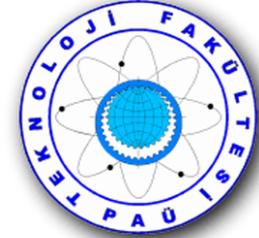




EKSERJİ VE UYGULAMALARI YAZ KURSU  
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# Exergetic Assessment of Geothermal District Heating Systems

## *Jeotermal Bölgesel Isıtma Sistemlerinin Ekserjetik Değerlendirilmesi*

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# Investigation of Thermodynamic Parameters of the Turkish Geothermal District Heating Systems (GDHSs)

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# Outline

- 1. Objective
- 2. Introduction
- 3. Description of the System
- 4. Modeling
- 5. Results and Discussion
- 6. Concluions

# 1. Objective

- To investigate some thermodynamic parameters of two geothermal district heating systems (GDHSs) using actual operational data:

The Balcova geothermal district heating system (BGDHS) in Izmir

and

the Salihli geothermal district heating system (SGDHS) in Manisa, Turkey.

## 2. Introduction

**Table 2. Ranking (in order) of Geothermal Direct Utilization 2005**

<u>Use (TJ/yr)</u>	<u>Capacity (MWt)</u>	<u>TJ/area</u>	<u>TJ/population</u>	<u>MWt/area</u>	<u>MWt/population</u>
China	USA	Iceland	Iceland	Denmark	Iceland
Sweden	Sweden	Israel	Sweden	Iceland	Sweden
USA	China	Switzerland	New Zealand	Switzerland	Denmark
Iceland	Iceland	Denmark	Georgia	Sweden	Norway
Turkey	Turkey	Georgia	Denmark	Hungary	Switzerland

Source: Lund, J.W., Freeston, D.H. and Boyd, T.L. 2005. World-Wide Direct Uses of Geothermal Energy 2005. Proceedings World Geothermal Congress 2005. Antalya, Turkey, 24-29 April 2005, pp. 1-20.

**Table 1**  
City-based geothermal district heating systems installed in Turkey

Location	Province	Capacity (MW <sub>t</sub> )	Geothermal fluid temperatures (°C)	Year commissioned	<sup>b</sup> District heating distribution network supply/return temperatures (°C)	Installed capacity (residence)/ number of dwellings heated	<sup>c</sup> Type of pipe distribution lines
Gonen	Balikesir	32	80	June 1987	—	4,500/3,400	Steel pipe system with 2 loops
Simav	Kutahya	25	120	October 1991	65/50	6,500/3,200	Fiberglass reinforced polyester system with 2 loops is replaced by steel pipe system with 3 loops
<sup>a</sup> Kirsehir	Kirsehir	18	54–57	March 1994	48/42	1,800/1,800	Steel pipe system with 2 loops
Kizilcahamam	Ankara	25	80	November 1995	—	2,500/2,500	Steel pipe system with 2 loops
Balcova (Narlidere)	Izmir	72	115	October 1996	85/60	20,000/6,849 (758)	Steel pipe system with 3 loops
Kozakli	Nevsehir	11.2	90	1996	—	1,250/1,000	Steel pipe system with 2 loops
Afyon	Afyon	40	95	October 1996	60/45	10,000/4,000	Steel pipe system with 3 loops
<sup>a</sup> Sandikli	Afyon	45	70	March 1998	70/40	5,000/1,700	Two loops: geothermal loop consisting of fiberglass reinforced polyester, district heating loop made of steel pipe
<sup>d</sup> Diyadin	Agri	42	78	September 1998	78/45	2,000/1,037	Steel pipe system with 3 loops
Salihli	Manisa	142	94	March 2002	80/43	<sup>e</sup> 20,000/200	Feasibility and project completed, put into operation

<sup>a</sup>Peak load boiler is used.

<sup>b</sup>Average values are given.

<sup>c</sup>In the system with 2 loops, a heat exchanger between the geothermal fluid and the district heating water is used, while in the system with 3 loops, a primary heat exchanger between the geothermal fluid and the district heating water and a secondary heat exchanger between the district heating water and building substation are being used.

