) for selected area is 3.2 ℃. While the optimum temperature (T_i) for cultivating lettuce is 21.1 ℃.

$$\dot{Q}_{Cover} = \frac{88\ m^2}{0.3055} \times (21.1 - 3.2) = 5156\ (kW_{th}) \tag{11}$$

The ratio of conductivity of glass to the wall in the greenhouse is enormously high. Therefore, $\dot{Q}_{Wall}$ can be negligible compared to $\dot{Q}_{Cover}$. Hence(Panagiotou 1996):

$$\dot{Q}_T \approx \dot{Q}_{Cover} \tag{12}$$

Another section which has an important role in greenhouse energy demand is infiltration of outside air through leak joints of the ceiling. The excessive heat demand will be calculated using equation 13.

$$\dot{Q}_I = \frac{A_{Cover}}{R_{V,Cover}} \times (T_i - T_o) \tag{13}$$

$R_{V,Cover}$ = Infiltration Thermal Resistance

According to DIN4701 standard, the value of $R_{V,Cover}$ for infiltration will be $2[m^2°C/W]$. Therefore, the equation 13 will be simplified as follows.

$$\dot{Q}_I = \frac{88\ m^2}{2} \times (21.1 - 3.2) = 787\ (kW_{th})$$

Hence the total heat demand of greenhouse will be 5943 kW_{th}, which is the sum of Q_{Cover} and $Q_{Infiltration}$ (equation 7).

$$\dot{Q}_G = 5156 + 787 = 5943\ (kW_{th})$$

2.4. Tourist Centre

One of the ancient direct use applications of geothermal energy is recreation which includes bathing and balneology. More than 70 countries have reported swimming pools heated by geothermal water in public and private spas and resorts. There are 70 countries well known for using geothermal fluids for bathing and swimming pools including Malaysia, Mozambique, Singapore and Zambia. Large scale development can be found in China, Iceland, Japan, Poland, Turkey, Brazil and Mexico (Lund and Boyd 2015).

Geothermal spas are reported in Iran such as the Sarayn thermal mineral pools. In this work, a tourist center is designed for balneology use taking social considerations into the design and operation of these pools. Due to considerations, semiprivate use of this center is assumed. Therefore, in this research it is assumed that there will be 10 private ponds with measurements of 6 meters length, 4 meters width and depth of 1.5 meters.

The heating demand for these ponds will be calculated by using the equation 14:

$$\dot{Q}_{T.C} = \dot{m} \times c \times \Delta\theta \tag{14}$$

$\dot{Q}_{T.C}$ =Tourist Center Required Power

The total volume of these ponds will be $360m^3$. In order to keep water temperature steady, there will be a need to refresh the water. Water in ponds should be refreshed 4 times per hour (Thain, et al., 2006). As a result mass flow rate of the water can be calculated as follows:

$$\dot{m} = \frac{360\ m^3 \times 4}{3600\ s} \times 1000\ \frac{kg}{m^3} = 400\ \left(\frac{kg}{s}\right) \tag{15}$$

$\dot{m}$ = Mass Flow (kg/s)

The difference between inlet and outlet flow temperature of ponds are assumed to be 5°C in order to provide optimum temperature control for users. Heat demand for this tourist center can be calculated by using equation 14.

$$\dot{Q}_{T.C} = \dot{m} \times c \times \Delta\theta = 0.4 \times\ 10^3 \times 4.2 * 5 = 8400\ (kW_{th})$$

c = Specific Heat Capacity $\Delta\theta$ = Temperature Difference

2.5. Fish Farm

Direct use of geothermal energy in aquaculture industry has witnessed 6.7% increase in the past five years. There are 21 countries with reported use of geothermal energy for fish farming and aquaculture. Four countries with considerable use of geothermal energy include the USA, China, Iceland and Italy, However, the growing rate in most established centers is low due to high wages required for the well-trained personnel that operates these facilities. A vast variety of aquatic species is farmed in aquaculture industry such as tilapia, salmon, trout, tropical fishes, lobsters, shrimp, prawns and alligators(Lund and Boyd 2015).

The water temperature where the different fish species make the best growth out of the consumed feed varies from 13 °C (Baldwin, 1957) to 15 °C (Molony, 2001). Hence, the optimal utilization of feed and the maximum appetite of rainbow trout also fall within this range of water temperature. In this research, the optimum temperature is assumed 15 °C. According to "Small-scale rainbow trout farming" for a fish farming purposes a pool with the volume of $300\ m^3$ and measurements of 20 meters length, 10 meters width and depth of 1.5 meters (Woynarovich, Hoitsy et al. 2011).

