Energy and ecological evaluation of ORC based geothermal CHP plant in Poland – a case study

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Abstract: The paper summarizes the energy and ecological analysis results of geothermal CHP plant operation in Polish conditions. The variant of CHP plant based on Organic Rankine Cycle (ORC) has been taken into consideration as the most favorable for the geothermal conditions prevailing in Poland. The existing geothermal well located in the town of Konin in the Wielkopolska voivodship has been chosen as the case study. The conceptual design of CHP plant has been proposed and evaluated from energy and environmental point of view. The non-renewable primary energy consumption has been chosen as energy performance criteria. In case of environmental performance carbon dioxide emission has been taken as evaluation criteria. The analysis has been performed for different operating conditions and three working fluids.

Keywords: energy performance, CO_2 emission, cogenerated heat and power (CHP), Organic Rankin Cycle (ORC)

1. Introduction

The geologically confirmed geothermal energy resources in Poland are limited to low and medium temperature geothermal water. The increase in use of renewable energy sources in Poland is crucial due to the poor performance of polish power production industry, based on traditional condensing power stations fired with coal. The utilization of geothermal energy in Poland has significantly increased within last years. Unfortunately, due to the available geothermal energy resources it is limited to the low temperature heat production, health care or water park operation. The intensity of heat flow in the earth shell in Poland is relatively low. Good geothermal conditions are located in West European tectonic plate, where the temperature of geothermal water in the depth of 2000 m reaches 80°C.[1] The largest of the geothermal provinces in Poland is the Polish Lowland Province, which covers seven geothermal regions and covers an area of 222,000 km2. Deposit temperatures range from 30 ° C to 130 ° C at a depth of 1 to 3 km, while general mineralization occurs in the range from 1 to 300 g / l [2]. Average heat flux of geothermal resources in Poland varies between 25 mW/m² and 90 mW/m² [3]. According to [1,2] geologically confirmed geothermal energy resources in Poland are located in West European tectonic plate and refer to the underground water pools of Carpatia Mountains, Sudety Mountains and Podhale – Figure 1.
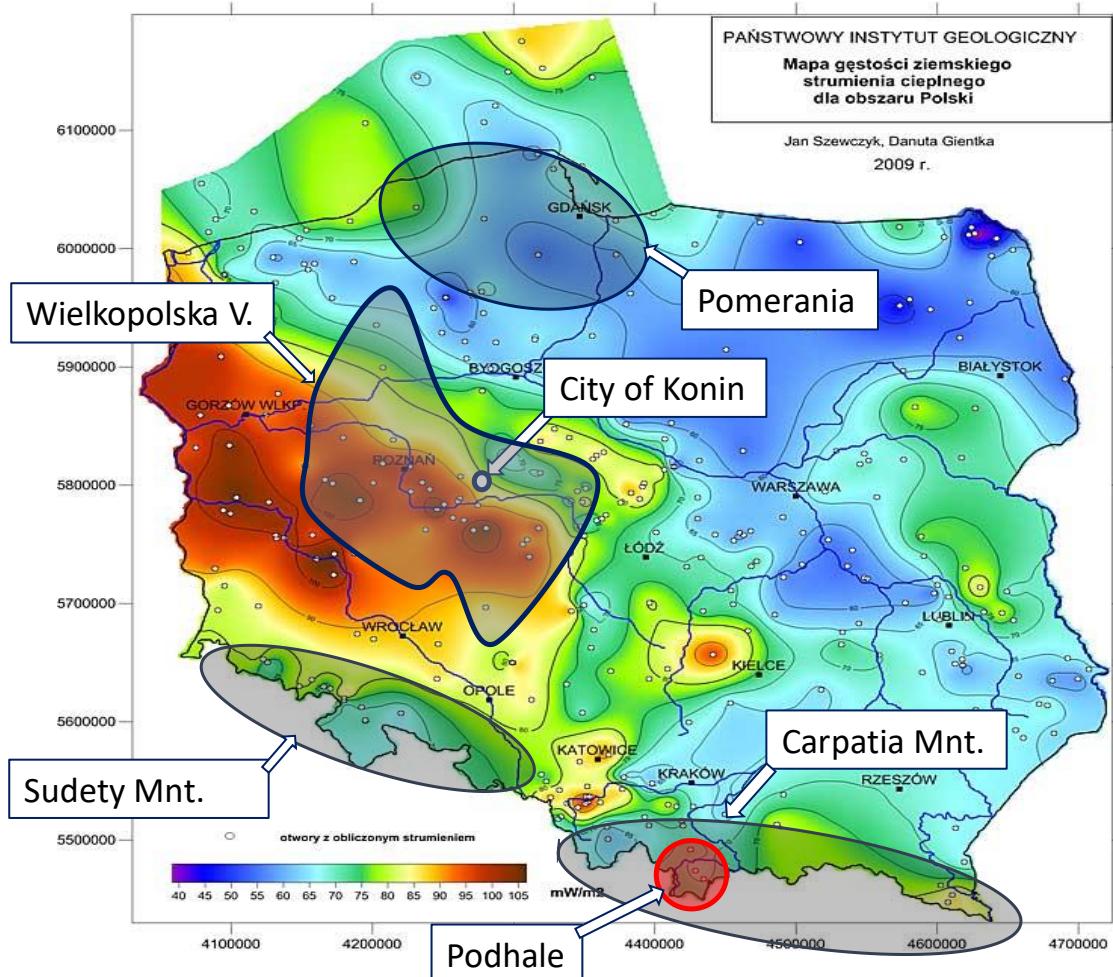
Fig. 1. The location of geologically confirmed geothermal energy resources in Poland [4]

The first geothermal heating station has been opened in Podhale region in 1994 – Geothermal Facility Banska – Biały Dunajec [5]. It was based on two wells providing water in the temperature range 80-86 $^{\circ}$C, and total flow of 670 m³/h. Total heating capacity of geothermal part of the system (after refurbishment in 2014) is 40,7 MW$_{th}$.

In 2015 there were nine geothermal SPA facilities under operation in Poland. The geothermal water resources of those facilities vary between 2-200 m³/h and the temperature of geothermal water is in the range of 18 to 60 $^{\circ}$C [1].