<sup>d</sup>An integrated geothermal application system consisting of district heating, agriculture (greenhouse heating), bathing and balneology (thermal hotel), aquaculture (fishing pond), and industrial processes (liquefied carbon dioxide and precipitated calcium carbonate productions).

<sup>e</sup>Target capacity.

Source: Batik et al., 2000; Mertoglu, 2000; Kucuka, 2001; Eltez et al., 2001; Mertoglu, 2001a,b; Karamanderesi, 2001; Arslan et al., 2001; OGI, 2001; Canakci, 2002; DGI, 2002.

Source : Hepbasli, A. 2004. Current Status of Geothermal Energy applications in Turkey. Energy Sources 25:667-677.

### 3. Description of the two Systems

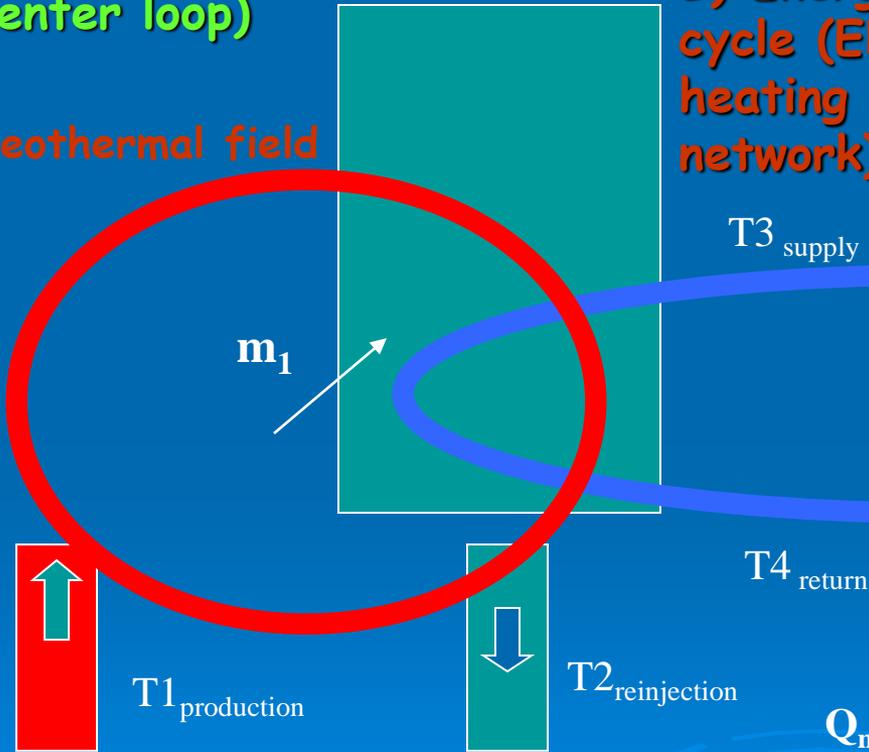
The BGDHS and SGDHS consists mainly of three cycles, such as:

- (a) energy production cycle (EPC) (geothermal well loop and geothermal heating center loop),
- (b) energy distribution cycle (EDC) (district heating distribution network), and
- (c) energy consumption cycle (ECC) (building substations)

