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The Investigation of Exergetic Performance of Cooling System With Geothermal Steam Ejector

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ABSTRACT :

In this study, application fields and potential of geothermal energy of Turkey are introduced. Then, steam ejector cooling systems using geothermal heat source are presented and thermodynamics of the system is explained. Energetic performance of the system (COP) is obtained by the first law of thermodynamics and exergetic performance of the system (COPEX) is obtained by the second law of thermodynamics. In this present study, generator temperatures for ejector cooling system, which will be designed suitably for geothermal fields with low and middle temperatures of Turkey, are selected at interval of two different temperatures (low and middle temperatures). Generator temperatures (T_g) are 60-90°C for applications with low temperatures, and 100-130°C for applications with middle temperatures. The energetic performance (COP) and the exergetic performance (COPEX) of the system are evaluated for three different conditions of evaporator temperature (T_e = 5, 10, 15 °C) and two different conditions of condenser temperature (T_c = 30, 35 °C). The intervals of temperature for evaluating the system performances are obtained from the experimental steam ejector cooling system designed. The 96 different cases are examined and the results are presented with graphics.

Keywords: *Geothermal energy, Steam ejector cooling, Energetic performance, Exergetic performance*

1. INTRODUCTION

Renewable energy sources, instead of conventional energy sources which are consumed fast, present new possibilities for humanity. Geothermal energy, that is one of the renewable energy sources, supplies many properties by itself. It is a native source that does not require dependency on foreign sources.

Tablo 1. *Nomenclature*

Nomenclature	
COP	coefficient of energetic performance
COPEX	coefficient of exergetic performance
$\dot{E}_e$	exergy of evaporator (kW)
$\dot{E}_g$	exergy of generators (kW)
h	specific enthalpy (kj/kg)
$\dot{m}$	mass flow (kg/s)
P	pressure (MPa)
$\dot{Q}_c$	conderser heat (kW)
$\dot{Q}_e$	cooling load (kW)
s	specific entropy (J/kgK)
T	Temperature K- °C
Greek Symbol	
μ	entrainment ratio
Subscripts	
$1, 2, 3, 4$	cycle locations
c	condenser
e	evaporator
g	generator
o	reference (dead-state) properties

Renewable energy sources except geothermal and biomass are not preferred because of both high primary investment costs and low energy densities. On the other hand, when environmental effects of biomass are considered, it is seen that geothermal energy is better than others. Geothermal energy has many application fields for processes from heating to cooling and production of electricity for countries which are on geothermal belt.

There are a lot of studies on the use of geothermal energy in heating and producing electric energy in the literature [1-6]. There are researches available on cooling systems with absorption and adsorption in cooling applications as well [7,8]. In ejector cooling systems, there are solar energy applications [9-12]. But, a few publications related to the ejector cooling systems with geothermal energy have been found in literature [13,14]. This paper presents a new approach in ejector cooling systems with geothermal energy. An application of geothermal energy using ejector cooling system in cold production and energetic and exergetic performance of proposed system are presented in this study.

2. GEOTHERMAL ENERGY POTENTIAL AND IT'S UTILIZATION in TURKEY

Turkey, located in the Mediterranean Region of Alpine-Himalayan Tectonic Belt, has a large potential of geothermal energy sources. In Fig.1 general tectonic, volcanic features and important geothermal fields in Turkey are shown. Geothermal energy is the heat stored in the earth. It is the thermal energy inside rocks and fluids (that fill the faults and holes within the rock) on the earth's crust. The deeper it penetrates into the interior of our planet, the hotter it gets: a continous heat flow rises from the core to the surface, heating the rocks and groundwater [1].