In recent years the increased activity in establishment of water park facilities can be observed. There were seven such facilities opened between 2006 and 2016 considering Podhale region only. Those facilities are ranked as the highest geothermal heat end users. Among them, the top ranked facility is Termy Bania, which utilizes the geothermal water from single well with the depth of 2500 m. The water temperature on the surface reaches 72 $^{\circ}$C [6].

In the Podhalan commune of Uniejów there are thermal baths that use groundwater from the time of the Lower Cretaceous. Renewable energy is also used there for therapeutic, heating, touristic, recreational or balneological purposes. Geothermal waters in this town reach a temperature of 70 $^{\circ}$C, which is their great advantage [7].

Since 2015 in Janowo, Baltic Sea region low temperature geothermal water taken from the 1200 m deep well is used in the production of Atlantic Salomon.

In general, the temperature of geothermal water in Poland does not exceed 70-80°C, what makes the power production or cogenerated heat and power (CHP) production in the direct solutions inefficient from the economical point of view [5]. It is caused by the fact that it is assumed that for the production of electricity it is profitable to use geothermal waters with a temperature of 120-150 °C.[2] Geothermal resources with temperatures above 130 °C are found in central Poland, but they are located at a depth of over 4000 m, therefore their extraction is not profitable.[8]

That is why the variant of CHP plant based on Organic Rankine Cycle (ORC) has been taken into consideration as the most favorable for the geothermal conditions prevailing in Poland.

Rankine cycle is well known thermodynamic cycle which enables production of work using heat as driving energy. In majority of cases heat is delivered in the form of chemical enthalpy of fuel and water is used as working fluid. Such systems are used in 85% of world production of electricity [9]. Unfortunately, ranking cycle based on water as working fluid requires very high temperature (and pressure) of steam introduced to turbine [10]. In consequence the heat introduced to the system as driving energy is limited to intensive energy forms – fossil fuel chemical enthalpy or nuclear energy. The principle of Organic Rankine Cycle (ORC) operation is similar. The main difference lays in working fluids which in the case of ORC are organic substances characterized by high molecular weight, lower temperature of evaporation and higher pressure of steam phase. It allows for the utilization of low temperature heat as driving energy, operation in lower pressure and application of turbines with lower rotation speed [9,11]. From the technological point of view ORC is less complicated with respect to traditional RC, it can use only one heat exchanger for heating, evaporating and overheating of working fluid. The additional heat regenerator is sometimes used for preheating liquid phase of working fluid [12]. Depending on low temperature heat source characteristic the working fluid has to be precisely selected [11]. The cost and market availability of working fluid have to be also considered [10,13]. The Organic Rankine Cycle attracted a lot of attention. This may be due to its contribution to mitigating the degradation of the ecosystem. This assessment is therefore very important and works on the basis of exergy analysis and life cycle methods [14,15]. Constantly developing power plants using the Organic Rankine Cycle are in addition to the Stirling engine, the only technology available on the market that allows the generation of electricity using low and medium temperature waste heat energy. Much effort has been put into improving the analysis techniques to find the best working fluid and ORC parameters for system configuration [16]. One of the main topics of investigations related to ORC is performance evaluation. However, adequate research on the effects of fluid charge on the operation outside the working system is still lacking. The correct liquid level in the condenser provides a large amount of working fluid, which also avoids cavitation of the pump [17]. Calculating the efficiency of both ORC and its components is not an easy task due to the lack of adequate instrumentation, inaccurate measurements and uncertainty as to the thermodynamic properties of the working fluid. This can have a significant impact on the final results of calculations, especially for complex fluids, with a small temperature drop in expansion [18].

Lubricating oil can help reduce the friction loss of the expander and prevent leaks. However, it affects the characteristics of the Organic Rankine cycle by mixing with a clean working fluid due to the lack

of an oil separator. Test results of the impact of the lubricating oil ratio (1.2%, 3.1%, 5.0%, 6.7% and 9.0%) on the behavior of the system based on the experimental ORC prototype with 3 kW power using R123 and degrees of overheating 5,10 and 15 °C showed that the deviation between the calculated heat input and the modified heat input is not more than 5%. The heat source temperature was 130 ° C and the mass flow was controlled by changes in pump frequency. The use of oil improves the behavior of the pump, however, it exacerbates the power of the expander shaft as well as the electrical power. The thermal efficiency is not sensitive to the lubricating oil ratio for the degree of superheat higher than 10 °C [19]. Due to the excellent results of the high-temperature Organic Rankine cycle in the use of renewable energy and industrial heat recovery, it has recently attracted a lot of interest. During the selection of working fluids, their stability is very important due to possible degradation at high temperatures. Studies have shown that siloxanes are a good choice for high-temperature ORCs, but there is not enough research on their thermal stability [20].

The possibility of use of existing low temperature geothermal energy source located in Konin, Poland has been the basis for conceptual design of ORC based co-generated heat and power plant.

2. Case study description - conceptual design of CHP plant based on ORC

The conceptual design of geothermal CHP plant has been settled on existing geothermal heat source located in the town of Konin in Wielkopolska voivodship, central part of Poland. The basic data of the source are listed in table 1.

Table 1. The basic data of geothermal heat source in the town of Konin [21]

Depth of geothermal well	[m]	2660
Temperature of geothermal water in the layer	[°C]	97,5
Temperature of geothermal water on the surface	[°C]	92,0
Mineralization of geothermal water (Cl-Na)	[%]	15,04
Mineralization of geothermal water (Cl-Na)	[g/kg]	150,4
Specific heat of geothermal water	[kJ/kg K]	3,549
Geothermal water flow	[m³/h]	114,0