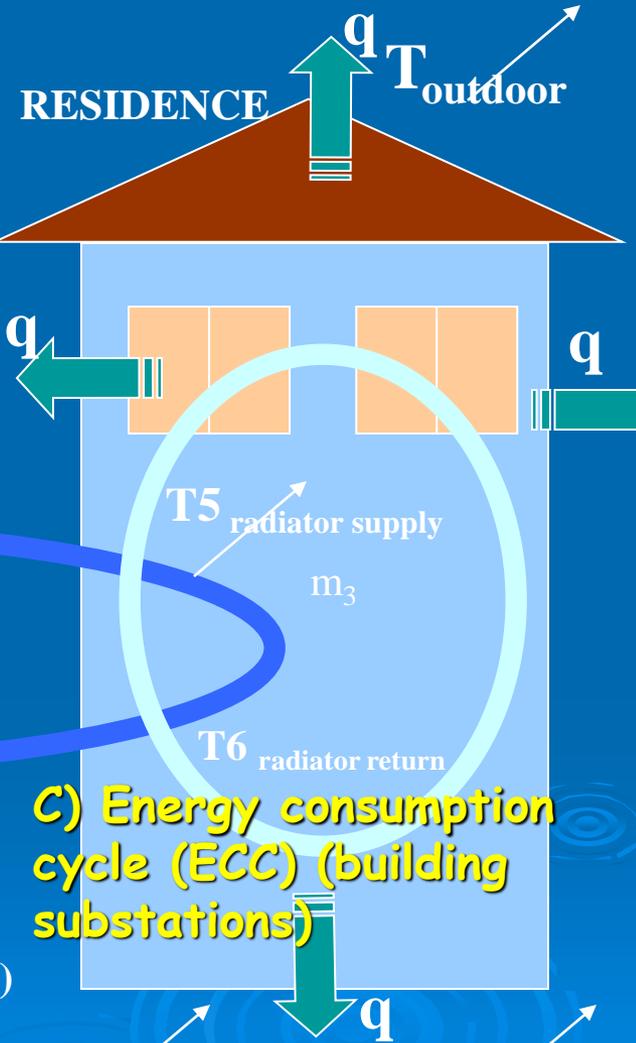
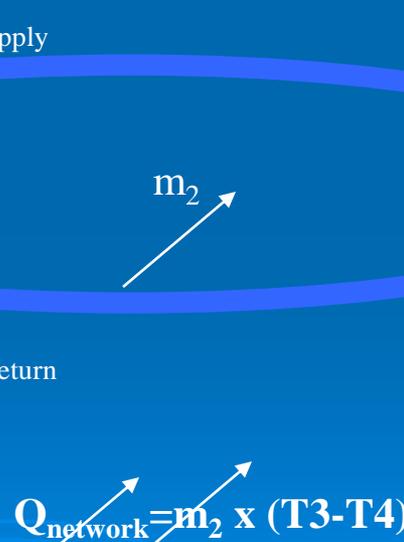
# Geothermal District Heating System

A) Energy production cycle (EPC) (geothermal well loop and geothermal heating center loop)

Geothermal field



B) Energy distribution cycle (EDC) (district heating distribution network)



C) Energy consumption cycle (ECC) (building substations)

