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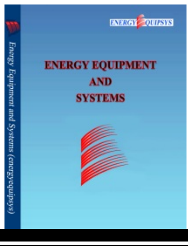

Investigation of a single-reheat condensing steam power plant based on energy and exergy analysis

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ABSTRACT

Nowadays, energy plays an important role in the economic and community development of the country. Consequently, performance analysis of energy systems is one of the effective methods being used to prevent waste of energy resources. Among the different power generation technologies, steam power plants make a significant contribution to power generation in Iran, with a share of 47 % of electricity generation. Therefore, it seems that exergy analysis of the power plant can help designers to reduce energy losses and increase efficiency. In this study, energy and exergy analysis of a single-reheat steam power plant in Iran is presented. This analysis considered the effect of environment temperature variation on the energy and exergy efficiencies. The results showed that the condenser has most energy losses (50%) in a cycle, while maximum exergy destruction (84%) occurs in the boiler. The thermal and exergy efficiencies at reference temperature were computed as 36.84% and 34.75%, respectively. Exergy destruction and efficiency of each component have been considered and are reported in the paper. The effects of various parameters such as steam pressure, steam temperature and condenser pressure have also been examined in the cycle performance.

Keywords: Boiler, Energy analysis, Exergy analysis, Steam power plant, Thermal efficiency.

1. Introduction

Considering the role of energy in industrial development and economic prosperity as well as the increase in energy demands, on the one hand, and the limitation of the world's energy resources, on the other hand, the importance of optimization in the generation and consumption of energy is clear. Performance evaluation of energy systems can be helpful in the optimum utilization of energy sources. Iran's energy information and data for 2011 reveal that electricity generation increased by about 3.1% in that year. Due to Iran's environmental conditions, electricity generation is mainly performed by thermal power plants. In this year, 94.7% of total electricity power was generated by thermal power, 5% by a hydroelectric power plant and 0.3% by renewable and atomic power plants. Figure 1 shows the comparison of different power generation forms in Iran in 2011 and 2005. It clearly illustrates that the steam power plant has the highest share of power

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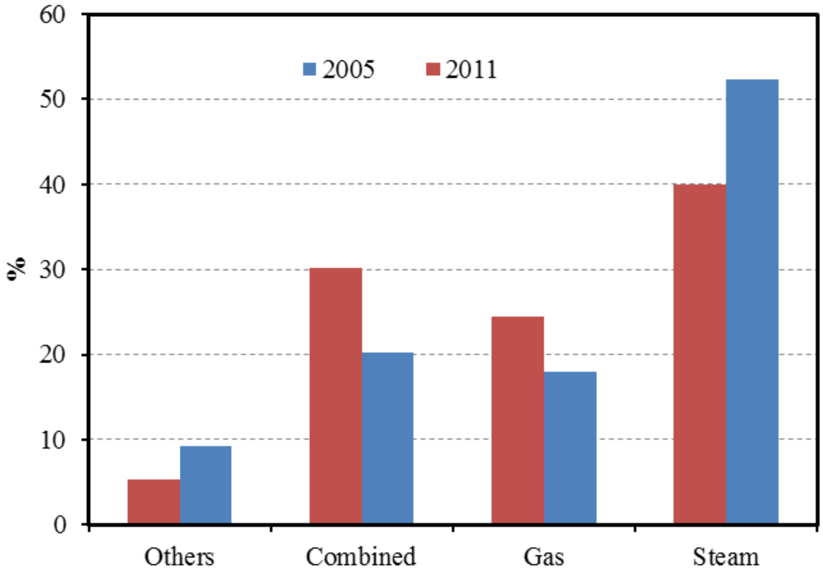


Fig. 1. Comparison of different power generation methods in Iran

generation in Iran. Therefore, optimization of thermal power plants and especially steam power plants based on the exergy analysis is an important way of increasing efficiency of the plants [1].

Energy analysis is traditionally used in industries to carry out performance comparison and optimization. The conventional methods of energy analysis are based on the first law of thermodynamics, which is concerned with the conservation of energy. The first law merely serves as a necessary tool for the bookkeeping of energy during a process [2]. However, there is increasing interest in the combined utilization of the first and second laws of thermodynamics, using such concepts as exergy, entropy generation and irreversibility in order to evaluate the efficiency with which the available energy is consumed [3]. Exergy analysis, by the integration of the first and second law of thermodynamics, makes possible an optimal method for the analysis of energy systems, and energy levels that are clearly unfavourable to the thermodynamic processes of a system should be identified. In exergy analysis, the main objective is to determine the location and production of irreversibility in thermodynamic cycles through different processes and factors affecting the production of irreversibility. Exergy analysis of steam power plants has been of great interest to researchers in recent years. The analysis of exergy losses identifies possibilities for improving thermal processes, and helps to select a rational scheme for thermal systems.

Many researchers have studied steam power plants from energy and exergy points of view. Regulagadda *et al.* [4] studied the thermodynamic analysis of a subcritical boiler-turbine generator for a coal-fired power plant. In their work, both energy and exergy formulations were developed for the system. They indicated that the boiler and the turbine have the highest exergy losses in the power plant. Aljundi [5] studied the energy and exergy analysis of the Al-Hussein Power Plant in Jordan. They observed that energy losses mainly occurred in the condenser (66%), and they found the highest total exergy destruction in the boiler system (77%). They introduced the boiler as the major source of irreversibilities in the power plant. Peng *et al.* [6] studied exergy evaluation of a typical 330 MW solar-hybrid coal-fired power plant in China. In this study, both conventional and advanced exergy analyses were conducted. Kumar *et al.* [7] studied the energy analysis and optimization of the Kalina cycle coupled with a coal-fired steam power plant. They considered the effect of key parameters, namely ammonia mass fraction in the mixture and ammonia turbine inlet pressure on the cycle performance. . Kaska [8] conducted energy and exergy analysis of an organic Rankine cycle for power generation from waste heat recovery in the steel industry. Verkhivker *et al.* [9] studied exergy analysis of power plants. They proposed that it would be better to define the entire nuclear power plant's efficiency by the system's coefficient of performance. Rosen *et al.* [10] considered exergoeconomic analysis of power plants operating on different fuels. Ameri *et al.* [11] performed exergy analysis of a 420 MW combined cycle power plant. They evaluated the irreversibility of each part of the CCPP using exergy analysis. Their results showed that the combustion chamber, gas turbine, duct burner and heat recovery steam generator (HRSG) were the main sources of irreversibility, representing more than 83% of the overall exergy losses.

Kotas [12] used an exergy method for analysis of a thermal power plant. Dincer *et al.* [13] implemeted energy, entropy and exergy concepts in a power plant and considered their roles in thermal engineering. Balli *et al.* [14] evaluated the exergetic performance of a typical combined heat and power (CHP) system in Turkey. The calculated exergetic efficiency of the MCHP system was 40.75% with 53269.53 kW as an electrical output. The calculated exergy consumption was 77444.14 kW in the CHP system.