The flow diagram of proposed geothermal CHP plant based on ORC is shown in Fig. 2. It consists of ORC part responsible for electricity production and heat exchanger located downstream from evaporator responsible for useable heat production. The characteristic points of working fluid thermodynamical properties for ORC cycle have been plotted in Fig. 3.
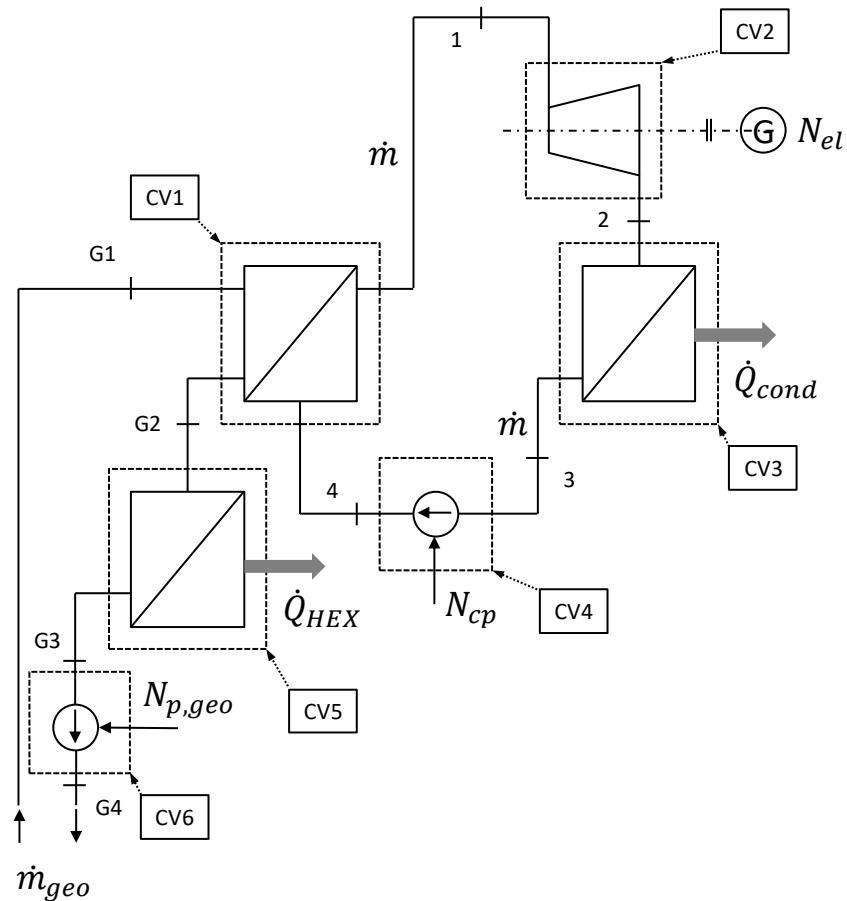
Fig. 2. The flow diagram of geothermal CHP plant based on ORC.

1 – working fluid high pressure vapor , 2- working fluid low pressure vapor, 3 – working fluid low pressure liquid, 4 – working fluid high pressure liquid
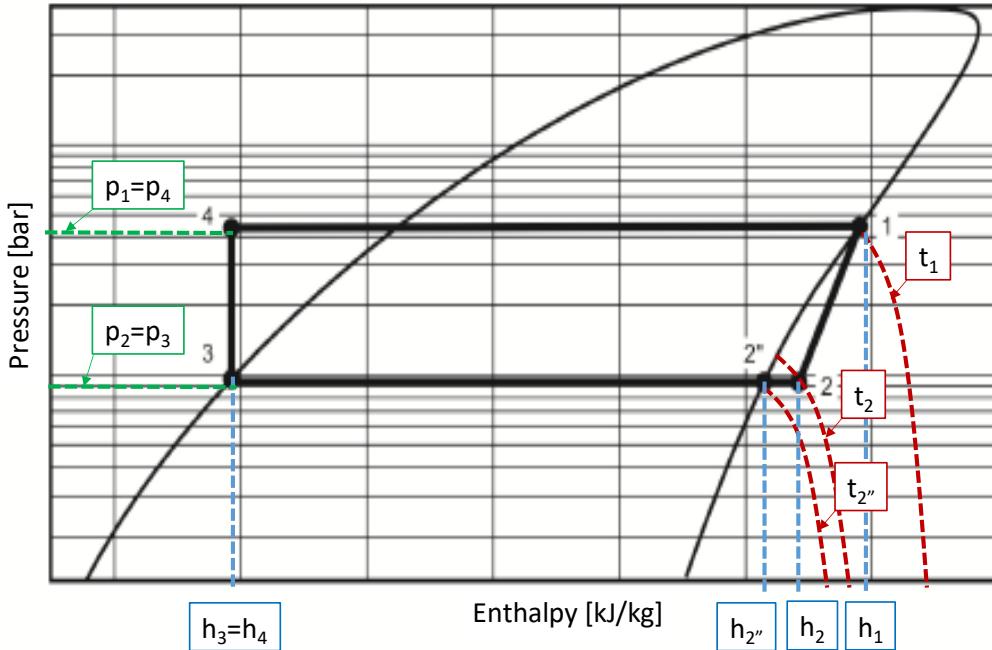
Fig. 3. Characteristic points of working fluid thermodynamic properties for ORC cycle

In order to evaluate the energy and ecological performance for the proposed ORC based CHP plant the First Law of Thermodynamics has been employed.

3. Evaluation method

3.1. Energy balance analysis

The calculations performed were settled on the First Law of Thermodynamics and energy balance equations derived for control   volumes (CVs) covering main system elements.

Energy balance equation for evaporator (CV1):

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{E}_{in} = H_{G1} = \dot{m}_{geo} \cdot h_{G1}$$

$$\dot{E}_{out} = \dot{Q}_{evap} + H_{G2} = \dot{Q}_{evap} + \dot{m}_{geo} \cdot h_{G2}$$

$$\dot{Q}_{evap} = \dot{m} \cdot (h_1 - h_4) \tag{1}$$

$$\dot{m} \cdot (h_1 - h_4) = \dot{m}_{geo} \cdot (h_{G1} - h_{G2})$$

$$\dot{Q}_{evap} = \dot{m}_{geo} \cdot (h_{G1} - h_{G2})$$

$$\dot{Q}_{evap} = \dot{m}_{geo} \cdot c_w \cdot (t_{G1} - t_{G2})$$

Where:

$\dot{m}$	-	mass flow of ORC working fluid, kg/s
$\dot{m}_{geo}$	-	mass flow of geothermal water, kg/s
$h_{G,i}$	-	specific enthalpies of geothermal water, kJ/kg
h_i	-	specific enthalpies of ORC working fluid, kJ/kg
$t_{G,i}$	-	temperatures of geothermal water, $^{\circ}$C
c_w	-	specific heat of geothermal water, kJ/kg$^{\circ}$C
$\dot{Q}_{evap}$	-	heat flux of evaporator, kW

Energy balance equation for turbine (CV2):