$$Q_{transfer} = m_3 \times (T_5 - T_6)$$

$$Q_{geothermal} = m_1 \times (T_1 - T_2)$$

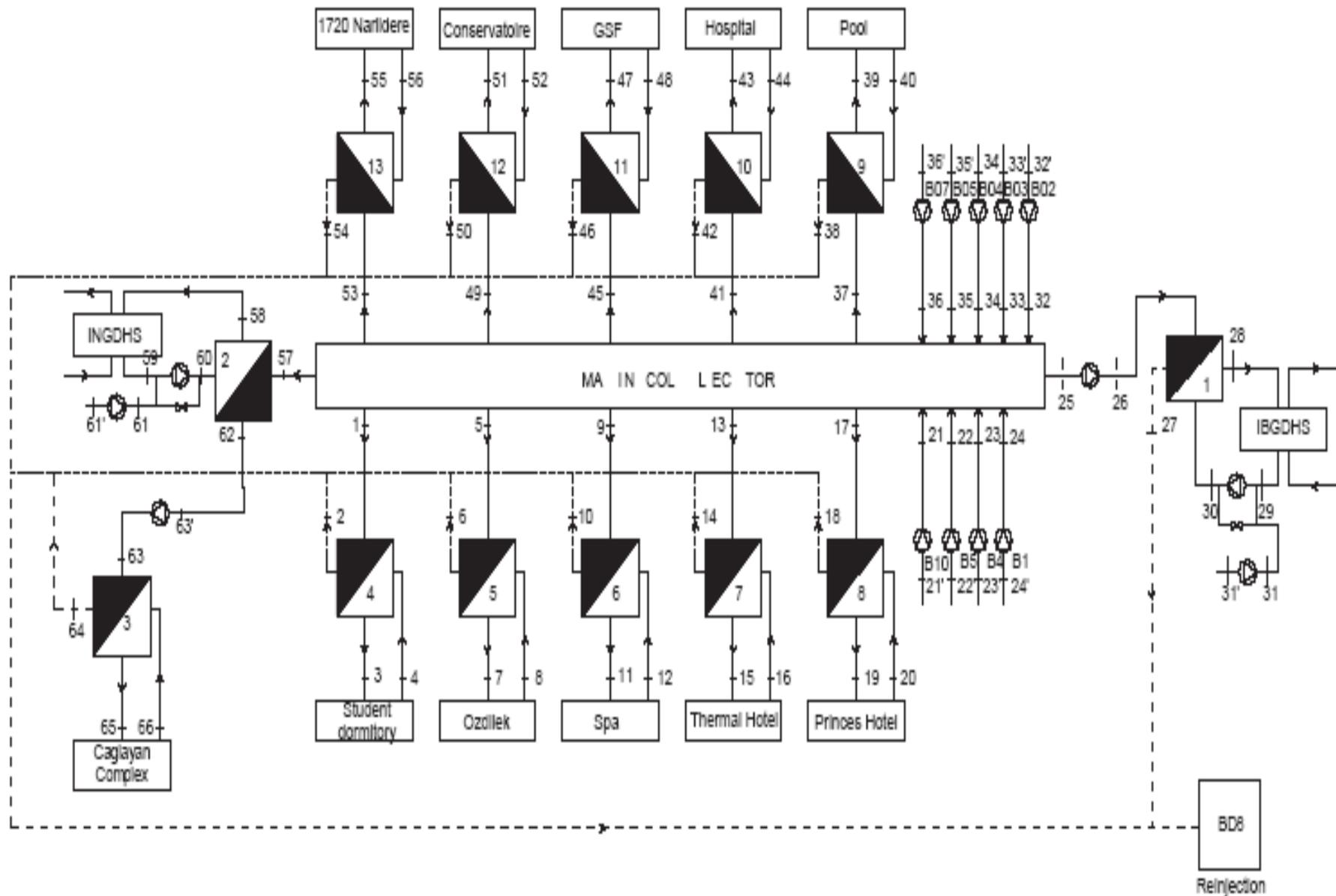


Fig. 1. Schematic diagram of the current BGHS.