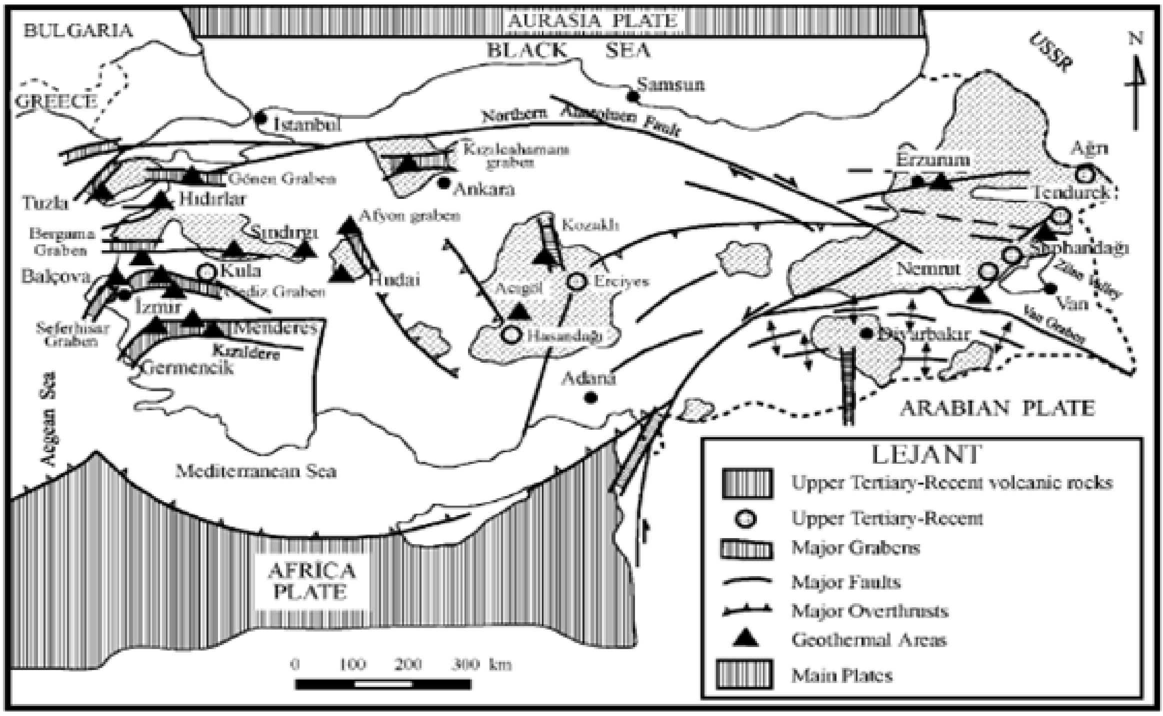

Figure.1 *General tectonic, volcanic features and important geothermal fields in Turkey [4,5].*

There are two parameters that determine the potential of geothermal energy; heat energy capacity of the area and generated fluid flow [15]. Geothermal energy is widely used in Turkey in the following areas: heating applications, greenhouse heating, electricity production, CO2 and dry ice production, balneology, process heating in the textile and food industry [16]. Besides these wide usage, geothermal energy can be used in absorption cooling applications [17]. The utilization of geothermal energy has increased rapidly during the last three decades. Turkey, for instance, is among the first five countries in the world that use geothermal energy in electric power generation and in other applications. Table 1 shows the potential of geothermal energy in Turkey Regions.

Turkey presently has one operating geothermal power plant with an installed capacity of 20.4 Mwe shown in Table 2. The total installed capacity has reached 820 MWt for direct use [1].

Table 2. *General Situation of Geothermal Sources in Turkey [18].*

Regions	**Energy Potential, MW_t**
The Marmara	133.6
Northern Anatolia	20.11
Aegean	697.27
Central Anatolia	159.2
Eastern Anatolia	26.6
Southeast Anatolia	1.95
The Mediterranean	7.0
Total	1045.79

Table 3. *The growth of Geothermal Energy Utilization [19].*

Geotermal utilization	**Unit**	**Capacity Growth**			
		2000	**2003**	**2010**	**2020**
Heating	MW_t	493	665	3500	8300
Balneology	MW_t	327	327	895	2300
Diretc-use	MW_t	820	992	4395	10600
Electricity generation	MW_e	20.4	20.4	500	1000
CO_2 generation	t/yıl	120.000	120.000	120000	120000

In Turkey, around 600 geothermal prospects and 170 geothermal fields with a temperature range of 40-242°C have been discovered as shown in Fig. 2. The potential for geothermal development in Turkey is generally considered large in terms of moderate and low temperature resources (<150°C). Therefore, the resources are mostly suitable for direct use applications [1].

Figure 2. *Map indicating Turkey’s geothermal fields suitable for power generation [1].*

3. STEAM EJECTOR COOLING SYSTEM DESCRIPTION

Converter systems are neccessary to utilize heat energy with renewable energy source in cooling applications. Cooling systems with adsorption, absorption and ejector can be used for this purpose. The adsorption and absorption cooling systems are not preferred because of complex structure and interrupted operating. However, in recent years ejector cooling systems have been preferred widely because of their simple structure, low budget, easy operation, ability of working with all kinds of fluid and their utility without interruption in spite of low COP.