The heating demand for fish farms will be calculated as follows:

$$\dot{Q}_{F.F} = \dot{m} \times c \times \Delta\theta \tag{16}$$

$\dot{Q}_{F.F}$ =Fish Farm Required Power

The subtraction of optimum temperature for fish farming, 15°C, and mean air temperature of the region is assumed 1.92 °C which is the Meshkin-Shahr average temperature of recent five years in January, therefore:

$$Q_{F.F} = \dot{m} \times c \times \Delta\theta = (300 \times 1000)\ kg \times 4.2\ \frac{kJ}{kg°\mathrm{C}} \times (15 - 1.92)\ °\mathrm{C} = 16.481\ (\mathrm{GJ}) \tag{17}$$

That is the heat demand for heating the pool for one time but it is needed to refill the pool three times each day, thereby it will be multiplied by three and the result will be 49.443 GJ. This is the total heat demand for one day and this demand should be fulfilled within 4 hours therefore in order to determine the required power the following step is taken:

$$\dot{Q}_{F.F} = 49.443 \frac{GJ}{day} \times \frac{1 day}{4\ hr \times 3600\ s} = 0.3432847\ (GW_{th}) = 3432.847\ (kW_{th})$$

Hence the required thermal power will be 3432.847 kWth (3.4 MWth) and this thermal power should be provided for 4 hours each day.

3. ENERGY AND EXERGY EVALUATION

In order to evaluate the performance of designed geothermal heating system, it is essential to calculate the system efficiency. Three common thermodynamic efficiencies measures have been used:

3.1. First Thermodynamics law

This concept explains that the efficiency of a system is related to useful output and total input. Since the output of designed geothermal system is heat instead of work which is more common in systems, therefore the first law efficiency will be more than Carnot.

$$\eta_{1st\ law} = \frac{E_{Useful}}{E_{Total}} = \frac{\Sigma \dot{Q}}{\dot{m} \times h_s} = \frac{(627.6 + 23251.88 + 5943 + 8400 + 3432.84)}{\left(150 \frac{kg}{s} \times 503.8 \frac{kJ}{kg}\right)} = 55.12\% \tag{18}$$

$\eta_{1st\ law}$ =First Thermodynamics Law Efficiency

E_{Useful} = Useful Energy

E_{Total} = Total Energy

h_s = Enthalpy of Supply

3.2. Second Thermodynamics Law

The second law of thermodynamics efficiency based on the exergy content of the operating fluid, this is also known as the utilization efficiency(Zarrouk and Moon 2015). Exergy is the maximum output work that a system could reach. The efficiency of the designed system can be calculated using equation 19 as shown in Table 5.

$$\eta_{2nd\ law} = \frac{\dot{Ex}_{useful}}{\dot{Ex}_{In} - \dot{Ex}_{Loss}} = \frac{\left(\dot{Ex}_{P1} - \dot{Ex}_{P2}\right) + \left(\dot{Ex}_{D1} - \dot{Ex}_{D2}\right) + \left(\dot{Ex}_{G1} - \dot{Ex}_{G6}\right) + \left(\dot{Ex}_{F1} - \dot{Ex}_{F2}\right)}{\dot{Ex}_S - \dot{Ex}_R - \dot{Ex}_5} = \frac{6234.9}{10168} = 58.94\% \tag{19}$$

$\eta_{2nd\ law}$ =Second Thermodynamics Law Efficiency $\dot{Ex_i}$ = Exergy in point "i"

4. RESULTS

Energy and Exergy analysis of the full cycle is simulated using engineering equation solver (EES™) are provided in Table 5.

Table 5. Results of the full simulated system.

