Thermodynamic Analysis of District Heating System Assisted by Geothermal Sourced Heat Pump

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Abstract: In this study, the usage of geothermal sourced heat pumps in district heating system was investigated By this way, Kutahya-Simav geothermal resources, amongst the 15 largest area of Turkey, were taken into account. The proposed system for geothermal sourced heat pump district heating cycle consists of four sub-circuits. The Circuit I is geothermal flow cycle which transfers the heat from the geothermal fluid to evaporator, Circuit II is heat pump cycle, Circuit III is district heating cycle and Circuit IV is residential heating cycle. Different refrigerant fluids such as R-134a, R-22 and R-600a were evaluated in system using energy and exergy analysis. As conclusion, the maximum COP_{sys} and overall efficiency of system were obtained for R-22 where maximum number of heated residence was obtained for R-134a.

Key-Words: Energy-exergy analysis, Geothermal, Heat pump, R-134a, R-22, R-600a, District heating.

1 Introduction

Increasing population and technological developments make the energy consumption of countries increase. Because of finite reserves of fossil fuels and their negative effects on environment, the countries have started to use renewable energy sources such as wind, sun, geothermal energy etc. Geothermal energy has great availability because it is not dependent on weather conditions. Many different types of using geothermal resources are available. Commonly, they are utilized for power generation and the direct applications such as district heating, industrial processes, greenhouse heating and balneological purposes [1].

The heating circuit of residences in Turkey is commonly based on the heating systems burned by fossil fuels in which the inlet temperature and outlet temperature are respectively 90°C and 70°C, but developments in the heating system technology enforce to use the heating systems with lower temperature. At this point, usage of lower energetic resources such as geothermal energy is available. A heat pump with its higher efficiency is an alternative heating system since it can be used with the lower enthalpy resources. Heat pumps are powered by electricity and transfer heat from the media with low temperature to the higher temperature one [2].

Although heat pumps are not very common in Turkey, the applications of soil and water sourced heat pumps have an increasing interest for the last decade. In literature, the analyses of heat pump systems with different working parameters and with different refrigerants were performed by using first and second thermodynamic law analysis in a large number [3-5]. Soil, air and geothermal sourced heat pumps and hybrid heat pump systems were investigated in the numerical and experimental basis [6-12].

In this study, the using capability of geothermal sourced heat pumps in district heating systems was investigated by means of energy and exergy analysis methods. In this aim, Kutahya-Simav geothermal resources were taken into account. Moreover, different refrigerants such as R-134a, R-22 and R-600a were also taken into account in the analyses.

2 Simav Geothermal Field

Simav geothermal field is located in the southern part of the Simav graben system (39° latitude, 28°.4' longitude) at Kutahya province in western Anatolia of Turkey. The Simav geothermal area is known as one of the most extensive geothermal fields in Turkey, attaining an aquifer temperature up to 162 °C. General Directorate of Mineral Research and Exploration (MTA) have drilled ten deep wells, in use or ready to use, ranging in depth from 169 m to 725 m in the Simav geothermal field from 1985 to 2008 [13]. Simav geothermal field and wells' location in the field are shown in Fig. 1.

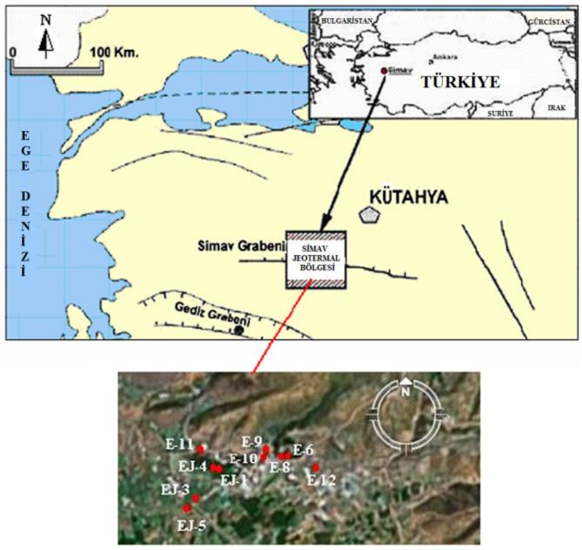


Fig.1 Location of the Simav geothermal fields and well locations

The temperatures and flow rates of geothermal fluids in well range respectively 42-162 ºC and 0,25-80 kg/s and these fluids are used for balneological purposes besides for residence and greenhouse heating at present.