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{E}_{in} = H_1 = \dot{m} \cdot h_1$$

$$\dot{E}_{out} = N_i + H_2 = N_i + \dot{m} \cdot h_2$$

$$N_i = H_1 - H_2 = \dot{m} \cdot (h_1 - h_2) \tag{2}$$

$$h_2 = h_1 - \eta_i \cdot (h_1 - h_{2s})$$

$$N_i = \dot{m} \cdot \eta_i \cdot (h_1 - h_{2s})$$

$$N_{el} = \dot{m} \cdot \eta_i \cdot (h_1 - h_{2s}) \cdot \eta_g = N_i \cdot \eta_{em}$$

Where:

N_i	-	internal power of ORC turbine, kW
N_{el}	-	electrical power of ORC turbine, kW
η_i	-	internal energy efficiency of ORC turbine,
η_{em}	-	electro-mechanical energy efficiency of ORC turbine,

Energy balance equation for condenser (CV3):

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{E}_{in} = H_2 = \dot{m} \cdot h_2$$

$$\dot{E}_{out} = \dot{Q}_{cond} + H_3 = \dot{Q}_{cond} + \dot{m} \cdot h_3$$

$$\dot{Q}_{cond} = \dot{m} \cdot (h_2 - h_3)$$

(3)

Where:

$\dot{Q}_{cond}$ -   heat flux of condenser, kW

Energy balance equation for circulation pump (CV4):

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{E}_{in} = H_3 + N_{cp,i} = \dot{m} \cdot h_3 + N_{cp,i}$$

$$\dot{E}_{out} = H_4 = \dot{m} \cdot h_4$$

$$N_{cp,i} = H_4 - H_3 = \dot{m} \cdot (h_4 - h_3)$$

$$N_{cp} = \frac{N_{cp,i}}{\eta_{cp,em}} = \dot{m} \cdot \frac{v \cdot (p_4 - p_3)}{\eta_{cp,i} \cdot \eta_{cp,em}}$$

(4)

Where:

$N_{cp,i}$ -   internal power of ORC circulating pump, kW

N_{cp} -   electrical power of ORC circulating pump, kW

$\eta_{cp,i}$ -   internal energy efficiency of ORC circulating pump,

$\eta_{cp,em}$ -   electro-mechanical energy efficiency of ORC circulating pump,

v -   specific volume of ORC working fluid, m³/kg

p_i -   pressure of ORC working fluid, kPa

Energy balance equation for heat exchanger (CV5):

$$\dot{E}_{in} = \dot{E}_{out}$$

(5)

$$\dot{E}_{in} = H_{G2} = \dot{m}_{geo} \cdot h_{G2}$$

$$\dot{E}_{out} = \dot{Q}_{HEX} + H_{G3} = \dot{Q}_{HEX} + \dot{m}_{geo} \cdot h_{G3}$$

$$\dot{Q}_{HEX} = \dot{m}_{geo} \cdot (h_{G2} - h_{G3})$$

$$\dot{Q}_{HEX} = \dot{m}_{geo} \cdot c_w \cdot (t_{G2} - t_{G3})$$

Where:

$\dot{Q}_{HEX}$ -   heat flux of district heating heat exchanger, kW

The set of energy balance equations listed above has been solved and used as energy analysis tool for proposed ORC cogenerated heat and power plant.

3.2. Energy and ecological evaluation

In order to evaluate energy and ecological performance of ORC based geothermal CHP plant two criteria have been employed. As energy performance criteria the non-renewable primary energy consumption has been chosen. In the case of environmental performance carbon dioxide (CO_2) emission has been taken as evaluation criteria. The analysis has been performed for different operating conditions and three working fluids. The total annual use of fossil fuels chemical enthalpy and carbon dioxide emission for reference energy system have been calculated using following equations:

$$H_{ch} = H_{ch,HC} + H_{ch,NG}$$

$$E_{CO2} = E_{CO2,HC} + E_{CO2,NG}$$

(6)

Where:

H_{ch} -   total annual use of fossil fuels for reference energy system, MWh/a

E_{CO2} -   total annual emission of CO_2 for reference energy system, $MgCO_2$/a

4. Results and discussion

4.1. Energy balance analysis

The calculations have been performed using the Excel based calculation tool [22]. It has been assumed that the temperatures of geothermal water entering and leaving evaporator (CV-1) are $t_{G1} = 90°C$ and $t_{G2} = 75°C$. It has been also assumed that the overall efficiency of turbine and generator is 80% and overall efficiency of working fluid and geothermal water pumps are 70%. The calculations have

been performed for three working fluids: R123, R134a and R227. In order to evaluate the production capability of the system the following operational parameters have been changed in calculations: evaporation temperature $t_1 = 75°C$ *and* $t_1 = 70°C$, condensation temperature $t_{2''} = 25°C$ *and* $t_{2''} = 30°C$ and temperature of geothermal water leaving the heat exchanger $t_{G3} = 30°C, t_{G3} = 35°C$ *and* $t_{G3} = 40°C$. The thermodynamic properties of working fluids in characteristic points of ORC have been imported from Solkane 8.0 selection software. Table 2 presents the example of calculation data for working fluid R123 and following thermal parameters $t_1 = 75°C, t_{2''} = 25°C, t_{G3} = 30°C$, and energy balance results are shown in Fig. 4.