Ahmadi *et al.* [15] studied exergy, exergoeconomic and environmental analyses of a combined cycle power plant and proposed an evolutionary algorithm based on the multi-objective optimization method. The optimization consisted of three objective functions, namely: CCPP exergy efficiency, total cost rate of the system products, and CO_2 emissions of the overall plant. Mansouri *et al.* [16] studied exergetic and economic evaluation of the effect of HRSG configurations on the performance of combined cycle power plants. In this research, the effect of HRSG pressure levels on exergy efficiency of combined cycle power plants was investigated. The results show how an increase in the number of pressure levels of the HRSG affect the exergy losses due to heat transfer in the HRSG and the exhaust of flue gas to the stack.

The aim of this study is energy and exergy analysis of a steam power plant located near Tehran in Iran. Energy and exergy relations are developed for each component of the plant. Energy losses and exergy destruction of each component of the systems were calculated. The effects of varying reference temperature on the exergy analysis of each component have been considered. Moreover, the effects of various operative parameters such as boiler part load, condenser pressure, boiler outlet temperature and pressure on the efficiency and output power have been investigated.

Nomenclature

C	$bulk\ velocity$ (m/s)
e	specific exergy (kJ/kg)
$\dot{E}$	total exergy rate (MW)
G	Gibbs energy (MW)
h	specific enthalpy (kJ/kg)
HHV	higher heating value (kJ/kg)
$\dot{I}$	exergy destruction rate (MW)
LHV	lower heating value (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (Pa)
$\dot{Q}$	heat rate (kW)
R	gas constant (kJ/kg K)
s	specific entropy (kJ/kg K)
T	temperature (K)
$\dot{W}$	work rate or power (MW)
x	molar fraction
Z	altitude above the sea level (m)
Greek	
η_I	energy efficiency
η_{II}	exergy efficiency
γ	exergy factor
Subscripts	
ch	chemical
f	Fuel
i	inlet
k	component
o	exit, dead state condition
ph	Physical
con	condenser

2. Cycle description

In this study, a steam power plant located near Tehran in Iran is considered. The power plant has a total 1000 MW capacity. The power plant consists of four units with a capacity of 250 MW (4×250). The natural gas used for the cycle as a fuel and the volume fraction of fuel components are summarized in Table 1. A schematic representation of one unit of the steam power plant is shown in Fig.2. The plant includes a package of HP, IP and butterfly LP turbines. The superheated steam enters the HP turbine at 811.15 K and 14 MPa. The operating conditions of one unit

Table 1. Volume fraction of the natural gas components

Component	Volume fraction (%)
H_2	0.36
O_2	0.07
N_2	3.65
CO	0.09
CO_2	0.34
CH_4	87
C_2H_6	8.46
C_2H_4	0.03

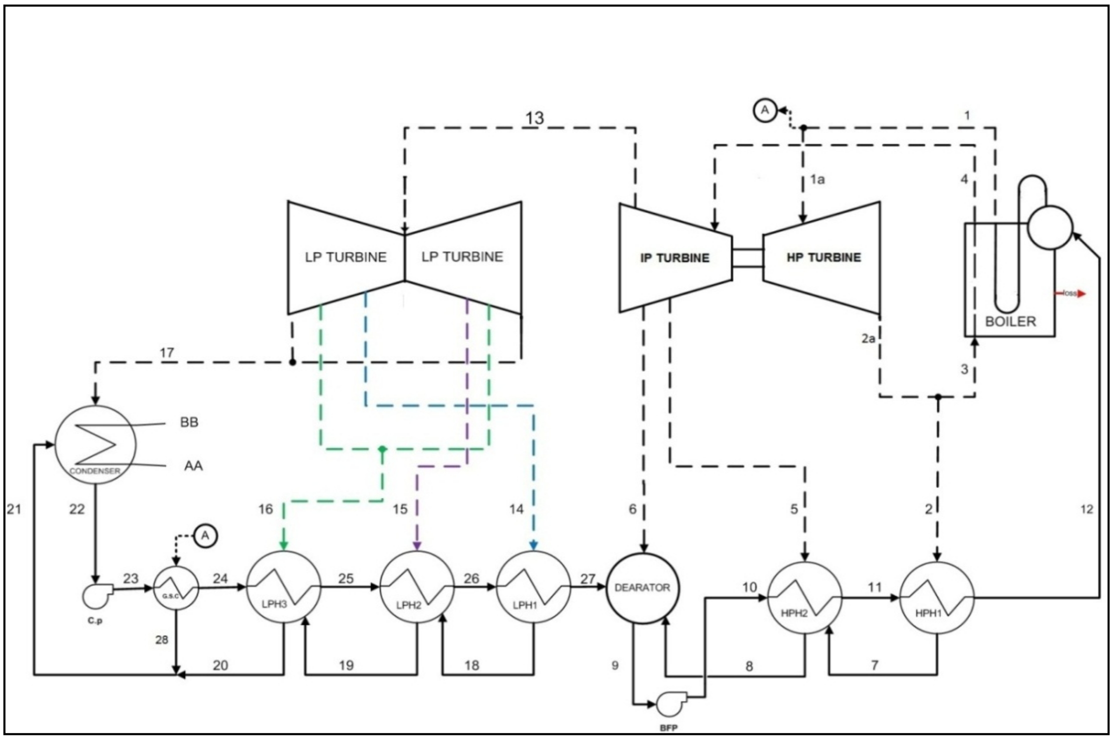


Fig. 2. Schematic diagram of one unit of the power plant

are indicated in Table 2. For all parts of the system, energy and exergy equations are developed and applied to evaluate the performance of the power plant.

3. Energy analysis

Each component of the steam power plant is considered as a control volume in steady state condition. By neglecting changes in potential and kinetic energy, mass and energy balance for each control volume can be written as below:

$$\sum_i \dot{m}_i = \sum_o \dot{m}_o \quad (1)$$

$$\sum \dot{Q}_k + \dot{m}_i\left(h_i + \frac{{c_i}^2}{2} + gz_i\right) = \dot{m}_o\left(h_o + \frac{{c_o}^2}{2} + gz_o\right) + \dot{W} \quad (2)$$

where $\dot{Q}_k$ is the heat transfer to system from the source at the temperature T_k, c is the fluid bulk velocity and z is the altitude of the stream above the sea level. Subscripts i and o stand for inlet and outlet conditions respectively. The energy balance of each component has been presented in Table 3.