3 Design of Geothermal Sourced Heat Pump System

The present wells drilled in the Simav geothermal fields are used for Simav geothermal district heating system (SGDHS). SGDHS has started the operation by heating 3200 residences in 1991. By the time, it has reached to 6500 residences [14].

3.1 System Description

In this study, the fluid with a flow rate of 462 kg/s, a pressure of 300 kPa and a temperature of 133.5 °C, obtained by combining all the wells, was taken into consideration for geothermal sourced heat pump district heating cycle which consists of four sub circuit [15]. The Circuit I is geothermal flow cycle which the heat is gained from the geothermal fluid, Circuit II is heat pump cycle, Circuit III is district heating cycle and Circuit IV is residential heat cycle which utilize the radiator with an inlet temperature of 60 °C and outlet temperature of 49 °C for an effective heat transfer [15, 16]. The minimum 10ºC effective temperature difference for the operation of the heat exchanger was included into calculations in the design and the results were compared with the current SGDHS. Three different refrigerant fluids named as R-134a, R-22, and R600a were used in Circuit II.

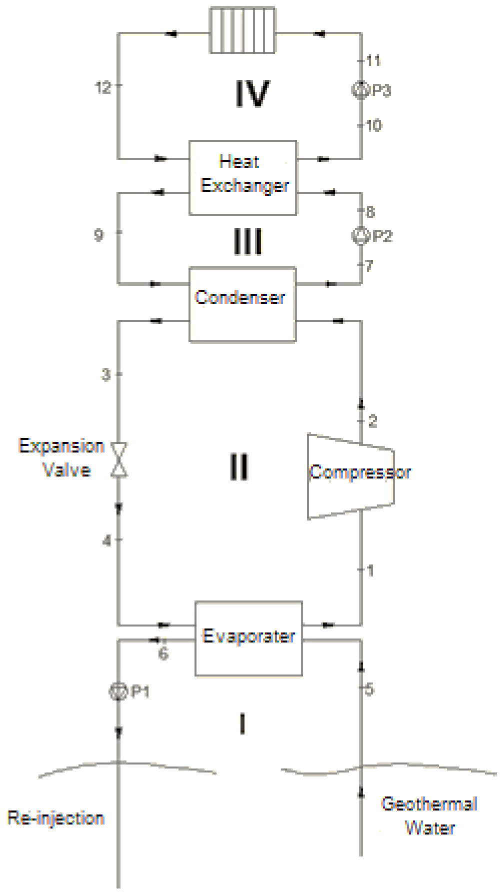


Fig.2 Geothermal sourced heat pump aided district heating system

These fluids have been chosen taking the different *T-s* trends into account. The thermodynamic properties of these refrigerant fluids are listed in Table 1.

Properties	R-134a	R-22	R-600a
Critical Temperature (ºC)	101,06	96,145	134,66
Critical Pressure (kPa)	4059,3	4990	3629
Normal Boiling Point (ºC)	-26,074	-40,81	-11,749

Table 1 The thermodynamics properties of refrigerant fluids

3.2 Energy and Exergy Analysis

The following assumptions are handled in the thermodynamic analysis;

(a) Kinetic and potential energy effects are negligible
(b) The compressor and pumps have an adiabatic efficiency of 80%
(c) The reference state is 20ºC and 101.325 kPa.

Under these assumptions, the energy transfer from geothermal fluid to evaporator is given as:

$$\dot{Q}_{geo} = \dot{m}_{geo} \times (h_5 - h_6) \quad (1)$$

where $\dot{m}_{geo}$ is the mass flow rate of geothermal fluid. So, the mass rate of refrigerant, $\dot{m}_{R134a}$, is calculated by the following equation:

$$\dot{Q}_{evap} = \dot{Q}_{geo} = \dot{m}_{R134a} \times (h_1 - h_4) \quad (2)$$