Table 2. The thermodynamic properties of characteristic points for R123

Point	P [bar]	t [°C]	v [dm³/kg]	h [kJ/kg]
1	4,32	75,00	38,54	427,00
2	0,92	37,81	176,48	406,79
2s	0,92	30,75	171,81	401,74
2''	0,92	25,00	167,97	397,66
3	0,92	25,00	0,68	227,01
4	4,32	25,31	0,68	227,34
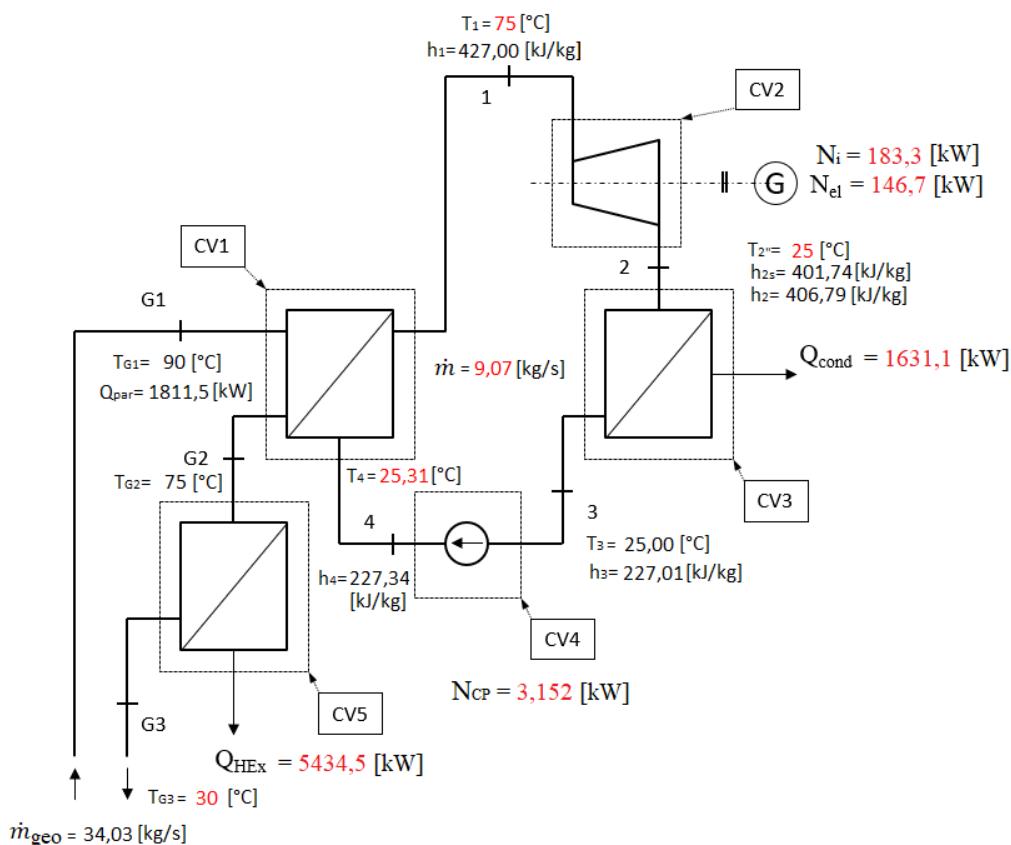
Fig. 4. Print screen of Excel calculation tool for working fluid R123
and thermal parameters: t₁=75°C, t₂'=25°C, t_{G3}=30°C .

Table 3 presents the example of calculation data for working fluid R134a and following thermal parameters $t_1 = 75°C, t_{2''} = 30°C, t_{G3} = 35°C$, and energy balance results are shown in Fig. 5.

Table 3. The thermodynamic properties of characteristic points for R134a

Point	P	t	v	h
	[bar]	[°C]	[dm³/kg]	[kJ/kg]
1	23,64	75,00	7,50	429,11
2	7,70	30,00	26,25	412,01
2s	7,70	30,00	25,61	407,74
2''	7,70	30,00	26,65	414,69
3	7,70	30,00	0,84	241,83
4	23,64	31,33	0,84	243,75
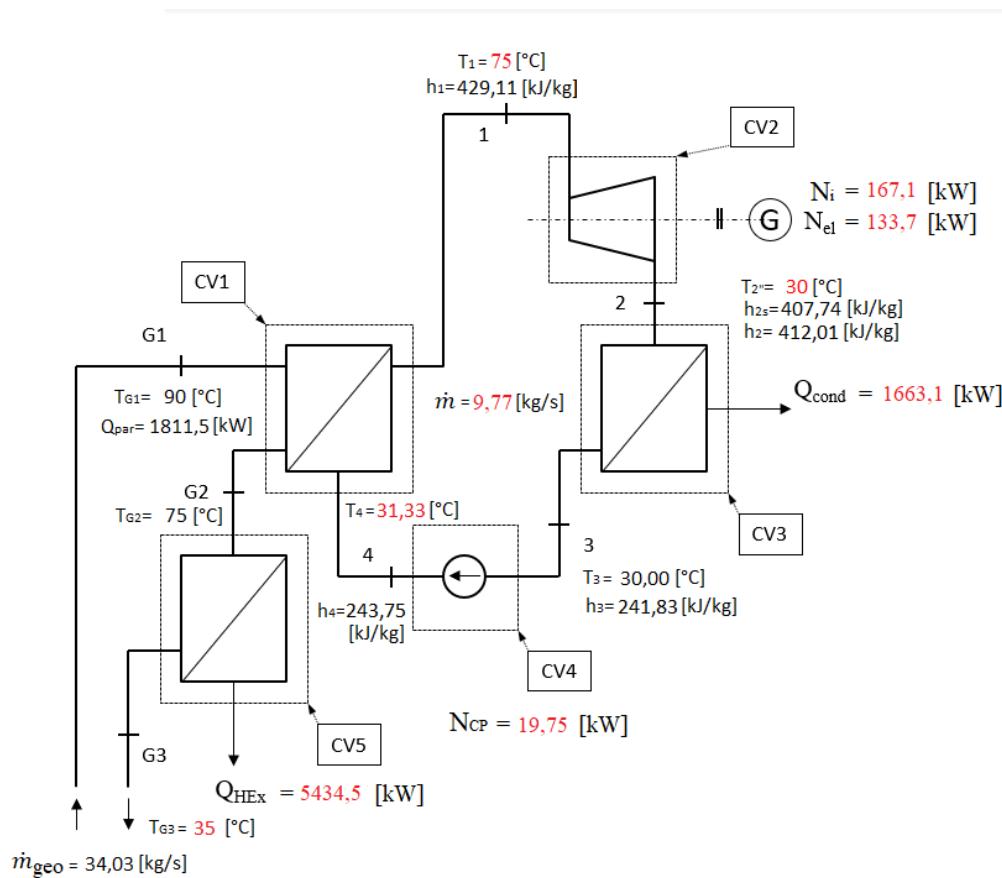
Fig. 5. Print screen of Excel calculation tool for working fluid R134a and thermal parameters: $t_1=75°C$, $t_{2''}=30°C$, $t_{G3}=35°C$.

Table 4 presents the example of calculation data for working fluid R227 and following thermal parameters $t_1 = 70°C, t_{2''} = 25°C, t_{G3} = 40°C$, and energy balance calculation results are shown in Fig. 6.