Table 2. Operation conditions of power plant

Operating condition	Value
Steam temperature	811.15 K
Steam pressure	14 MPa
Steam flow rate	773.874 t/h
Mass flow rate of fuel	13.64 kg/s
Stack gas temperature	373.05 K
Feed water inlet temperature to boiler	516.25 K
Fuel input energy	631.31 MW
Heat rate (LHV)	9772 kJ/kWh
Net power output	232.579 MW
Combined power / motor efficiency	0.97

3.1 Boiler

Writing the first law of thermodynamics for the boiler, the energy equation for the boiler becomes:

$$\dot{Q}_k = \dot{m}_{12}(h_1 - h_{12}) + \dot{m}_3(h_4 - h_3) - E.L \quad (3)$$

where E. L represents the energy losses in the boiler. The first law efficiency of the boiler is given by Eq. 4:

$$\eta_{I,boiler} = \frac{Energy\ output}{Energy\ input} = \frac{\dot{m}_{12}(h_1 - h_{12}) + \dot{m}_3(h_4 - h_3)}{\dot{Q}_k} \quad (4)$$

3.2 High pressure turbine

The energy equation for the HP turbine is similarly derived from the balance of energy in turbine control volume, as given below:

$$-E.L_{HP} + \dot{m}_{1a}h_{1a} = \dot{m}_{2a}h_{2a} + \dot{W}_{HPT} \quad (5)$$

where E. L is the losses in the turbine, and is primarily due to the irreversibilities associated with fluid flow through the turbine. Heat transfer is usually a minor loss, and is considered of secondary importance. Rearranging the above equation for the loss results in:

$$E.L_{HP} = \dot{m}_{1a}h_{1a} - \dot{m}_{2a}h_{2a} - \dot{W}_{HPT} \quad (6)$$

3.3 Intermediate pressure turbine

The energy balance for the IP turbine is similar to that of the HP turbine, and is given by:

$$-E.L_{IP} + \dot{m}_4h_4 = \dot{m}_5h_5 + \dot{m}_6h_6 + \dot{m}_{13}h_{13} + \dot{W}_{IPT} \quad (7)$$

Thus, the equation can be written for the IP turbine losses as below:

$$E.L_{IP} = \dot{m}_4h_4 - (\dot{m}_5h_5 + \dot{m}_6h_6 + \dot{m}_{13}h_{13}) - \dot{W}_{IPT} \quad (8)$$

3.4 Low pressure turbine

Considering the inlet and outlet energy flows for the LP turbine, we have:

$$-E.L_{LP} + \dot{m}_{13}h_{13} = \dot{m}_{14}h_{14} + \dot{m}_{15}h_{15} + \dot{m}_{16}h_{16} + \dot{m}_{17}h_{17} + \dot{W}_{LPT} \quad (9)$$

Rearranging Eq. 9 in the following form results in:

$$E.L_{LP} = \dot{m}_{13}h_{13} - (\dot{m}_{14}h_{14} + \dot{m}_{15}h_{15} + \dot{m}_{16}h_{16} + \dot{m}_{17}h_{17}) - \dot{W}_{LPT} \quad (10)$$

3.5 Condenser

The process in the condenser is assumed to be steady state steady flow (SSSF) with no changes in kinetic and potential energies. The losses in the condenser are relatively small. Energy balance for the condenser can be written by the below equation:

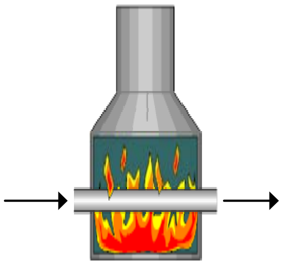
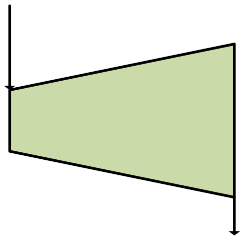
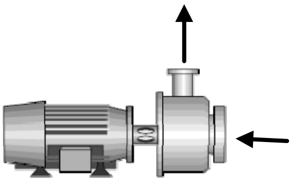
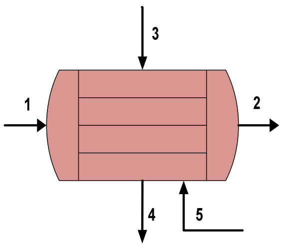
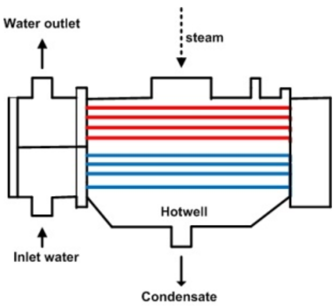
$$E.L_{con} = \dot{m}_{17}\,(h_{17} - h_{21}) - \dot{Q}k \quad (11)$$

3.6 Power cycle

All processes in the steam power cycle are considered SSSF processes. The states and processes are given on a T-s diagram in Fig.3. The thermal efficiency of the power cycle is defined as the ratio of the summation of output work to the input heat of the cycle, as follows:

$$\eta_{I,Cycle} = \frac{\sum \dot{w}_k}{\dot{Q}_f} \quad (12)$$

Table 3. Energy and exergy relations of each component of the steam power plant

Boiler		$\dot{Q}_k = \dot{m}_{main}(h_{out} - h_{in})_{main} + \dot{m}_{reheat}(h_{out} - h_{in})_{reheat} - E.L$ $\eta_{I,boiler} = \frac{\dot{m}_{main}(h_{out} - h_{in})_{main} + \dot{m}_{reheat}(h_{out} - h_{in})_{reheat}}{\dot{Q}_k}$ $\dot{I}_{boiler} = \dot{E}_{fuel} + \dot{E}_i - \dot{E}_o$ $\eta_{II,boiler} = \frac{\dot{E}_i - \dot{E}_o}{\dot{E}_{fuel}}$
Turbine		$-E.L + \dot{m}_{in}h_{in} = \sum \dot{m}_{out}h_{out} + \dot{W}_T$ $\dot{I}_{turbine} = \dot{E}_i - \dot{E}_o - \dot{W}_e$ $\eta_{II,turbine} = 1 - \frac{\dot{I}_{turbine}}{\dot{E}_i - \dot{E}_o}$
Pump		$-\dot{W}_p = m_{in}(h_{out} - h_{in}) - E.L$ $\dot{I}_{pump} = \dot{E}_i - \dot{E}_o + \dot{W}_{pump}$ $\eta_{II,pump} = 1 - \frac{\dot{I}_{pump}}{\dot{E}_i}$
Heater		$0 = \sum m_{out}h_{out} - \sum m_{in}h_{in} - E.L$ $\dot{I}_{heater} = \dot{E}_i - \dot{E}_o$ $\eta_{II,heater} = 1 - \frac{\dot{I}_{heater}}{\dot{E}_i}$
condenser		$E.L = \dot{m}_{steam}(h_{steam} - h_{out}) - \dot{Q}k$ $\dot{I}_{condenser} = \sum_{i,c} \dot{E} - \sum_{o,c} \dot{E}$ $\eta_{II,condenser} = 1 - \frac{\dot{I}_{condenser}}{\sum_{in,cond} \dot{E}}$