## Balcova GDHS



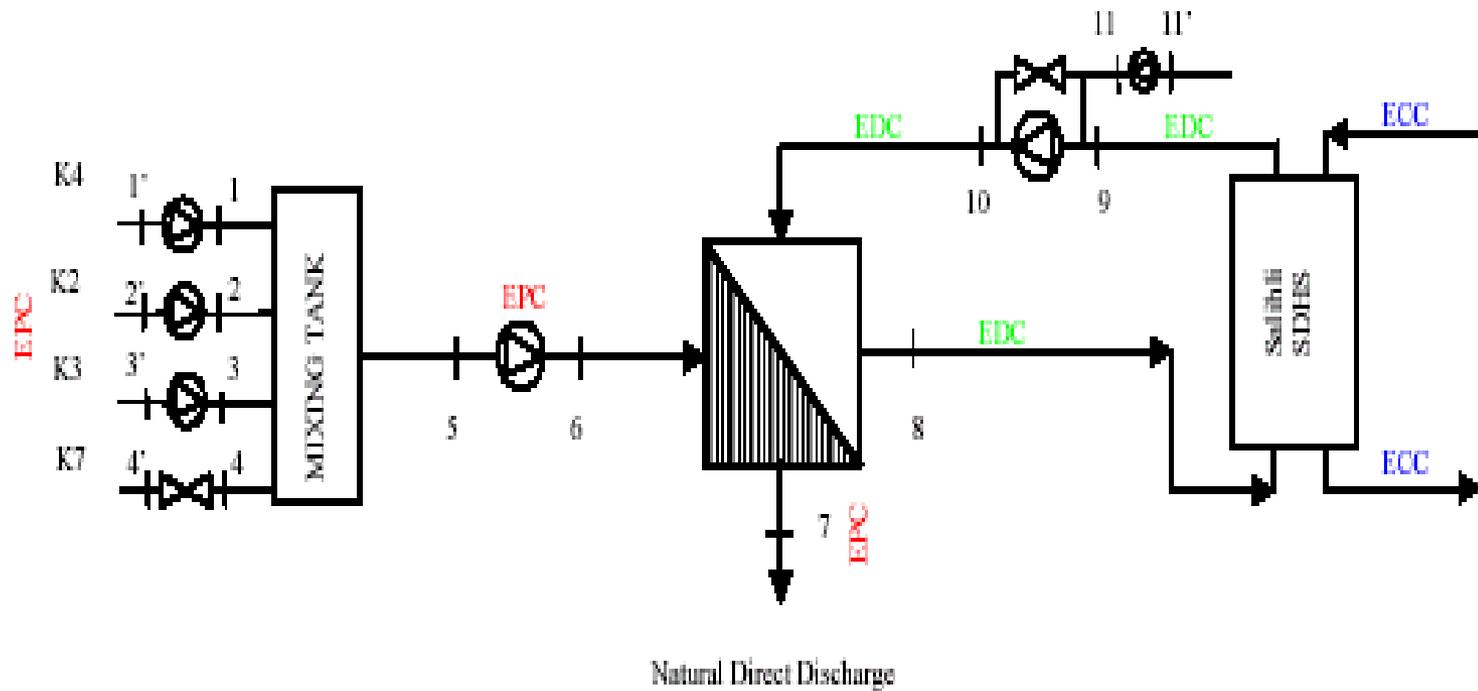


Figure 1. A schematic of the Salihli geothermal district heating system



Salihli GDHS



# 4. Modeling

The mass balance equation:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out}$$

The general energy balance:

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

The general exergy balance:

$$\dot{E}x_{in} - \dot{E}x_{out} = \dot{E}x_{dest}$$

The exergy rate:

$$\dot{E}x = \dot{m}[(h - h_0) - T_0(s - s_0)]$$

Other balance equations ???

For the both geothermal district heating systems studied, the mass balance equations are written as follows:

$$\sum_{i=1}^n \dot{m}_{w, \text{tot}} - \dot{m}_r - \dot{m}_d = 0$$

and,

$$\sum_{i=1}^n \dot{m}_{w, \text{tot}} - \dot{m}_d = 0$$

where  $\dot{m}_{w, \text{tot}}$  is the total mass flow rate at wellhead,  $\dot{m}_r$  is the flow rate of the reinjected thermal water and  $\dot{m}_d$  is the mass flow rate of the natural direct discharge.

The geothermal brine energy inputs from the production field of the both systems investigated are calculated from the following equation:

$$\dot{E}_{\text{brine}} = \dot{m}_w (h_{\text{brine}} - h_0)$$

The energy efficiency of the two systems:

$$\eta_{\text{system}} = \frac{\dot{E}_{\text{useful, HE}}}{\dot{E}_{\text{brine}}}$$

The geothermal brine exergy inputs from the production field of the two geothermal district heating systems

$$\dot{E}x_{\text{brine}} = \dot{m}_w [(h_{\text{brine}} - h_0) - T_0 (s_{\text{brine}} - s_0)]$$

The exergy destructions in the heat exchanger, pump and the system itself are calculated using

$$\dot{E}x_{\text{dest, HE}} = \dot{E}x_{\text{in}} - \dot{E}x_{\text{out}} = \dot{E}x_{\text{dest}}$$

$$\dot{E}x_{\text{dest, pump}} = \dot{W}_{\text{pump}} - (\dot{E}x_{\text{out}} - \dot{E}x_{\text{in}})$$

and

$$\dot{E}x_{\text{dest, system}} = \sum \dot{E}x_{\text{dest, HE}} + \sum \dot{E}x_{\text{dest, pump}}$$

The exergy efficiencies of the BGDHS and SGDHS:

$$\varepsilon_{\text{BGDHS}} = 1 - \frac{\dot{E}X_{\text{dest,system}} + \dot{E}X_{\text{reinject}} + \dot{E}X_{\text{ndd}}}{\dot{E}X_{\text{brine}}}$$

and

$$\varepsilon_{\text{BGDHS}} = 1 - \frac{\dot{E}X_{\text{dest,system}} + \dot{E}X_{\text{ndd}}}{\dot{E}X_{\text{brine}}}$$