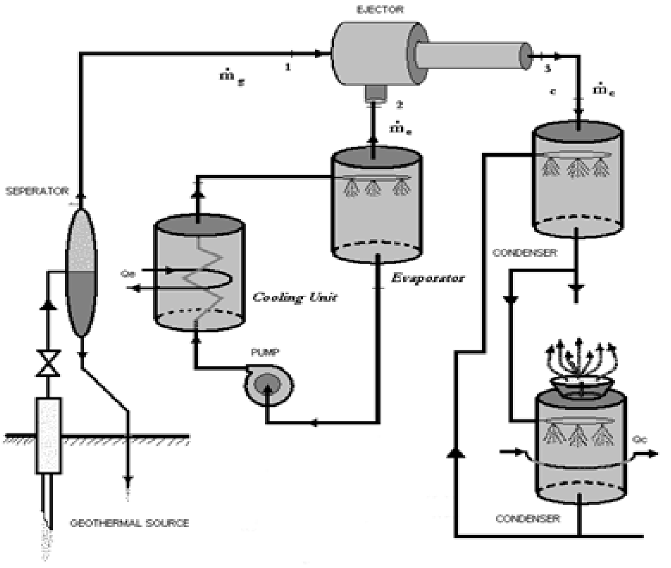

Figure 3. Geothermal steam ejector cooling system (Open system) [13].

There are two applications of ejector cooling system on geothermal energy utilization. One of them is open system method shown in Figure 3 where the vapour obtained by geothermal sources with high enthalpy is sent to ejector directly. The other one is a method shown in Figure 4 that vapour obtained by geothermal sources with middle and low enthalpy is used in suppliying the generator heat of a secondary steam ejector system which can work with various refrigeration fluids and with pressure under atmosphere [14]. In this study the second method is carried out.

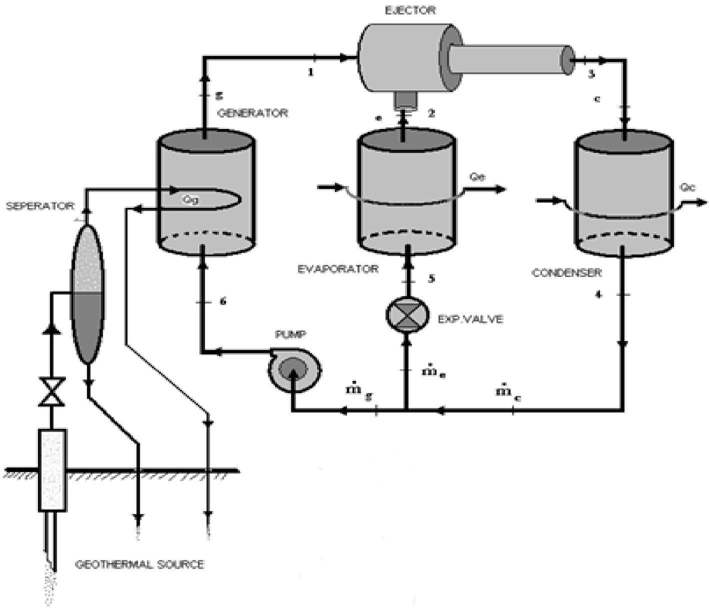

Figure 4. Geothermal steam ejector cooling system (Closed system) [14].

This system shown in Figure 4, consists of two sub-systems. One of them is geothermal energy sub-system which supplies generator heat to produce secondary system's vapour. The other is steam ejector cooling sub-system. Combined system consists of these two systems. Cooling sub-system contains a steam generator working under atmosphere pressure, an evaporator supplying the cooling load and a condenser. Heat from geothermal source, generates the vapour as a saturated vapour with Tg and Pg conditions in steam generator. While generated vapour in generator is passing through the ejector with high velocity, vacuum occurs in the evaporator and this causes that temperature of evaporator increases in Te with evaporation under low pressure (vacuum conditions) (Pe). The ejector which is designed and manufactured for this study is given in Fig.5.