Point	Temperature[°C]	Enthalpy [kJ/kg]	Entropy [kJ/kg °C]	Mass Flow[kg/S]	Exergy[kW]
supply	120	503.8	1.528	150	11843
Reinjection	40	167.7	0.5722	150	1289
0	10	42.08	0.151	141.6	14.34
1	95	398	1.25	141.6	7133
2	93.95	393.6	1.238	141.6	6980
3	54.79	229.4	0.7652	141.6	2353
4	30.58	128.2	0.4445	141.6	645.7
5	24.78	103.9	0.3639	141.6	374.8
p1	90	376.9	1.193	9.956	450.9
p2	75	314	1.016	9.956	314
d1	80	334.9	1.075	185.1	6643
d2	50	209.3	0.7679	185.1	2521
g1	50	209.3	0.7037	157.2	2141
g2	50	209.3	0.7037	56.83	773.8
g3	25	104.8	0.367	56.83	153.5
g4	50	209.3	0.7037	100.4	1367
g5	30	125.7	0.4365	100.4	428.8
g6	28.19	118.1	0.4115	157.2	576.5
f1	25	104.8	0.367	82.05	221.6
f2	15	62.92	0.2242	82.05	45.59

The following, a Sankey diagram for enthalpy is provided in Figure 2 to indicate an overall vision of the energy flow in the designed geothermal system.

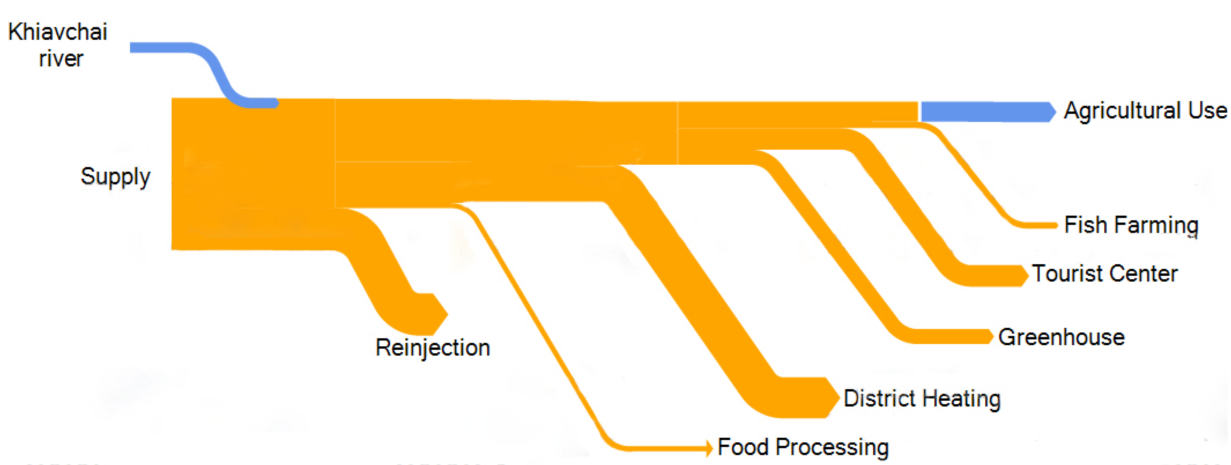

Figure 2. Sankey flow diagram of enthalpy.

5. ECONOMICAL ANALYSIS

To assess the profitability of the proposed system, we have carried economic analysis using the rate of return as the criterion. Using a 25 years life of the geothermal system and rate of inflation and time value of money are considered to be 0.1 and 0.15 respectively.
Heat transfer system costs could be divided into two sections:

- Pipelines:

In this project, two piping are considered. The first part is responsible for transferring fluid from the heat exchanger 5 to place of use. The second part is for district heating in Meshkin-Shahr. The length, diameter and cost of each pipeline are given in Table 6.
These costs include material (steel, insulation and cladding) and installation in Iran.

Table 6. Piping specifications.

	Diameter [mm]	Length [km]	Cost [$/km]
Suburban Piping	300	20	300,000
Urban Piping	150	15	250,000

- Heat Exchangers:

For each heat exchanger, the initial cost is related to the heat transferring surface of the heat exchanger. Initial costs for heat exchangers are available in Table 7. To calculate the heat transferring surface, the LMTD method is used (Sonntag, Borgnakke et al. 2002).

$$C_{H.E} = 588 \times (A_{H.E})^{0.8} \tag{20}$$

$C_{H.E} = \text{Heat Exchanger Cost}$ $A_{H.E} = \text{Heat Exchanger Surface}$

Table 7. Heat exchangers cost and surface.