The heat transferred to Circuit III is given by:

$$\dot{Q}_{con} = \dot{m}_{R134a} \times (h_3 - h_2) \quad (3)$$

The required work in compressor is given by:

$$\dot{W}_{comp} = \frac{\dot{m}_{R134a} \times (h_1 - h_2)}{\eta_{comp}} \quad (4)$$

where η_{comp} is the compressor efficiencies. The overall coefficient of performance of the system is [6]

$$COP_{sys} = \frac{\dot{Q}_{con}}{\dot{W}_{comp} + \dot{W}_{pumps}} \quad (5)$$

where $\dot{W}_{pumps}$ is the rate of work input to all pumps in system. The exergy balance equation for steady systems is given by the following equation:

$$\dot{E}_{X_{heat}} - \dot{E}_{X_{work}} + \dot{E}_{X_{m,i}} - \dot{E}_{X_{m,o}} = \dot{E}_{X_{dest}} \quad (6)$$

Here the exergy terms occurred by heat, work and mass flow are given as following:

$$\dot{E}_{X_{heat}} = \sum \left(1 - \frac{T_0}{T_k}\right) \dot{Q}_k \quad (7)$$

$$\dot{E}_{X_{deworkst}} = \dot{W} \quad (8)$$

$$\dot{E}_{X_{m,i}} = \sum \dot{m}_i \, \psi_i$$
$$\dot{E}_{X_{m,o}} = \sum \dot{m}_o \, \psi_o \quad (9)$$

where ψ indicates the physical exergy term and given as:

$$\psi = (h - h_0) - T_0(s - s_0) \quad (10)$$

where h is enthalpy, s is entropy, and the subscript zero indicates properties of fluids at the dead state.

The exergetic efficiency of system is then calculated by the following equation [17]:

$$\eta_{O,sys} = 1 - \frac{\dot{Ex}_{dest,overall}}{\dot{Ex}_{m,i}} \quad (11)$$

The performance of the geothermal source heat pump assisted district heating systems was evaluated using the parameters given in Table 2.

Cycle Points	Temperature (ºC)	Pressure (kPa)		
	All Refrigerant Fluids	*R134a*	*R22*	*R600a*
0	20	101.325		
1	System Parameters	200-1600	200-2400	200-800
2	80 90 100	System Parameters		
3	69	2070	2937	850
4	System Parameters	200-1600	200-2400	200-800
5	133,5	300		
6	100 110 120			
7	>70	Saturated liqiuid		
8	>70			
9	>59			
10	60			
11	60			
12	49			

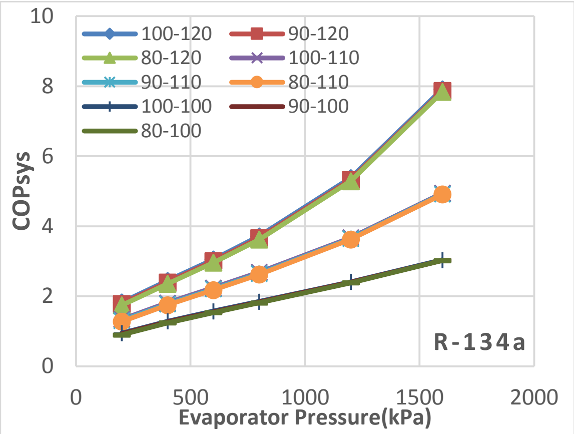
Table 2 The design parameters.

As seen in Table 2, the outlet temperature of geothermal fluid at the evaporator was taken into consideration as 100, 110 and 120ºC; then temperature, pressure and flow rate values of the other points in the cycle were calculated. The numerous system designs for three different refrigerant fluids were carried by performing parametrical study. Pumps used in the system were used to overcome the parasitic losses which were assumed as 10% of the total each sub-circuits. The thermodynamic properties of refrigerant fluids were taken from the software named Reference Fluid Thermodynamic Properties of Refrigerant Thermodynamic and Transport Properties (REFPROP).

4 Results and Discussion

The best performance of geothermal sourced heat pump was performed for the different condenser pressures at the saturated temperature of 69 ºC [18].

According to this, the condenser pressures of R-134a, R-22, and R-600a were defined respectively 2070kPa, 2937kPa, and 850kPa.