(a)

(b)

Figure 5. *The views of ejector (a. The cross section of ejector which is designed. b. The shape of ejector which is manufactured.)*

Generated vapour in evaporator with Pe pressure and vapour from the generator are mixed in ejector. This mixed vapor goes to condenser with Tc and Pc conditions. Refrigerator fluid which is condenced in the condenser is sent to the evaporator and generator again [12]. The experimental steam ejector cooling system is shown in Fig. 6. As well as water can be used as a refrigerator fluid for air-conditioning applications, various kinds of fluids can also be used for cooling systems with low temperature in the system.

Figure 6. *A photograph of experimental steam ejector cooling system*

4. SYSTEM MODELLING AND A CASE STUDY

Basis equations in system thermodynamic for steady state conditions are given as follows. At first, cooling load is determined in the analysis. The studies related to ejector design and shocked flow are available in literature and using theory [20-24] an experimental steam ejector cooling system is constructed with project support. Calculation method in the literature was used but not given in this study. Because system energetic and exergetic performances are focused. System cooling load is obtained with heat from the evaporator.

Heat from the evaporator (Q_e) is,

$$\dot{Q}_e = \dot{m}_e(h_2 - h_4)$$

Heat which has to be given to the generator (Q_g) is,

$$\dot{Q}_g = \dot{m}_g(h_1 - h_2)$$

Heat to the surrounding (enviroment) is,

$$\dot{Q}_c = \dot{m}_c(h_3 - h_4)$$

Heat and mass balance are shown respectively as follows,

$$\dot{Q}_g + \dot{Q}_e = \dot{Q}_c$$

$$\dot{m}_g + \dot{m}_e = \dot{m}_c$$

μ is the ratio of entrained vapour to the motive stream and given as

$$\mu = \frac{\dot{m}_e}{\dot{m}_g} = \frac{h_1 - h_3}{h_3 - h_2}$$

The energetic performance (*COP*) of a cooling cycle is calculated as

$$COP = \frac{\dot{Q}_e}{\dot{Q}_g} = \mu(\frac{h_2 - h_4}{h_1 - h_4})$$

The exergetic performance (COPEX) is given as

$$COPEX = \frac{\dot{E}_e}{\dot{E}_g}$$

Where,

$\dot{E}_e$ = exergy of evaporator,

$\dot{E}_g$ = exergy of generator,

and exergy of a refrigeration is calculated as,

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

In this study, performances (COP, COPEX) of closed system using geothermal energy and ejector cooling system with water vapour are calculated for different operating conditions. These cases are given in Table 4.

Table 4. *The operating conditions cases of ejector cooling system*

CASES														
Case no	**T_g**	**T_e**	**T_{cs}**	**T_c**	**Case no**	**T_g**	**T_e**	**T_{cs}**	**T_c**	**Case no**	**T_g**	**T_e**	**T_{cs}**	**T_c**
1	60	5	30	45	33	60	10	30	45	65	60	15	30	45
2	60	5	35	45	34	60	10	35	45	66	60	15	35	45
3	60	5	30	40	35	60	10	30	40	67	60	15	30	40
4	60	5	35	40	36	60	10	35	40	68	60	15	35	40
5	70	5	30	45	37	70	10	30	45	69	70	15	30	45
6	70	5	35	45	38	70	10	35	45	70	70	15	35	45
7	70	5	30	40	39	70	10	30	40	71	70	15	30	40
8	70	5	35	40	40	70	10	35	40	72	70	15	35	40
9	80	5	30	45	41	80	10	30	45	73	80	15	30	45
10	80	5	35	45	42	80	10	35	45	74	80	15	35	45
11	80	5	30	40	43	80	10	30	40	75	80	15	30	40
12	80	5	35	40	44	80	10	35	40	76	80	15	35	40
13	90	5	30	45	45	90	10	30	45	77	90	15	30	45
14	90	5	35	45	46	90	10	35	45	78	90	15	35	45
15	90	5	30	40	47	90	10	30	40	79	90	15	30	40
16	90	5	35	40	48	90	10	35	40	80	90	15	35	40
17	100	5	30	45	49	100	10	30	45	81	100	15	30	45
18	100	5	35	45	50	100	10	35	45	82	100	15	35	45
19	100	5	30	40	51	100	10	30	40	83	100	15	30	40
20	100	5	35	40	52	100	10	35	40	84	100	15	35	40
21	110	5	30	45	53	110	10	30	45	85	110	15	30	45
22	110	5	35	45	54	110	10	35	45	86	110	15	35	45
23	110	5	30	40	55	110	10	30	40	87	110	15	30	40
24	110	5	35	40	56	110	10	35	40	88	110	15	35	40
25	120	5	30	45	57	120	10	30	45	89	120	15	30	45
26	120	5	35	45	58	120	10	35	45	90	120	15	35	45
27	120	5	30	40	59	120	10	30	40	91	120	15	30	40
28	120	5	35	40	60	120	10	35	40	92	120	15	35	40
29	130	5	30	45	61	130	10	30	45	93	130	15	30	45
30	130	5	35	45	62	130	10	35	45	94	130	15	35	45
31	130	5	30	40	63	130	10	30	40	95	130	15	30	40
32	130	5	35	40	64	130	10	35	40	96	130	15	35	40