Table 4. The thermodynamic properties of characteristic points for R227

Point	P [bar]	T [°C]	v [dm³/kg]	h [kJ/kg]
1	14,87	70,00	7,64	365,25
2	4,56	39,80	29,79	353,28
2s	4,56	36,42	29,30	350,29
2''	4,56	25,00	27,59	340,22
3	4,56	25,00	0,72	228,84
4	14,87	25,98	0,72	229,90
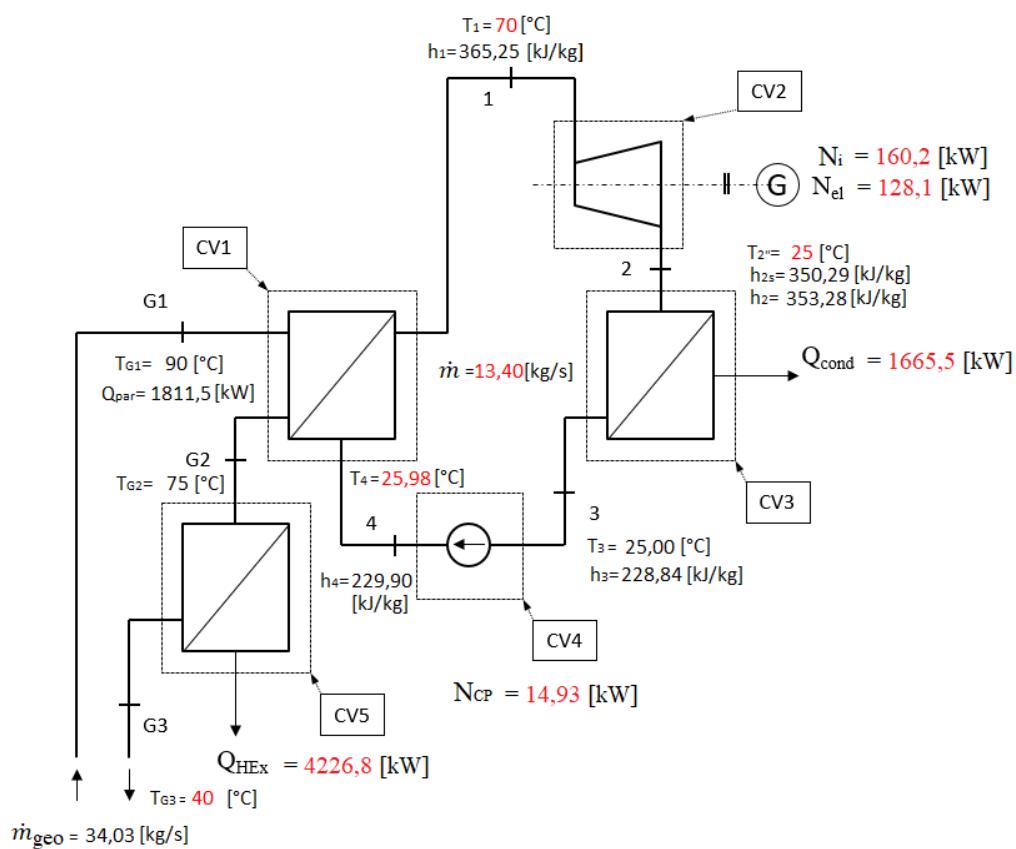
Fig. 6. Print screen of Excel calculation tool for working fluid R227
and thermal parameters: $t_1=70°C$, $t_{2''}=25°C$, $t_{G3}=40°C$.

Table 5 presents the summary of energy balance calculation results for all working fluids and operating parameters.

Table 5. Energy performance of ORC for different working fluids

Working fluid	t_1	$t_{2''}$	$\dot{m}$	N_i	N_{el}	Q_{skr}	N_{cp}
	[°C]	[°C]	[kg/s]	[kW]	[kW]	[kW]	[kW]
R123	75	25	9,07	183,3	146,7	1631,1	3,15
	75	30	9,32	166,8	133,5	1647,7	3,14
	70	25	9,20	169,3	135,5	1644,7	2,71
	70	30	9,46	152,2	121,8	1661,7	2,59
R134a	75	25	9,41	182,7	146,2	1647,7	19,92
	75	30	9,77	167,1	133,7	1663,1	19,75
	70	25	9,42	169,4	135,5	1658,3	17,05
	70	30	9,78	153,1	122,5	1674,2	16,68
R227	75	25	13,21	172,3	137,8	1655,5	17,24
	75	30	13,80	158,0	126,4	1669,8	17,14
	70	25	13,38	160,2	128,1	1665,5	14,93
	70	30	14,00	145,2	116,2	1680,2	14,73

The influence of the temperature of geothermal water leaving heat exchanger (CV-5) on the heating capacity of district heating heat exchanger is shown in Table 6.

Table 6. Calculation results for heat exchanger (CV5) for different temperatures

of water leaving HEx

t_{G2}	t_{G3}	$\dot{m}_{geo}$	c_w	$\dot{Q}_{HEX}$
[°C]	[°C]	[kg/s]	[kJ/(kg K)]	[kW]
75	30	34,03	3,549	5434,5
75	35	34,03	3,549	4830,7
75	40	34,03	3,549	4226,8

The calculation results show that for all three working fluids the highest production of electrical power refers to the evaporation temperature $t_1 = 75°C$ and condensation temperature $t_{2''} = 25°C$. The differences are rather small, for R123 and R134a the electricity production is a little bit higher comparing with R227 working fluid. It is worth to underline that significant part of electricity production would be used for covering self-energy requirements of district heating system and ORC CHP plant.

In the case of heat the increase of temperature of geothermal water leaving heat exchanger t_{G3} significantly decrease the production of that form of useable energy. It has been assumed that geothermal CHP plant is capable to cover full requirements of heat end users.