The exergy efficiency of the two systems:

$$\varepsilon_{\text{system}} = \frac{\dot{E}X_{\text{useful,HE}}}{\dot{E}X_{\text{brine}}}$$

Some thermodynamic parameters for geothermal energy systems are

Fuel depletion ratio:  $\delta_i = \frac{\dot{I}_i}{\dot{F}_{\text{Tot}}}$

Relative irreversibility:  $\chi_i = \frac{\dot{I}_i}{\dot{I}_{\text{Tot}}}$

Productivity lack:  $\xi_i = \frac{\dot{I}_i}{\dot{P}_{\text{Tot}}}$

Exergetic factor:  $f_i = \frac{\dot{F}_i}{\dot{F}_{\text{Tot}}}$

Xiang J.Y., Cali M. and Santarelli M. 2004. Calculation for physical and chemical exergy of flows in systems elaborating mixed-phase flows and a case study in an IRSOFC plant, *International Journal of Energy Research* 28, 101-115.

Table I. Exergy rates and other properties at various system locations for one representative unit. State numbers refer to Figure 1.

State no.	Fluid	Phase	Temperature $T$ ( $^{\circ}\text{C}$ )	Pressure $P$ (kPa)	Specific enthalpy $h$ ( $\text{kJ kg}^{-1}$ )	Specific entropy $s$ ( $\text{kJ kg}^{-1}\text{K}^{-1}$ )	Mass flow rate $\dot{m}$ ( $\text{kg s}^{-1}$ )	Specific exergy $ex$ ( $\text{kJ kg}^{-1}$ )	Exergy rate $\dot{E}_x$ (kW)	Energy rate $\dot{E}$ (kW)
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The reference state for the BGDHS and SGDHS were considered to be  $13.1^{\circ}\text{C}$  and  $2.9^{\circ}\text{C}$ , respectively, and the atmospheric pressure was taken as and  $101.325\text{ kPa}$  ( $\approx 1\text{ atm}$ ), respectively.

# 5. Results and Discussion

**Table 1.** Some exergetic, energetic and thermodynamics analysis data provided for one representative unit of BGDHS [2-4]

Component	Exergy destruction rate (kW)	P (kW)	F (kW)	Exergy (second law) efficiency (%)	Relative irreversibility $\chi$ (%)	Fuel depletion rate $\delta$ (%)	Productivity lack $\xi$ (%)	Exergetic factor $f$ (%)
Heat Ex 1	617.38	3314.78	3931.95	84.3	7.72	7.13	8.63	45.36
Heat Ex 2	78.05	614.05	693	88.6	0.99	0.91	1.10	8.00
Heat Ex 3	26.88	126.42	153.3	82.5	0.34	0.31	0.38	1.77
Heat Ex 4	81.76	379.24	461.01	82.3	1.02	0.94	1.14	5.32
Heat Ex 5	110.69	26.39	137.38	19.2	1.38	1.28	1.55	1.59
Heat Ex 6	9.15	117.2	126.36	92.8	0.11	0.11	0.13	1.47
Heat Ex 7	10.04	130.3	140.34	92.8	0.13	0.12	0.14	1.62
Heat Ex 8	30.16	238.6	268.76	88.8	0.38	0.35	0.42	3.10
Heat Ex 9	4.33	87.74	92.07	95.3	0.05	0.05	0.06	1.06
Heat Ex 10	286.1	1526.35	1812.44	84.2	3.58	3.30	4.00	20.91
Heat Ex 11	8.31	28	36.3	77.1	0.10	0.10	0.12	0.43
Heat Ex 12	3.73	6.17	9.9	62.3	0.05	0.04	0.05	0.11
Heat Ex 13	1.83	214.48	216.3	99.1	0.02	0.02	0.03	2.49
B10 Well Pump	11	16.45	27.45	59.9	0.14	0.13	0.15	0.32
B5 Well Pump	26.41	11.84	38.25	30.9	0.33	0.30	0.37	0.44
B4 Well Pump	9.62	4.13	13.75	30	0.12	0.11	0.13	0.16
B1 Well Pump	15.83	15.52	31.35	49.5	0.20	0.18	0.22	0.36
BD2 Well Pump	7.33	7.67	15	51.13	0.09	0.08	0.10	0.17
BD3 Well Pump	28.45	10.05	38.5	26.1	0.36	0.33	0.40	0.44
BD4 Well Pump	31.02	21.78	52.8	41.3	0.39	0.36	0.43	0.60
BD5 Well Pump	17.27	13.53	30.8	43.9	0.22	0.20	0.24	0.36
BD7 Well Pump	23.88	8.57	32.45	26.4	0.30	0.28	0.33	0.38
Balcova Booster Pump	26.98	41.03	68	60.34	0.34	0.31	0.38	0.78
Balcova Circ. Pump	14.02	177.98	192	92.7	0.18	0.16	0.20	2.21
Pressurized Water Tank (Balcova)	10.93	0.26	11	0.64		0.12	0.15	0.13
Narlıdere Circ. Pump	5.98	9.02	15	60.13	0.07	0.07	0.08	0.17
Pressurized Water Tank (Narlıdere)	0	0	-	-	-	-	-	-
Caglayan Booster Pump	14.13	7.87	22	35.7	0.18	0.16	0.20	0.25
Heat Exchangers and Pumps	1512.29	7155.42	8667.46	-	-	-	-	-
Overall Plant <sup>a</sup>	7998.43	7155.42	8667.46	46.00	-	-	-	100.00