where,

T_g = generator temperature,

T_e = evaporator temperature,

T_{cs} = condenser outlet temperature,

T_c = condenser temperature.

In investigation, with considering changes between following values basicly, energetic and exergetic performances are calculated for 96 cases and the results are discussed in section 5.

5. RESULTS AND DISCUSSION

In the study, total 96 cases are examined for ejector cooling system working with pressure under atmosphere (T_g = 60, 70, 80, 90 °C) and above atmosphere (T_g = 100, 110, 120, 130°C). Results are shown in Figs. 7-12. Fig. 7 shows the comparison of ejector entrainment ratio (μ) for various eveparator temperatures (T_e) and generator temperatures (T_g). When T_g and T_e increase, the entrainment ratio increases, too.

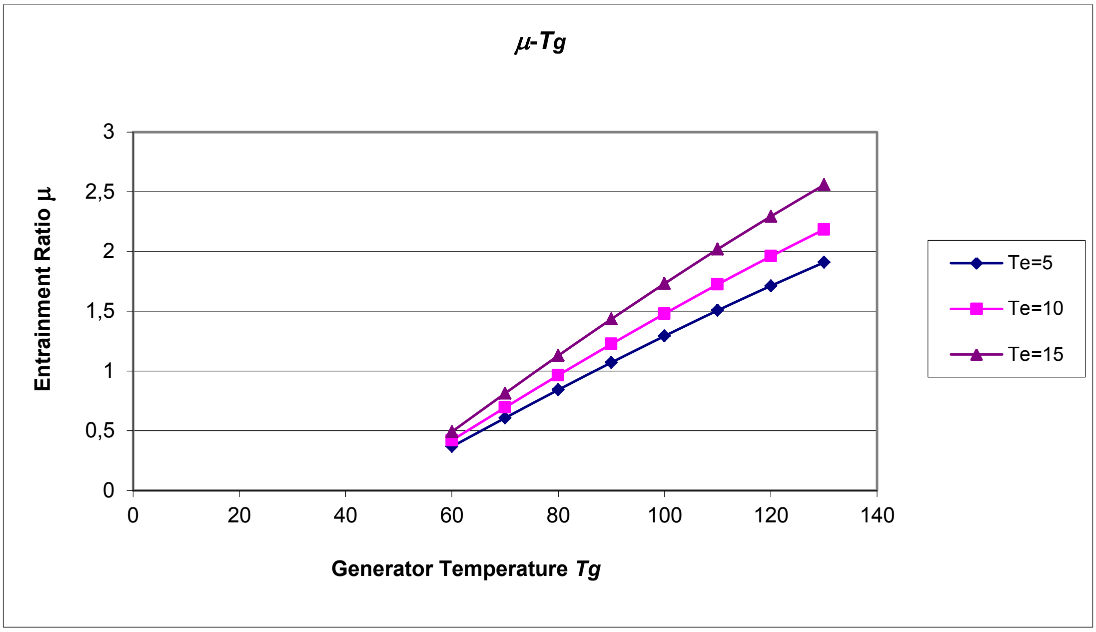

Figure 7. *The comparision of ejector entrainment ratio (μ) for various evaporator temperatures (T_e) and generator temperatures (T_g).*