4.2. Energy and ecological evaluation

Performing energy and environmental evaluation of ORC based geothermal CHP plant it has been assumed that for geothermal CHP plant the use of chemical enthalpy of fossil fuels and the emission of carbon dioxide are equal: $\dot{H}_{ch,GEO} = 0 \, kW$ and $\dot{E}_{CO2,GEO} = 0 \, kgCO_2/h$. In order to evaluate energy performance of geothermal CHP plant the calculation of chemical enthalpy of fossil fuels use for typical (reference) energy system has been derived. In the case of environmental performance carbon dioxide emission for reference energy system has been calculated. As the reference energy system the separate production of heat in gas fired condensing boilers (η_{CB} =100%) and electrical power in conventional steam condensing power plant fired with hard coal (η_{PP} =33%) [23], has been taken into consideration. Electrical power production and heat flux production have been taken the same as for geothermal CHP plant. The emission of carbon dioxide has been derived for hourly and annual conditions. It has been assumed that energy system has to operate for $\tau_{EL} = 8760/a$ in the case of electrical power production and for $\tau_{HEX} = 2000 \, h/a$ in the case of heat production. The carbon dioxide emission factors for hard coal and natural gas have been taken as: $e_{CO2,HC} = 0{,}35$ kgCO₂/kWh and $e_{CO2,NG} = 0{,}20$ kgCO₂/kWh.

Table 7. Chemical enthalpy of hard coal use and carbon dioxide emission in production

of electrical power for reference energy system

Working fluid	N_{el}	N_{cp}	$N_{el,net}$	$\dot{H}_{ch,HC}$	$\dot{E}_{CO2,HC}$	$H_{ch,HC}$	$E_{CO2,HC}$
	[kW]	[kW]	[kW]	[kW]	[kgCO₂/h]	[MWh/a]	[MgCO₂/a]
R123	146,7	3,15	143,5	434,9	152,2	3809,7	1333,5
	133,5	3,14	130,3	395,0	138,2	3460,2	1211,0
	135,5	2,71	132,8	402,3	140,8	3524,1	1233,4
	121,8	2,59	119,2	361,1	126,4	3163,2	1107,2
R134a	146,2	19,92	126,2	382,6	133,9	3351,6	1172,9
	133,7	19,75	113,9	345,2	120,8	3024,0	1058,3
	135,5	17,05	118,5	359,0	125,6	3144,8	1100,8
	122,5	16,68	105,8	320,6	112,2	2808,5	983,0
R227	137,8	17,24	120,6	365,5	127,9	3201,8	1120,5
	126,4	17,14	109,3	331,1	115,9	2900,4	1015,1
	128,1	14,93	113,2	343,1	120,1	3005,6	1051,8
	116,2	14,73	101,4	307,4	107,6	2692,8	942,5

Table 8. Chemical enthalpy of natural gas use and carbon dioxide emission in production

of heat in reference energy system

t_{G2}	t_{G3}	$\dot{Q}_{HEX}$	$\dot{H}_{ch,NG}$	$\dot{E}_{CO2,NG}$	$H_{ch,NG}$	$E_{CO2,NG}$
[°C]	[°C]	[kW]	[kW]	[kgCO₂/h]	[MWh/a]	[MgCO₂/a]
75	30	5434,5	5434,5	1086,9	10869,0	2173,8
75	35	4830,7	4830,7	966,1	9661,4	1932,3
75	40	4226,8	4226,8	845,4	8453,6	1690,7

It can be seen (Tables 7 and 8) that construction of geothermal CHP plant can significantly reduce the chemical enthalpy of fossil fuels use and emission of carbon dioxide what is of greatest importance concerning poor performance of energy systems in Poland. The calculations have been performed for all three working fluids and 12 discrete temperature conditions of ORC CHP plant operation listed in Table 9.

Table 9. Discrete temperature conditions (DTC) for energy and ecological analysis

of ORC CHP plant operation

DTC	t_1	$t_{2''}$	t_{G2}	t_{G3}
[-]	[°C]	[°C]	[°C]	[°C]
1	75	25	75	30
2	75	25	75	35
3	75	25	75	40
4	75	30	75	30
5	75	30	75	35
6	75	30	75	40
7	70	25	75	30
8	70	25	75	35
9	70	25	75	40
10	70	30	75	30
11	70	30	75	35
12	70	30	75	40

The results of calculations have been plotted in Fig. 7 and Fig. 8.
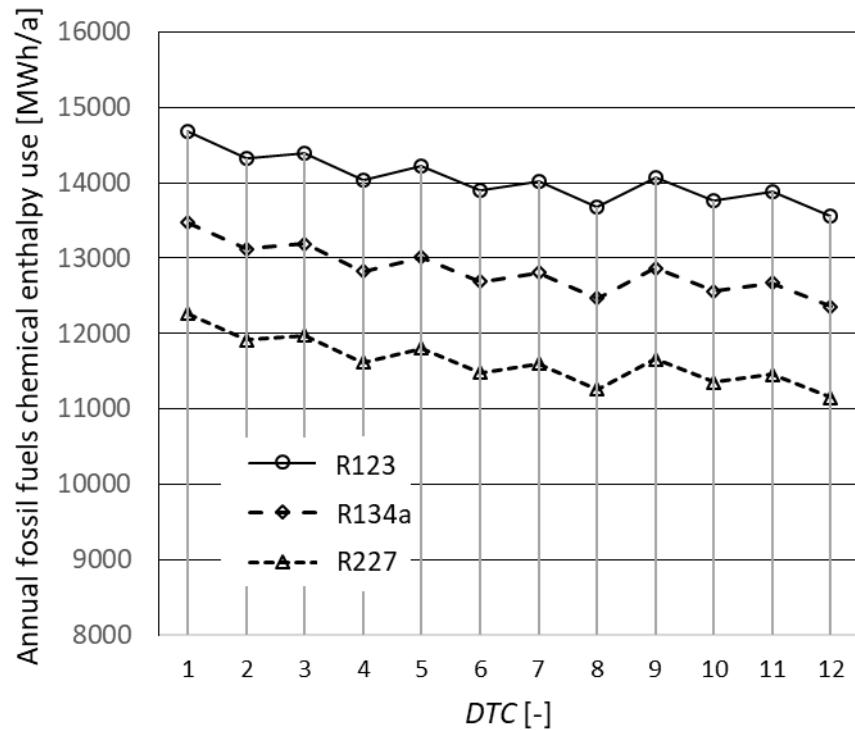
Fig. 7. Total annual use of fossil fuels for reference energy system
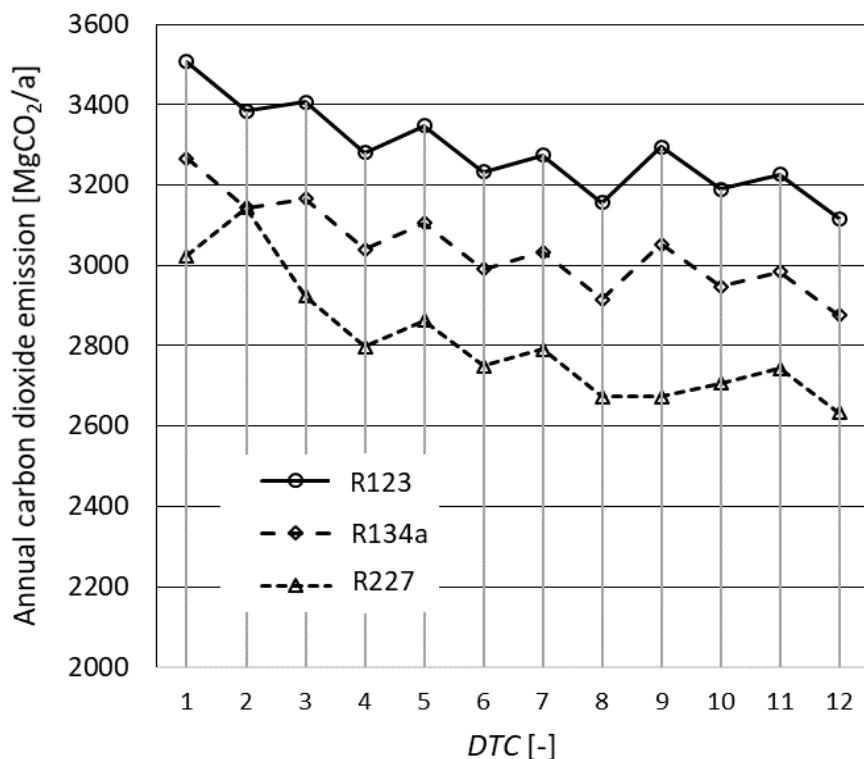
Fig. 8. Total annual emission of carbon dioxide for reference energy system