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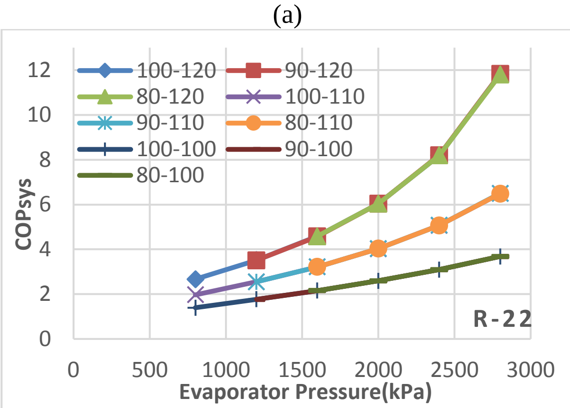

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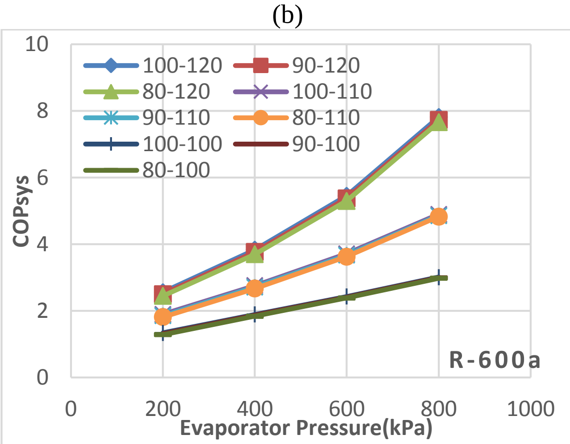
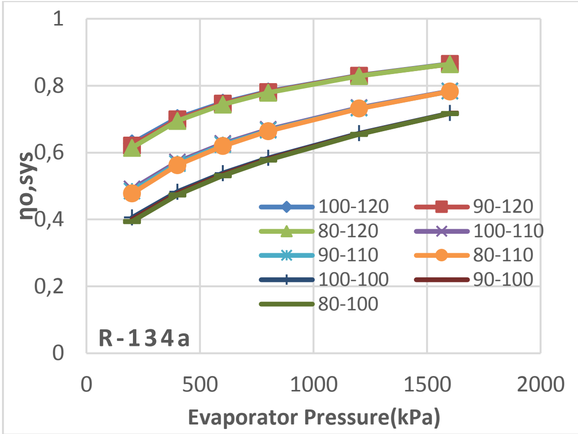


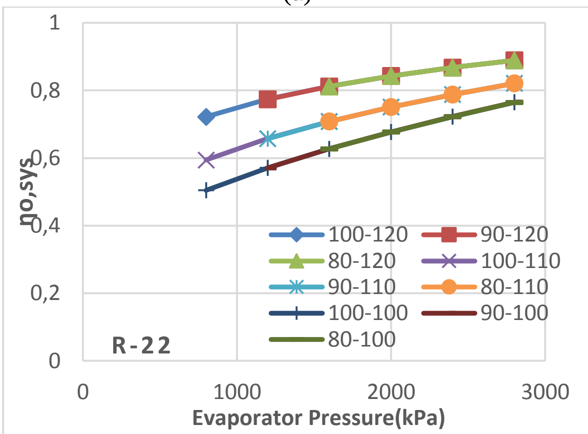
(c)

Fig.3 The variation of COP_{sys} versus evaporator pressures (a) R-134a, (b) R-22, and (c) R-600a

The variation of COP_{sys} versus evaporator pressures is given in Fig.3. The COP_{sys} values of R-134a range between 0.8976 and 7.9163 (Fig.3a) while those of R-600 range between 1.2885 and 7.8132 (Fig.3c). The maximum COP_{sys} value is obtained from R-22 as 11.8268 (Fig.3b).



(a)



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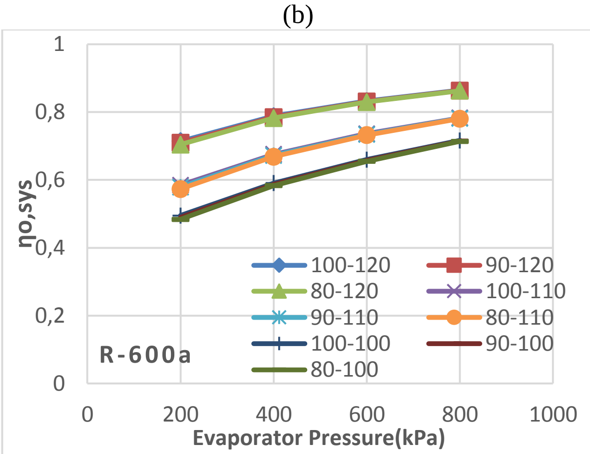

(c)

Fig.4 The variation of $\eta_{o,sys}$ versus evaporator pressures (a) R-134a, (b) R-22, and (c) R-600a

The variation of $\eta_{o,sys}$ with evaporator pressures is given in Fig.4. The $\eta_{o,sys}$ values of R-134a range between 0.39354 and 0.86522 (Fig.4a) while those of R-600a range between 0.4237 and 0.86426 (Fig.4c). The maximum $\eta_{o,sys}$ values are obtained from R-22 (Fig.4b).