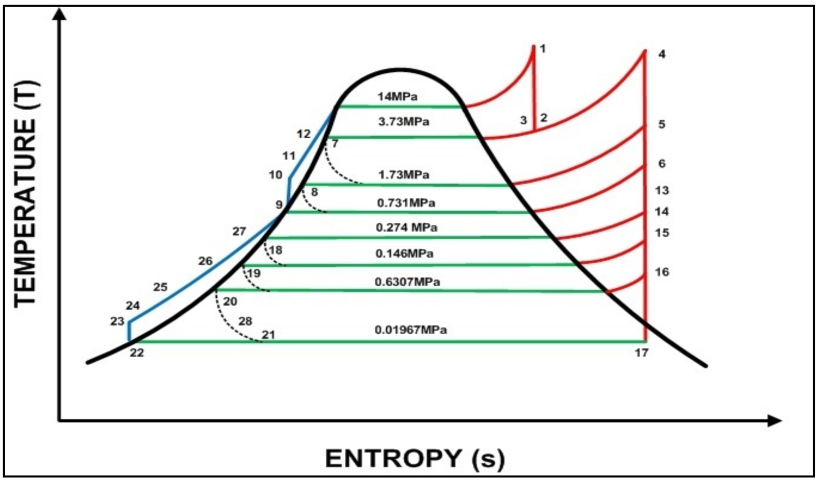


Fig. 3. Theoretical T-s diagram of the steam power plant

4. Exergy analysis

Analysis of exergy can be considered as a guideline for more effective use of energy in different thermal systems, such as steam power plants. In general terms, exergy is not conserved like energy in the thermal system but is destroyed. Exergy analysis, which is based on the second law of thermodynamics, states that all macroscopic processes are irreversible. This irreversible process includes a non-recoverable loss of energy. Every such exergy loss can be calculated by the product of the ambient temperature and the entropy generated. The sum of entropy generation is always positive [13]. Exergy can be divided into four components: physical, exergy analysis of a thermal power plant enables us to identify the source of irreversibilities, reduce the losses and maximize resources.

4.1 Dead state

Consider a system which is in a state of pressure and temperature equilibrium, and also in chemical equilibrium with the surroundings, meaning that there is no chemical reaction or mass transfer between them. The system has zero velocity and minimum potential energy. This state of the system is known as the dead state. This system, despite having considerable internal energy, is unable to produce work; in other words, its exergy is zero.

4.2 Exergy relations

The exergy law for a steady state process of an open system is given by:

$$\sum_i \dot{m}_i e_i + \sum_k \left(1 - \frac{T}{T_k}\right) \dot{Q}_k = \sum_o \dot{m}_o e_o + \dot{w} + \dot{I} \tag{13}$$

where $\dot{m}_i$ and $\dot{m}_o$ are the outlet and inlet mass flow rates of the system, respectively. In addition, $\dot{w}$ and $\dot{I}$ are work rate and irreversibility of the system, respectively. In the above equation, e is the specific exergy, which is defined as follows [14]:

$$e = e_{ph} + e_{ch} \tag{14}$$

where e_{ph} and e_{ch} are specific physical and chemical exergy, respectively. The specific physical exergy is defined as follows [14]:

$$e_{ph} = h - h_o - T_o(s - s_o) \tag{15}$$

where h, s and T are enthalpy, entropy and absolute temperature, respectively, and the subscript o refers to the dead state condition.

It can be noticed that chemical exergy is significant in fuel use systems [15]. The mixture of chemical exergy is defined as follows:

$$e_{mix}{}^{ch} = \left[\sum_{i=1}^{n} X_i e^{ch_i} + RT_o \sum_{i=1}^{n} X_i \ln X_i + G^E\right] \tag{16}$$

The last term, G^E, which is excess free Gibbs energy, is negligible at low pressure gas mixture [15]. The above equation cannot be used to calculate the exergy of fuel. Then, the fuel specific exergy is defined to calculate chemical exergy of the fuel as follows:

$$e_{fuel} = \gamma_f \times LHV$$

where γ_f =1.06 is the exergy factor based on the lower heating value [11].

Furthermore, the total rate of fuel exergy is calculated as follows:

$$\dot{E}_{fuel} = \dot{m}_{fuel} \times e_{fuel} \quad (17)$$

The second law efficiency is defined as written below:

$$\eta_{II} = \frac{Actual\ work}{reversibble\ work} \quad (18)$$

The relations of exergy loss and efficiency for each component of the cycle have been formulated and are listed In Table 3.

5. Results and discussion

In this study, a typical thermal steam power plant is analysed at the reference condition (T_0=298.15 K, P_0= 101.3 kPa) near Tehran, Iran. The energy balance of the steam power plant and its percentage ratio were calculated, and are indicated in Table 4. The results show that 50 % of cycle energy losses occur in the condenser. The boiler has the next highest heat loss among the cycle's components. Due to the low quality, energy loss is thermodynamically insignificant, even though it may have a large quantity. The exergy analysis of each state shown in Fig. 2 was calculated using the equations given in the previous section, and is summarized in Table 5. In Table 6, the exergy destruction and exergy efficiency of the steam power plant are presented. In this study, each turbine and heater has been analysed separately. The results show that high exergy destruction and irreversibilities in the cycle occur in the boiler. This can be attributed to the fact that in the boiler heat transfer occurs with high temperature difference between the burners and the working fluid. This alone would account for 84% of the total losses in the power plant. The exergy efficiency of each component is summarized in Table 6 according to the equations presented in Table 3. In addition, the calculated power plant exergy efficiency is 34.75%. The effect of environment temperature on the total exergy destruction of power plant components is illustrated in Figs 4 and 5. Figures 4 and 5 indicate that destruction exergy of each component increases with increasing environment temperature. The effects of environment temperature on the exergy efficiency of power plant components are depicted in Figs. 6 and 7. These figures show that the exergy efficiency of all components except the condenser decreases with increasing environment temperature. As is clear in Fig. 6, the condenser has different trends (decreasing and increasing trends) for exergy efficiency. The exergy efficiency of the boiler varies from 49% to 45%, and causes a slight reduction in the efficiency of the turbines. Condenser efficiency decreases from 40% at an environment temperature of 283 K to 25% at 293 K, thereafter rising to 39% at 313K. Fig. 8 shows that the cycle and boiler efficiencies increase with increasing environment temperature. The effect of condenser pressure on cycle output power and efficiency is presented in Figs. 9 and 10. By increasing the pressure, the average temperature of the working fluid is increased in the heat dissipation process, which causes efficiency and output power to reduce in the power plant. In Fig. 11, the effect of the boiler's load on efficiency and output power is shown. It is obvious that the power and efficiency increase with an increase in boiler load. Decreasing the boiler load decreases the capacity of steam production, and may cause a decrease in the network of the cycle and of efficiency as well. The effect of boiler outlet steam temperature has been investigated in Fig.12. This figure reveals that increasing steam temperature increases the average