As shown in Fig. 6, that application of ORC based geothermal CHP plant can significantly   reduce annual consumption of chemical enthalpy of fossil fuels. The best energy performance can be spotted for working fluid R123, for which the reduction varies between 14700 and 13600 MWh/a. The working fluid R134a has a worse energy performance, which allows for the reduction of fossil fuels energy consumption in the range of 13500 and 12300 MWh/a. The worst performance has been noted for working fluid R227 – the reduction between 12200 and 11100 MWh/a. The same relation concerning ecological performance – the reduction of carbon dioxide emission, can be found – see Fig. 7. The total reduction of CO_2 emission is the highest for working fluid R123: 3500 to 3120 $MgCO_2$/a, the medium one for working fluid R134a: 3260 to 2870 $MgCO_2$/a and the lowest for working fluid R227: 3160 to 2620 $MgCO_2$/a.

In all cases mentioned above, the reduction can be considered significant regarding energy and ecological performance of energy systems in Poland. Therefore, it should be taken into consideration to expand the use of geothermal energy beyond the production of heat only.

5. Conclusions

The aim of the work was to propose the conceptual design of geothermal CHP plant that would be applicable in Poland. Bearing in mind the geothermal conditions prevailing in Poland the use of ORC seems to be the only one reasonable solution. The energy and environment evaluation of geothermal CHP plant based on ORC has been conducted. The evaluation referred to the existing geothermal well located in the city of Konin in Wielkolpolska voivodship, the central part of Poland . It has been assumed that the system is capable to cover heat and electrical power of energy end users, thus does not require additional energy sources. Such   system is characterized by zero chemical enthalpy of fossil fuels use and zero carbon dioxide emission. Nevertheless, that electrical power production is not high the use of ORC can significantly reduce the emission of carbon dioxide comparing with traditional energy systems based fossil fuels and separate production of heat and electrical power. The amount of heat production highly depends on the thermal parameters of heat exchanger operation. The lower is the temperature of heat exchanger operation the higher is production of heat. On the other hand, the decrease of that temperature determines the need of installation of low temperature heating systems in end users what can be difficult concerning economical and organizational aspects.

It has been shown that construction of geothermal CHP plants based on Organic Rankine Cycle can be reasonable solution in polish conditions. It is of greatest importance concerning poor performance of energy systems in Poland.

In order to make the final decision concerning the system application the future research work will have to be performed. It has to cover economic evaluation of the system – investment and total operating cost calculations, as well as ecological evaluation joined with the global warming potential (GWP) of the working fluids available for the ORC based geothermal CHP plant.

Nomenclature

c_w -   specific heat of geothermal water, kJ/kg°C

e_{CO2}	-	carbon dioxide emission factor for fossil fuel, kgCO_2/kWh
$\dot{E}$	-	energy flux, kW
$\dot{E}_{CO2}$	-	carbon dioxide emission, kg/h
$\dot{H}_{ch}$	-	chemical enthalpy flux of fossil fuel, kW
$h_{G,i}$	-	specific enthalpies of geothermal water, kJ/kg
$h_{G,i}$	-	specific enthalpies of geothermal water, kJ/kg
$\dot{m}$	-	mass flow, kg/s
$N_{cp,i}$	-	internal power of ORC circulating pump, kW
N_{cp}	-	electrical power of ORC circulating pump, kW
N_i	-	internal power of ORC turbine, kW
N_{el}	-	electrical power of ORC turbine, kW
p_i	-	pressure of ORC working fluid, kPa
v	-	specific volume of ORC working fluid, m³/kg
$\eta_{cp,i}$	-	internal energy efficiency of ORC circulating pump,
$\eta_{cp,em}$	-	electro-mechanical energy efficiency of ORC circulating pump,
η_{em}	-	electro-mechanical energy efficiency of ORC turbine,
η_i	-	internal energy efficiency of ORC turbine,
τ_{EL}	-	equivalent number of hours of electricity production per year, h/year

τ_{HEX} -   equivalent number of hours of heat production per year, h/year

Indices

cp -   circulating pump

$cond$ -   condenser

em -   electro-mechanical

$evap$ -   evaporator

geo -   geothermal water

HC -   hard coal

HEX -   heat exchanger

NG -   natural gas

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