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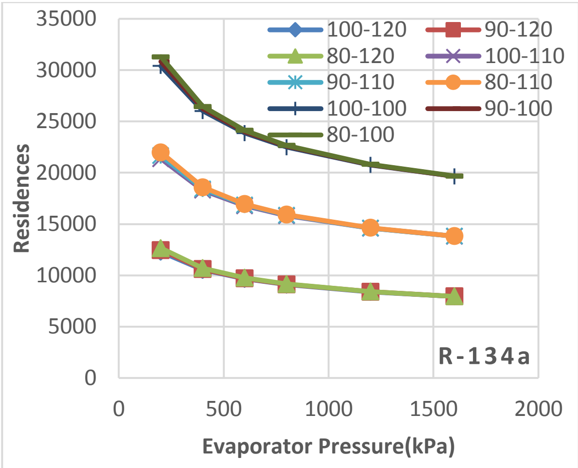
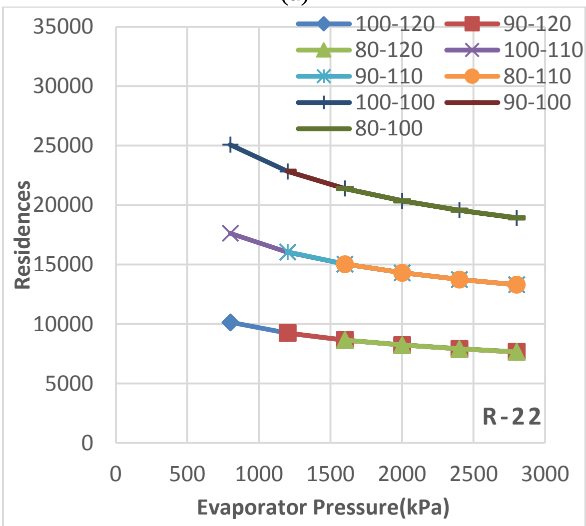


(a)



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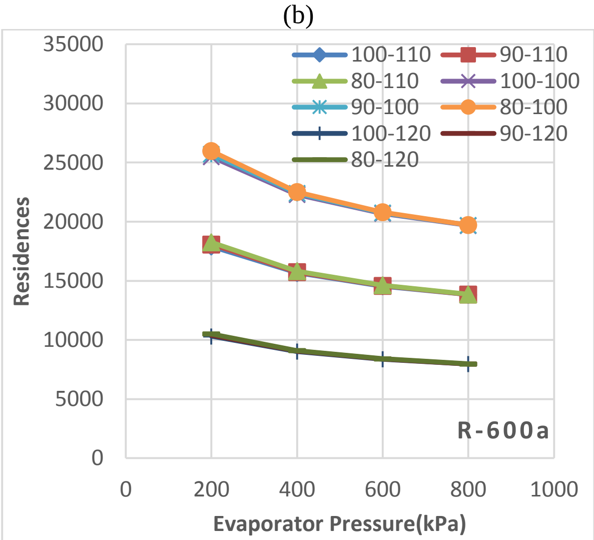

(c)

Fig.5 The variation of residences versus evaporator pressures (a) R-134a, (b) R-22, and (c) R-600a

The variation of residences versus evaporator pressures is given in Fig.5. The number of heated residences for R-22 range between 7,660 and 25,091 (Fig.4b) while those of R-600a range between 7,961 and 25,974 (Fig.4c). The most number of residences are obtained from R-134a as 31,295 (Fig.5a).

5 Conclusion

Although the interest in heat pumps are not very common in Turkey, the applications of soil and water sourced heat pumps started to increase in a limited number. In this study, the geothermal sourced heat pump using R-134a, R-22, and R-600a as refrigerant was investigated in district heating system aided by geothermal resources of Kutahya-Simav.