Table 4. The energy balance of power plant components and percentage ratio to fuel energy input

component	*Heat loss (MW)*	*Percent ratio*
Boiler	119.851	16.69
Turbine	4.393	0.610
Condenser	354.759	49.41
Piping	1.542	0.214
Net power	232.580	32.39
Heaters and pump	4.933	0.686
Total	718.05	100

temperature of the heat absorption process in the boiler, while the average temperature of the heat rejection process in the condenser does not change. Thus, in a temperature range, the efficiency increases. In other words, from Fig. 3, it is obvious that increasing the temperature can increase the work due to the increased heat transfer area in the boiler. Therefore, the cycle efficiency increases due to the new ratio of area to work and heat transfer. Figure 13 represents the effect of steam pressure on net power output and efficiency of the power plant. This figure indicates that efficiency increases with increase in steam pressure. The mean temperature at which heat is supplied increases with increase in pressure. It is notable that the pressure can be increased only in a certain range, because out of this range the cycle efficiency may decrease.

Table 5. The exergy analysis of power plant at (T_0=298.15 K, P_0=101.3kPa)

point	$T\ (K)$	$P\ (MPa)$	$h(kJ/kg)$	$s(kJ/kg\ K)$	$\dot{m}(t/h)$	$e(kJ/kg)$	$\dot{E}(MW)$
1	811.15	14	3427.094	6.524	772.097	1486.435	318.797
1a	811.15	14	3427.094	6.524	772.097	1486.435	318.797
2a	622.25	3.73	3099.07	6.623	772.097	1128.894	242.115
2	622.25	3.73	3099.07	6.623	62.838	1128.894	19.704
3	622.25	3.73	3099.07	6.623	709.259	1128.894	222.410
4	811.15	3.43	3536.942	7.276	709.259	1372.074	270.321
5	707.35	1.73	3327.082	7.308	42.862	1152.673	13.723
6	591.45	0.731	3097.383	7.334	42.524	915.073	10.809
7	482.35	3.54	894.67	2.414	62.838	179.317	3.129
8	446.45	1.64	733.0368	2.091	105.7	114.076	3.349
9	437.75	0.709	695.516	1.988	773.888	107.205	23.045
10	440.85	15.1	717.213	2.001	773.888	124.966	26.863
11	476.75	15.066	874.113	2.343	773.888	180.018	38.698
12	516.25	14.98	1053.699	2.705	773.888	251.674	54.102
13	603.65	0.731	3122.92	7.387	623.873	924.957	160.293
14	483.25	0.274	2885.705	7.399	21.412	684.164	4.069
15	422.95	0.146	2772.37	7.431	24.486	561.288	3.817
16	362.57	0.06307	2659.98	7.527	22.058	420.276	2.575
17	332.85	0.01967	2506.369	7.606	555.921	243.111	37.541
18	384.45	0.26	466.898	1.432	21.412	44.418	0.2641
19	361.36	0.139	369.467	1.171	45.898	24.5958	0.3135
20	339.96	0.05992	279.632	0.915	67.956	11.0962	0.2094
21	340.783	0.05992	283.0749	0.925	69.729	11.5486	0.2236
22	332.98	0.0496	250.403	0.828	625.66	7.7675	1.3499
23	333.2	1.338	252.403	0.830	625.66	9.1414	1.5887
24	334.5	1.336	257.839	0.847	625.66	9.74737	1.6940
25	355.76	1.177	346.761	1.105	625.66	21.6870	3.7690
26	378.85	1.034	443.8	1.370	625.66	39.8057	6.9180
27	398.45	0.9199	526.737	1.583	625.66	59.2367	10.2950
28	366.83	0.0803	415.037	1.296	1.773	33.1058	0.0163
A	673.95	0.0803	3008.661	5.955	1.773	1237.4101	0.6094
AA	295.15	1.364	93.496	0.324	30505	1.3666	11.5803
BB	305.15	1.364	135.25	0.463	30505	1.5287	12.9536

Table 6. The exergy destruction and exergy efficiency of the power plant (T_0=298.15 K, P_0=101.3kPa)

component	Exergy destruction (MW)	Eexery percent destruction	Percent exergy efficiency
Boiler	358.981	84.3853	46.60
HP Turbine	8.107	1.9057	89.42
IP Turbine	6.336	1.4895	92.58
LP Turbine	8.611	2.0242	92.33
Condenser	35.042	8.2373	21.19
Condensate pump	0.112	0.0264	62.17
BFP	0.397	0.0934	88.25
HPH1	1.171	0.2752	97.99
HPH2	1.669	0.3925	96.18
Dearetor	1.407	0.3308	94.24
LPH1	0.428	0.1006	96.10
LPH2	0.619	0.1455	92.11
LPH3	0.604	0.1420	86.81
G.S.C	1.917	0.0045	12.76
power cycle	433.009	100	34.75

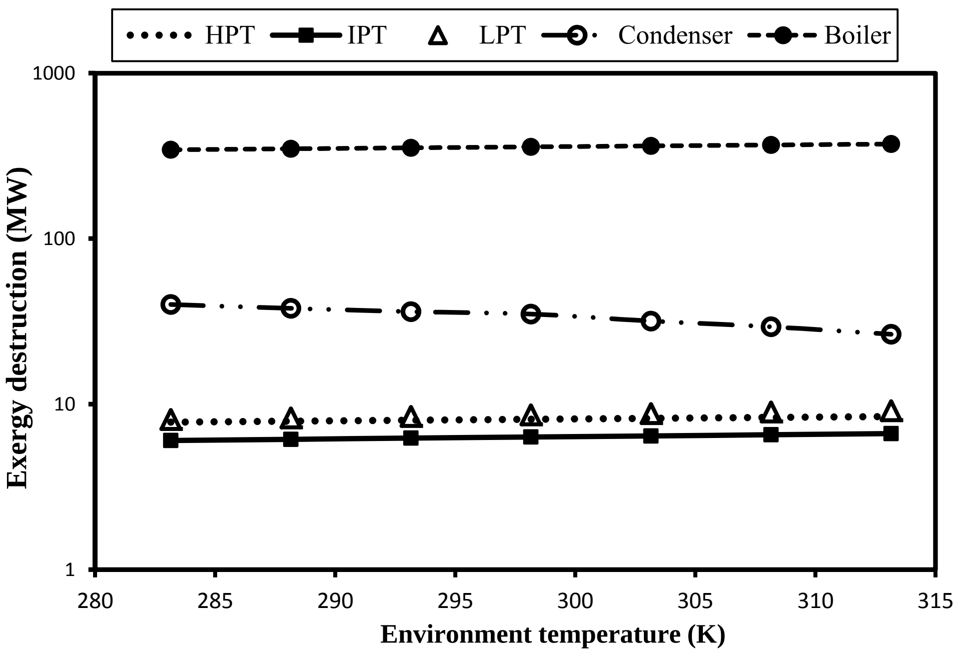


Fig. 4. Effect of environment temperature on total exergy destruction of components