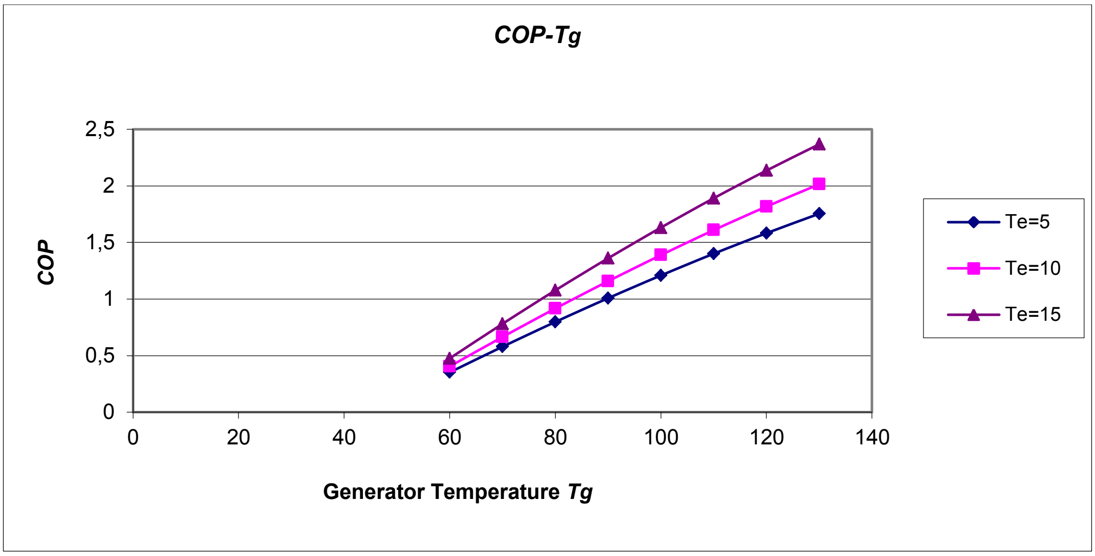

Figure 8. *The coefficient of energetic performances (COP) versus generator temperatures(T_g) for different evaporator temperatures (T_e)*

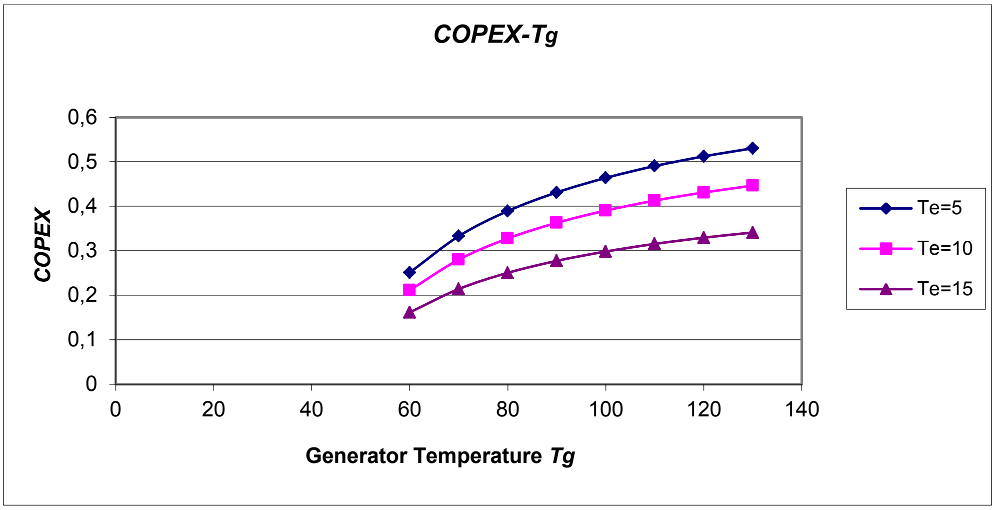

Figure 9. *The coefficient of exergetic performances (COPEX) versus generator temperatures (T_g) for different evaporator temperatures (T_e)*

Energetic and exergetic performances are shown in Figs. 8-9. Fig.8 shows the coefficient of energetic performances (COP) versus generator temperature (T_g) for different evaporator temperatures (T_e). It is quite clear that with an increase of T_g and T_e, COP value increases. In Fig. 9 coefficient of exergetic performance (COPEX) increases with an increase of T_g. However, COPEX decreases with an increase of T_e. This is a result of the second law of thermodynamics. Fig. 10 shows the comparison of generator mass flow rate ($\dot{m}_g$) for different cooling loads ($\dot{Q}_e$) under the various generator temperatures (T_g). It is seen from that with an increase of generator temperature (T_g), generator mass flow rate ($\dot{m}_g$) decreases.