The highest COP_{sys} value was found as 11.796 when the highest $\eta_{o,sys}$ was found as 0.88908 that was calculated for R-22. The highest values of $\eta_{o,sys}$ for R-134a and R-600a were found closer to those of R-22 as 0.86522 and 0.86426. The maximum number of heated residences was found as 31,295 for the case of using R-134a in the system. In this case, COP_{sys} and $\eta_{o,sys}$ values of the system was determined as 0.8976 and 0.39354 respectively.

References:

[1] Barbier E., Geothermal energy technology and current status: an overview, *Renew Sustain Energy Rev*, Vol.6, 2002, pp. 3–65.

[2] Yamankaradeniz R., Horuz I, Kaynakli Ö., Çoskun S., and Yamankaradeniz N., *The Technic of Refrigeration and Applications of Heat Pumps*, Dora Publish, 2013 (in Turkish).

[3] Yildirim N., Toksoy M. and Gokcen G., District heating system design for a university campus, *Energy and Buildings*, Vol.38, 2006, 1111–1119.

[4] Omer A. M., Ground-source heat pumps systems and applications, *Renewable and Sustainable Energy Reviews*, Vol.12, 2008, pp. 344–371.

[5] Ozcan O. and Ozgener O., Energetic and exergetic performance analysis of Bethe-Zeldovich-Thompson (BZT) fluids in geothermal heat pumps, *International Journal of Refrigeration*, Vol.34, 2011, pp. 1943-1952.

[6] Akpinar E. K. and Hepbasli A., A comparative study on exergetic assessment of two ground-source (geothermal) heat pump systems for residential applications, *Building and Environment*, Vol.42, 2007, pp. 2004–2013.

[7] Ozgener O., Hepbasli A. ve Ozgener L., A parametric study on the exergoeconomic assessment of a vertical ground-coupled

(geothermal) heat pump system, *Building and Environment*, Vol.42, 2007, pp. 1503–1509.
[8] Ozgener O. and Hepbasli A., A parametrical study on the energetic and exergetic assessment of a solar-assisted vertical ground-source heat pump system used for heating a greenhouse, *Building and Environment*, Vol.42, 2007, pp. 11–24.
[9] Hackel S. and Pertzborn A., Effective design and operation of hybrid ground-source heat pumps: Three case studies, *Energy and Buildings*, Vol.43, 2011, pp. 3497–3504.
[10] Ally M. R., Munk J. D., Baxter V. D., and Gehl A. C., Exergy and energy analysis of a ground-source heat pump for domestic water heating under simulated occupancy conditions, *International Journal of Refrigeration*, Vol.36, 2013, pp. 1417-1430.
[11] Self S. J., Reddy B. V. and Rosen M. A., Geothermal heat pump systems: Status review and comparison with other heating options, *Applied Energy*, Vol.101, 2013, pp. 341–348.
[12] Choi J., Kang B. and Cho H., Performance comparison between R22 and R744 solar-geothermal hybrid heat pumps according to heat source conditions, *Renewable Energy*, Vol.71, 2014, pp. 414-424.
[13] Arslan O. and Köse R., Exergoeconomic optimization of integrated geothermal system in Simav, Kutahya, *Energy Conversion and Management*, Vol.51, 2010, pp. 663–676.
[14] Tuğcu A., Thermodynamic evaluation and ANN optimization of geothermal aided absorbtion refrigeration system for food cooling, *PhD Dissertion*, Dumlupinar University, 2015 (in Turkish).
[15] Arslan O., The examination of Kütahya-Simav geothermal resources: Design and energy-exergy analysis of integrated system, *PhD Thesis*, Dumlupinar University, 2008.
[16] Arslan O., Ozgur M.A., Köse R. ve Tugcu A., Exergoeconomic evaluation on the optimum heating circuit system of Simav geothermal district heating system, *Energy and Buildings*, Vol.41, 2009, pp. 1325–1333.
[17] Bejan A., Tsatsaronis G. and Moran M., *Thermal System and Optimization*, John Wiley&Sons Publications, 1995.
[18] Arat H., Acar M.S. and Arslan O., Geothermal heat pump system using Kutahya-Simav district heating system, *20th Turkish National Congress on Thermal Sciences and Technology (ULIBTK'15),* Balikesir/Türkiye, 2015 (in Turkish).