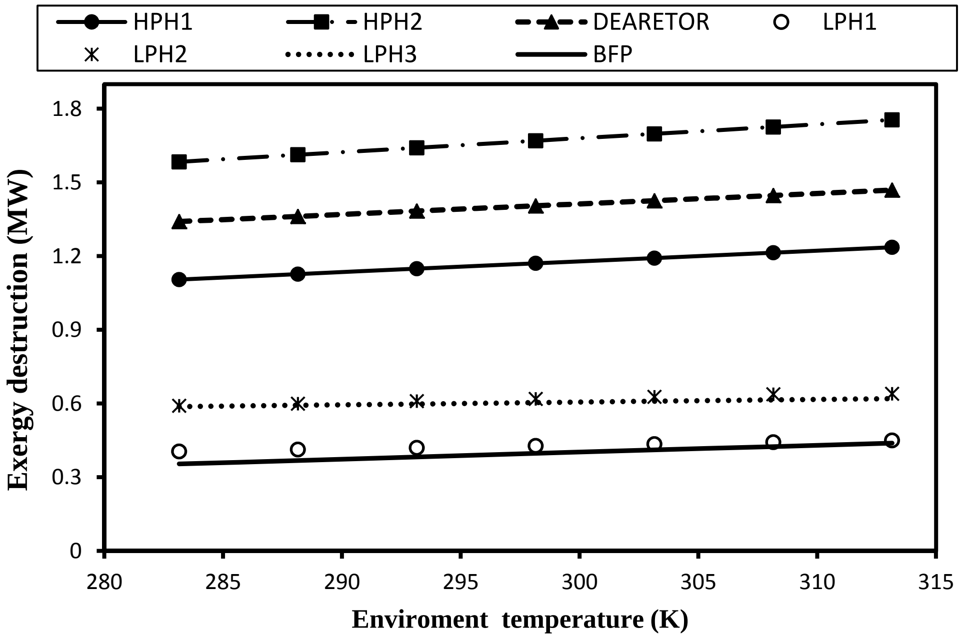


Fig. 5. Effect of environment temperature on total exergy destruction of heater and BFP