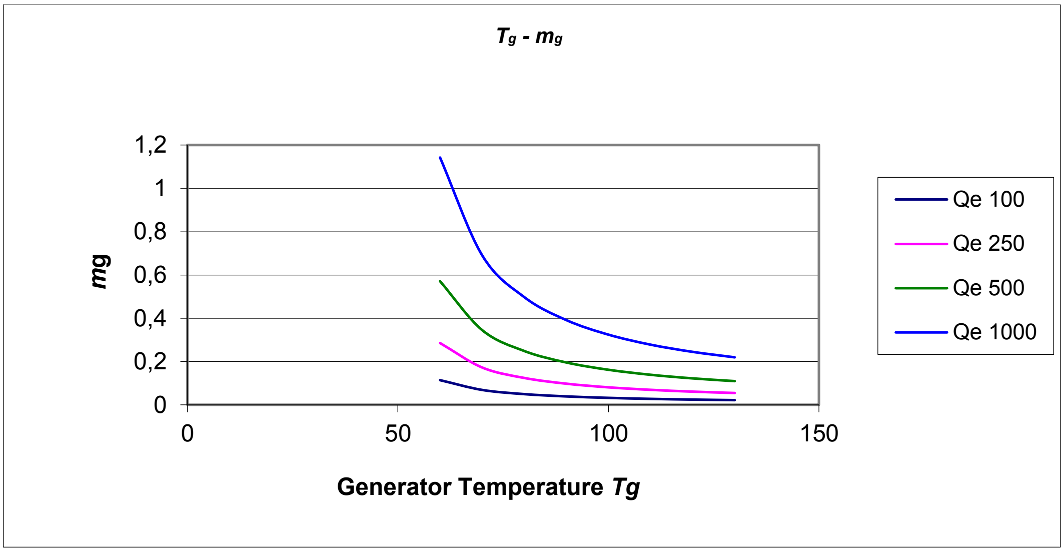

Figure 10. *The comparision of generator mass flow rate ($\dot{m}_g$) for different cooling loads ($\dot{Q}_e$) under the various generator temperatures.*

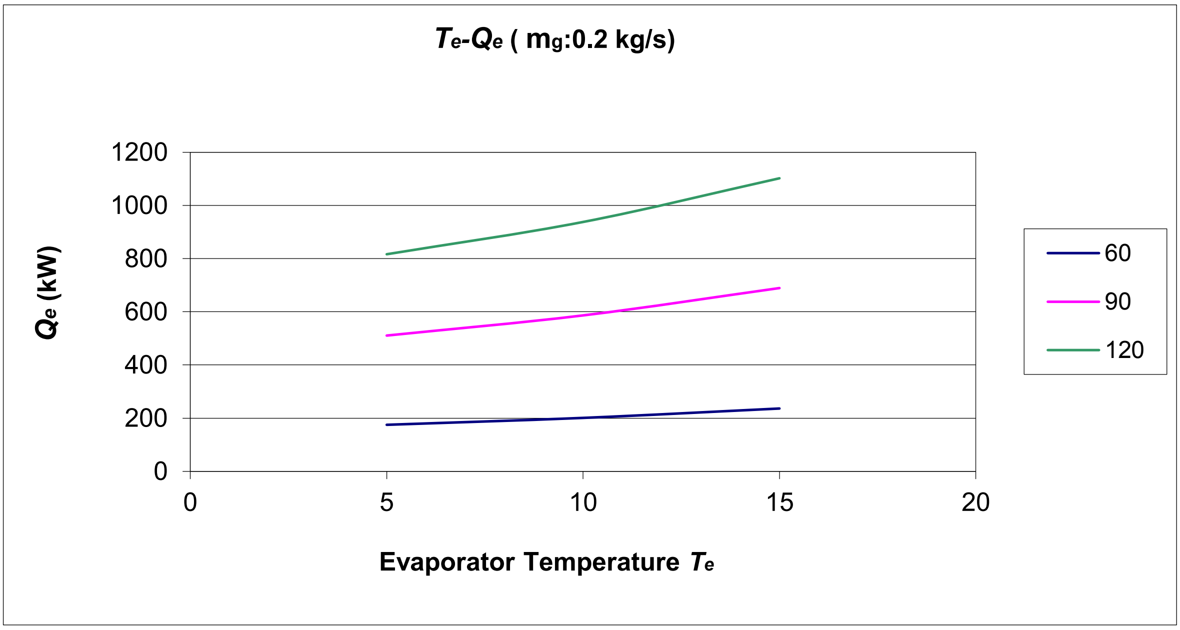

Figure 11. *The comparision of cooling loads ($\dot{Q}_e$) for different generator temperatures (T_g) under the various evaporator temperatures (T_e).*

It is seen from Fig. 11 that when generator temperature (T_g) and evaporator temperature (T_e) increase, cooling load ($\dot{Q}_e$) increases, too. Fig. 12 shows that increases of T_g and T_e cause a decrease of mass flow rate ($\dot{m}_g$).