**Table 2.** Some exergetic, energetic and thermodynamics analysis data provided for one representative unit of the SGDHS [4,5]

Component	Exergy destruction rate (kW)	P (kW)	F (kW)	Exergy efficiency (%)	Relative irreversibility $\chi$ (%)	Fuel depletion rate $\delta$ (%)	Productivity lack $\xi$ (%)	Exergetic factor $f$ (%)
Heat exchanger	458.46	1524	1982.36	76.87	44.09	20.69	30.08	89.49
K4 well pump	21.46	3.29	24.75	13.29	2.06	0.96	1.40	1.12
K2 well pump	12.74	7.51	20.25	37.09	1.22	0.57	0.83	0.92
K3 well pump	5.23	15.02	20.25	74.17	0.50	0.23	0.34	0.92
K7 well pump	-	-	-	-	-	-	-	-
Salihli booster pump	7.3	47.7	55	86.72	0.70	0.32	0.47	2.48
Salihli circulation pump	10.28	102.22	112.5	90.86	0.98	0.46	0.67	5.07
Heat exchangers and pumps	515.47	1524	1982.36	-	-	-	-	-
Overall System <sup>a</sup>	1039.67	1524	1982.36	59.44				

<sup>a</sup> Based on the exergy (or energy) input to thermal water and water

Parametric studies on energetic and exergetic efficiencies of the GDHSs studied

Geothermal district heating systems	Energy efficiency correlation	Correlation coefficient ( $R^2$ )
BGDHS	$\eta_{c1} = 0.01 - 0.5T_a^3 - 0.0029T_a^2 + 0.3228T_a + 38.27$	0.99
SGDHS	$\eta_{c3} = 0.0014T_a^3 - 0.0349T_a^2 + 0.7423T_a + 53.69$	0.99

Geothermal district heating systems	Exergy efficiency correlation	Correlation coefficient ( $R^2$ )
BGDHS	$\varepsilon_{c2} = -0.000001 - 0.5T_a^3 + 0.0004T_a^2 - 0.1279T_a + 45.21$	0.99
SGDHS	$\varepsilon_{c4} = 0.0007T_a^3 - 0.0396T_a^2 - 0.1412T_a^2 + 0.4593T_a + 5$	0.97

# 6. Conclusions

Exergy analysis is more significant tool, than energy analysis, for system performance assessment and improvement since it allows true magnitudes of the losses to be determined.

The results are expected to be beneficial to the researchers, government administration, and engineers working in the area of geothermal district heating systems.



Thank you very much for  
your standing till the end !

Arif Hepbasli