Heat exchanger Number / Heat exchanger Specification	1	2	3	4	5
Surface [m^2]	59.89	2714	4162	458.2	1736
Cost [$]	15533	328297	462147	79108	229623

Total initial cost is equal to the sum of piping and heat exchanger costs. To consider contingency, the expenses in Table 7 were multiplied by 1.5. In other words, 50 percent of unpredicted costs are assumed.
The net present values (NPV) by year for different natural gas prices and results are given in Figure 4(The price of each cubic meter of Iranian natural gas is 0.1$ in 2014). Figure 4 shows that under worst case scenario the project will achieve positive NPV within four years.

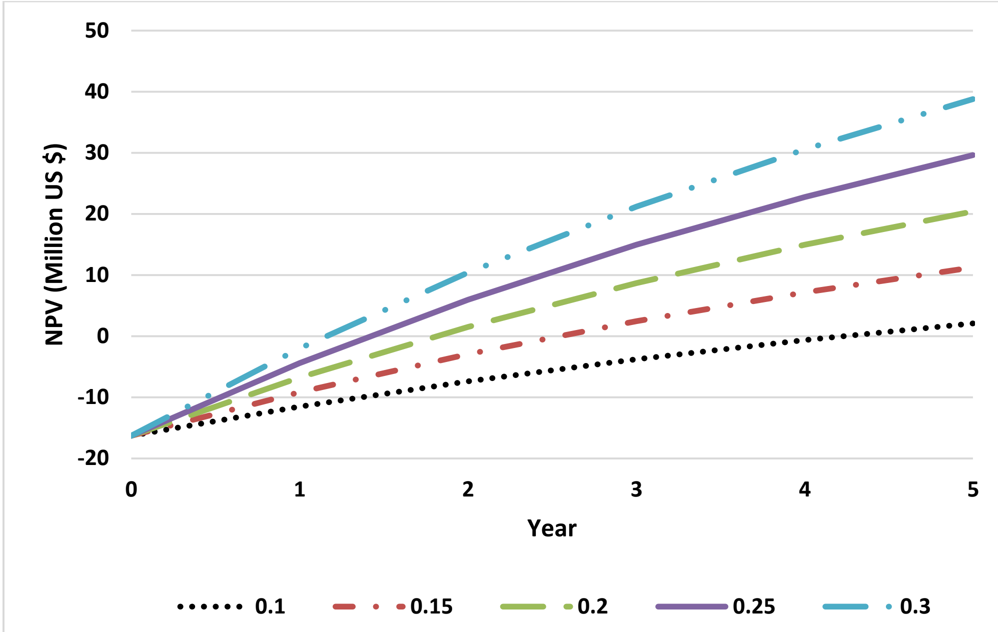

Figure 4. NPV diagram with different natural gas prices.

6. ENVIRONMENTAL EFFECTS

Using the designed geothermal system will lead to significant decrease of natural gas consumption in the area. There will be much lower natural gas consumption. Table 8 shows the emissions reduction from not using natural gas and costs of these emissions are indicated. The external costs definition in this research is the benefits of preventing 6 pollutants spreading into the air.

Table 8. Natural gas emissions and external costs.

	CO_2	NO_x	SO_2	CO	SPM	CH_4
Emissions [gr/kWh]	870.53	2.671	0.792	0.096	0.145	0.019
External Costs Per Ton[$/Ton]	2.5	150	456.25	46.875	1,075	52.5
Amount [Ton]	616,440	1,891	560.8	67.98	102.7	13.5
Total External Cost Saving [$]	1,541,100	283,650	255,865	3,186.563	110,402.5	708.75

7. CONCLUSIONS

In this paper, the case of utilizing geothermal flow leaving Meshkin-Shahr power plant to supply some energy consumers is studied. The flow rate and temperature of the stream are 150 lit/s and 120°C, respectively. After exchanging the energy with Khiavchai river stream in a heat exchanger, the geothermal flow will be sent to injection well.

The direct heating system could provide 41.6 MW of heat demand. Carnot, first thermodynamics law and second thermodynamics law efficiencies for this system are 24.2, 55.12 and 58.94 percent respectively. Economic analysis of the rate of return is conducted with regards to capital costs of heat exchangers, piping system and savings because of natural gas consumption decrease. Calculations indicated that the rate of return will be between 1.2 and 4.5 years in cases of assuming natural gas price to be between 0.3 and 0.1 dollars per cubic meters. In addition, regarding the amount of produced CO_2, NOx, SO_2, CO, SPM and CH_4 emissions per cubic meter of natural gas combustion the amount of emission reduction will be 619,076 tons annually.

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