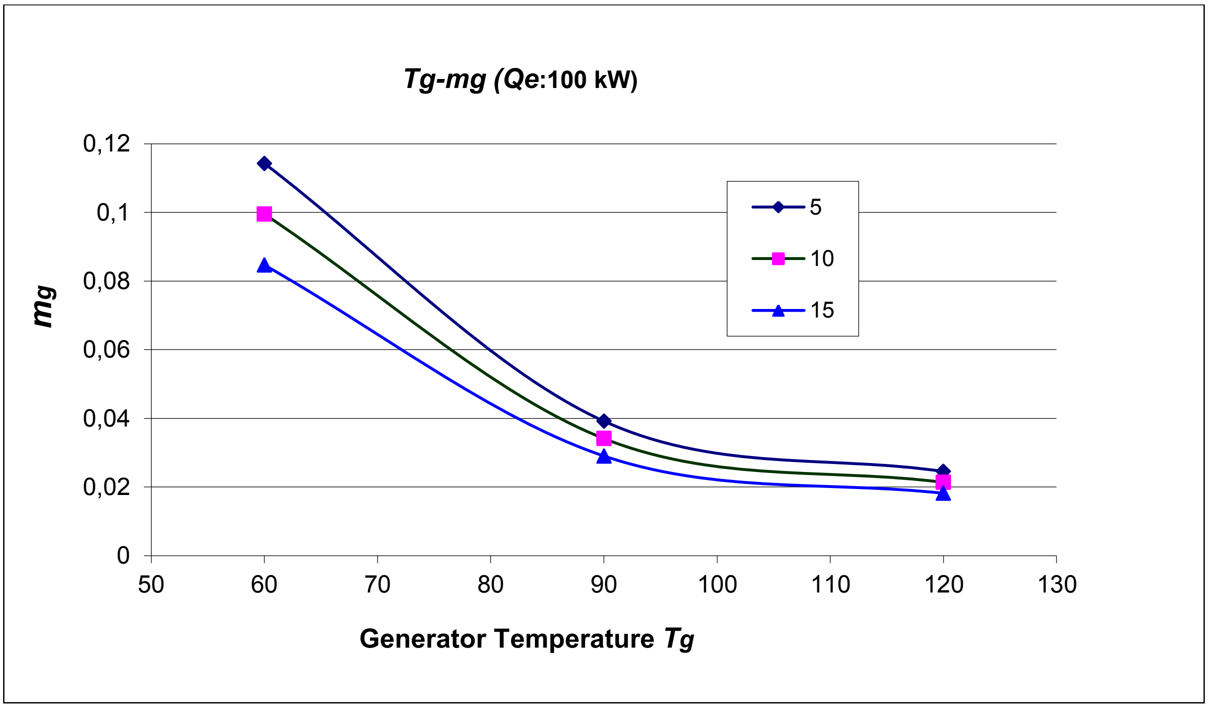

Figure 12. *The comparision of mass flow rate ($\dot{m}_g$) for different evaporator temperatures (T_e) under the various generator temperatures (T_g).*

6.CONCLUSIONS

Using heat through geothermal energy source is one of the most attractive applications for researchers to obtain the cooling effects. Ejector cooling sytems that run with geothermal energy, which can convert heat energy with all renewable energy sources to cooling effect, are quite effective, economical and enviroment-friendly. They are also favorable with their low-cost construction.

In this study, energetic and exergetic performances of ejector cooling system, which use heat with geothermal energy source at various temperatures to supply generator heat, are evaluated for 96 cases including different operating conditions. System performances, which can be constructed with considering the temperature of available geothermal source, are discussed with graphics. It is resulted that especially COP has the high values for the high temperatures. This study presents a new approach for ejector cooling systems with geothermal source.

Acknowledgements

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