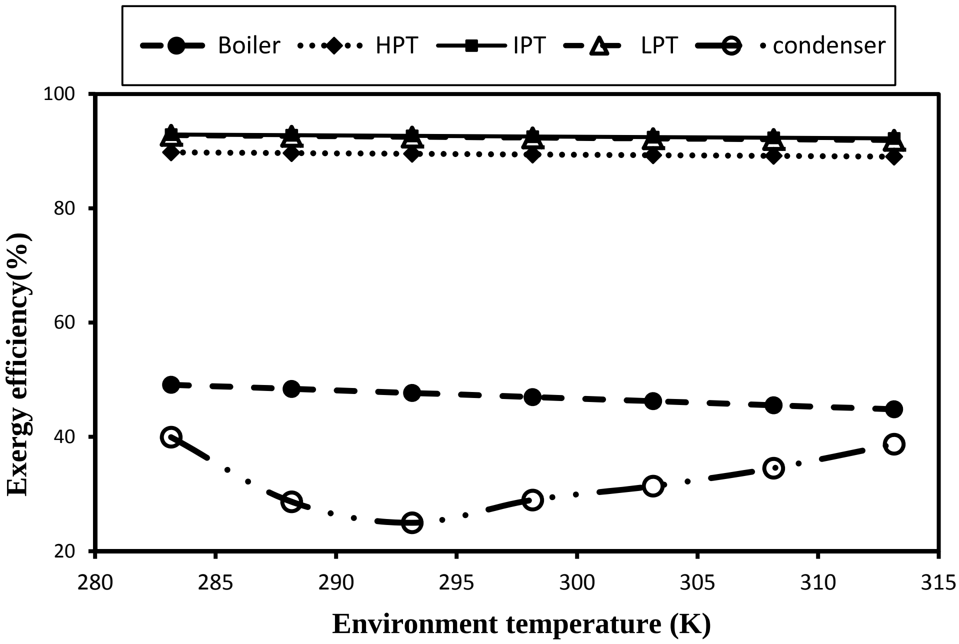


Fig. 6. Effect of environment temperature on exergy efficiency of components

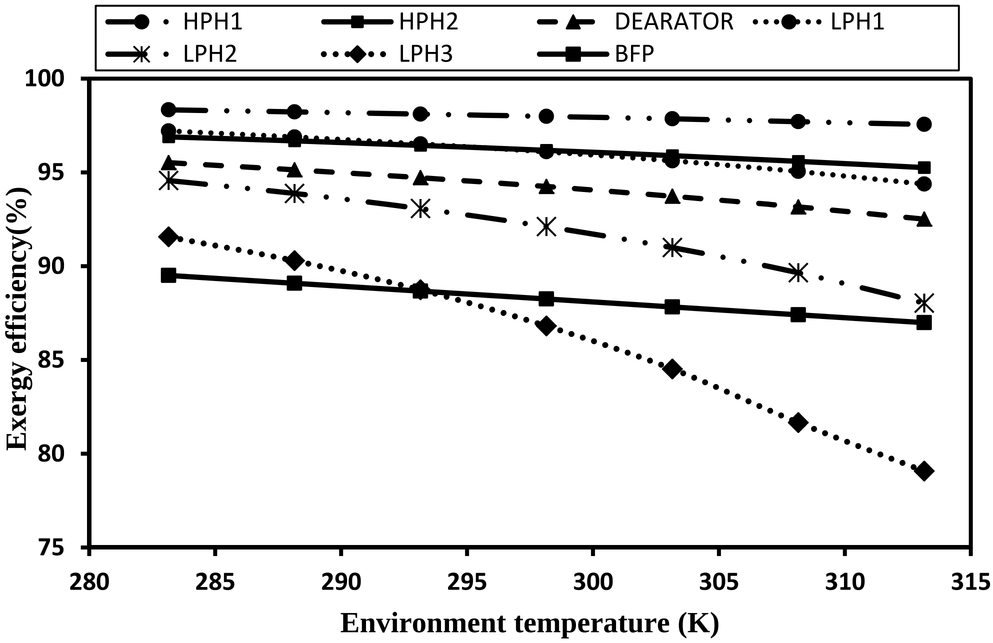


Fig. 7. Effect of environment temperature on exergy efficiency of heater and BFP

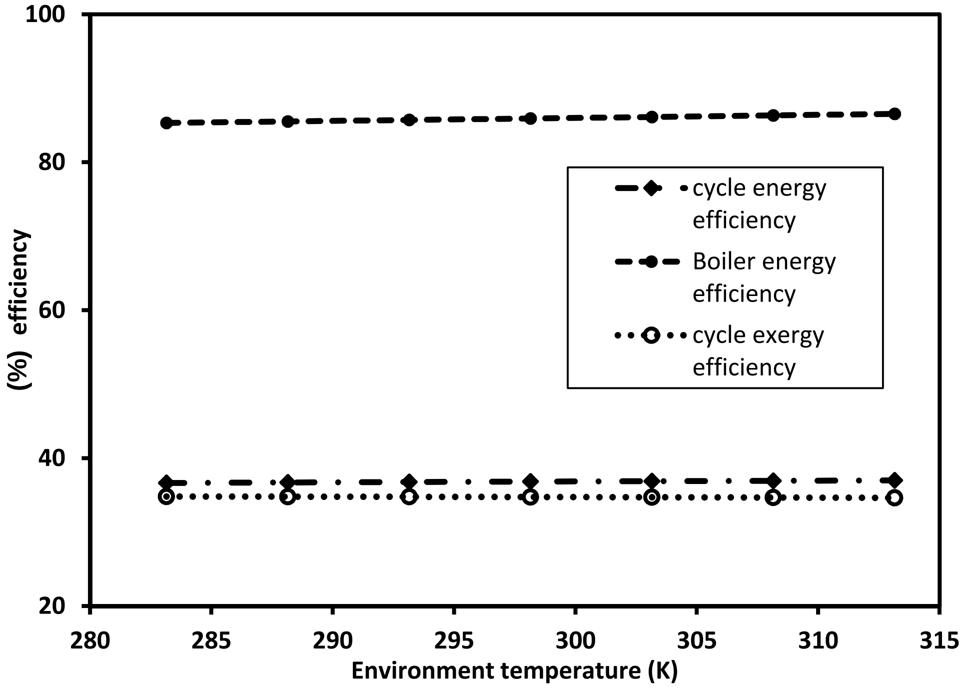


Fig. 8. Effect of environment temperature on energy and exergy efficiency of cycle

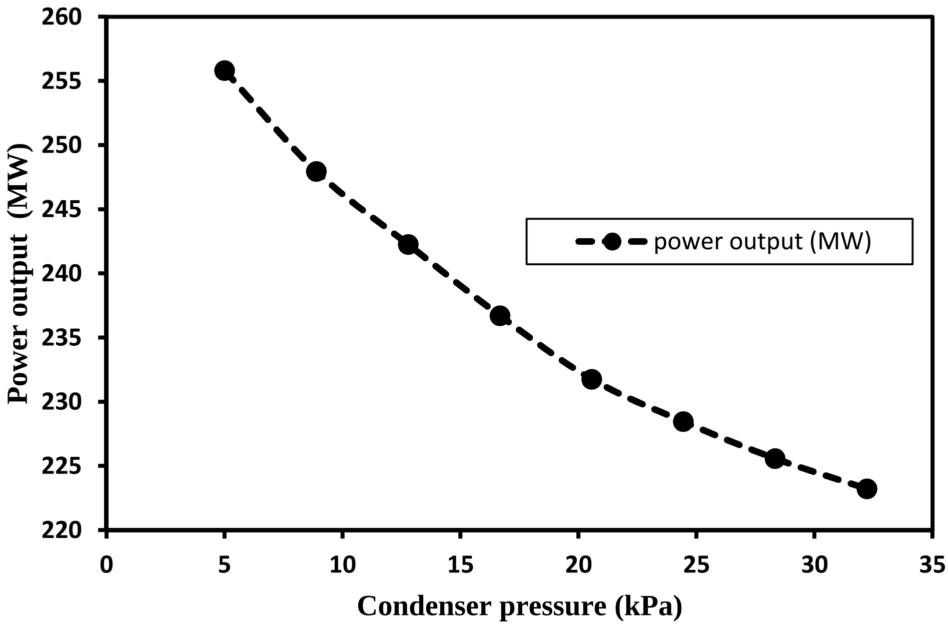


Fig. 9. Effect of condenser pressure on power output

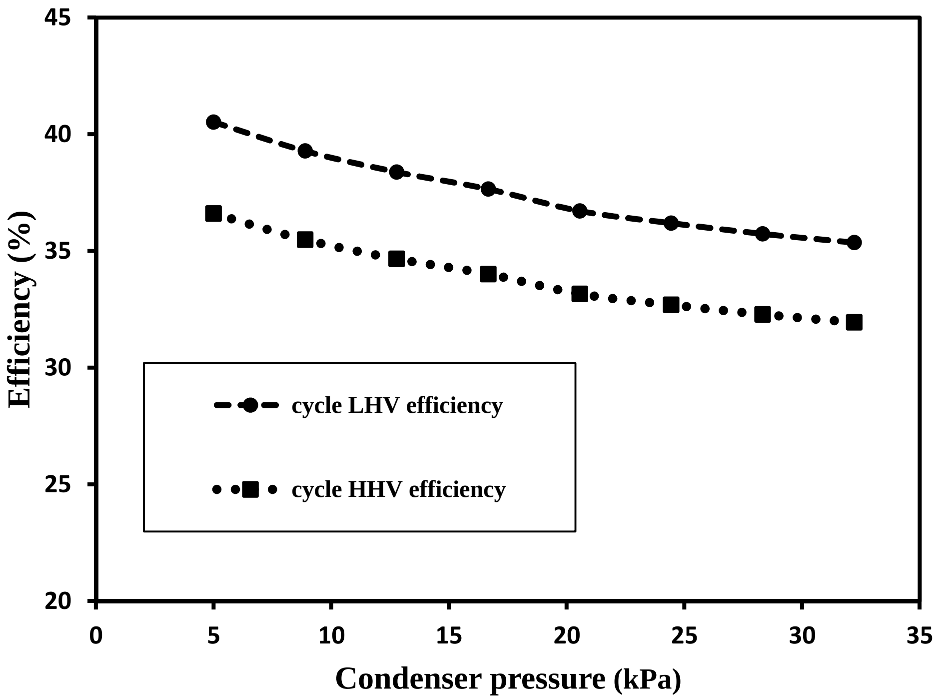


Fig. 10. Effect of condenser pressure on efficiency of power plant

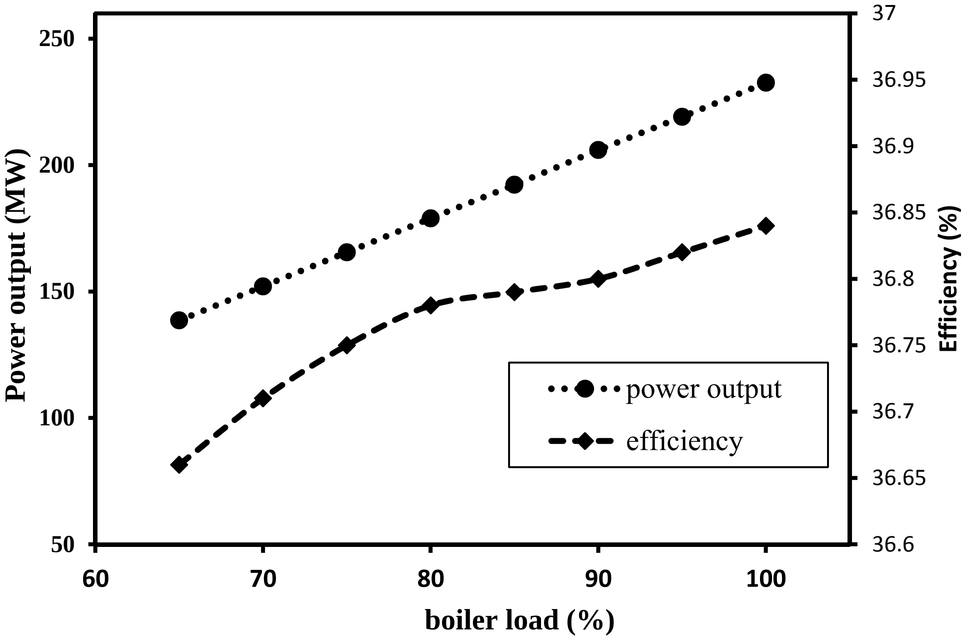


Fig. 11. Effect of boiler load on power output and energy efficiency of power plant

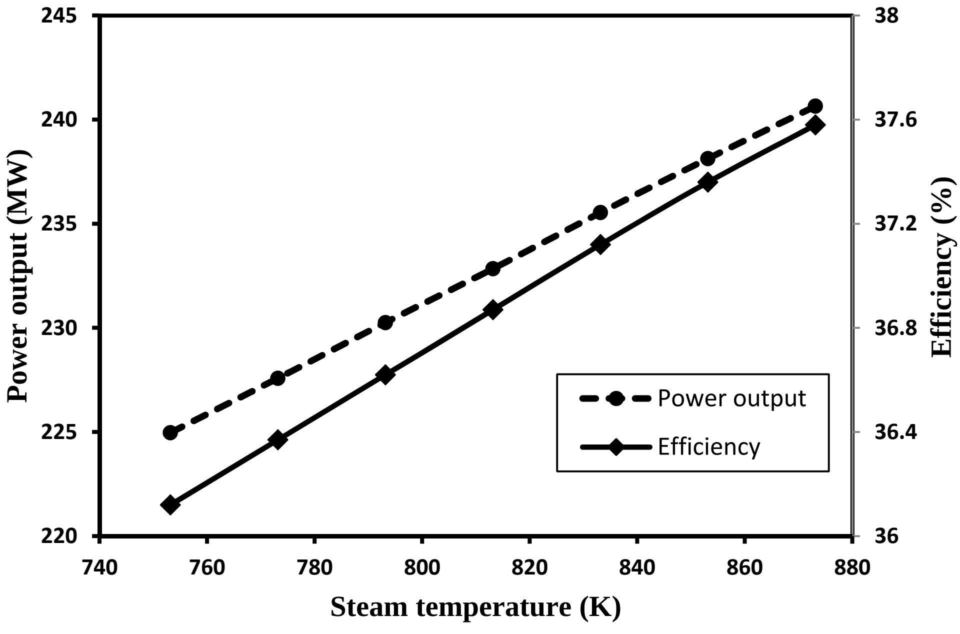


Fig. 12. Effect of steam temperature on net power output and efficiency of power plant

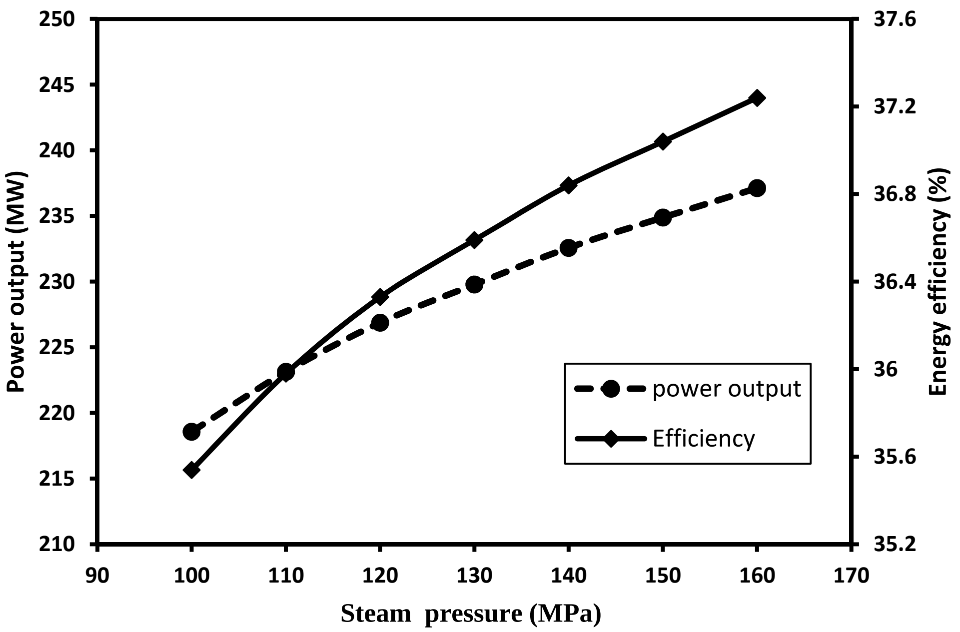


Fig. 13. Effect of steam pressure on net power output and efficiency of power plant

6. Conclusions

In this paper, the first and second law analysis of a typical steam power plant in Iran has been performed. The effect of reference environment temperature was considered for the performance of the thermal system. Moreover, the effect of various parameters, such as boiler part load, condenser pressure, and boiler outlet temperature and pressure, on cycle efficiency were evaluated. The results showed that the calculated energy efficiency of the entire cycle is 36.84%, and the largest heat loss occurs in the condenser. The boiler has maximum exergy destruction in the cycle, and the exergy efficiency of the power plant is 34.75% at design condition. Finally, it is recommended that boiler performance be considered to reduce waste and improve cycle efficiency. A survey of energy losses in power plant boilers shows that loss resulting from the lack of an air-fuel ratio is one of the important issues that should be considered to improve boiler performance.

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