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A Parametric Study on Exergy and Exergoeconomic Analysis of a Diesel Engine based Combined Heat and Power System

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ABSTRACT

This paper presents exergy and exergoeconomic analysis and parametric study of a Diesel engine based Combined Heat and Power (CHP) system that produces 277 and 282 kW of electricity and heat, respectively. For this purpose, the CHP system is first thermodynamically analyzed through energy and exergy. Then, cost balances and auxiliary equations are applied to subsystems. The exergoeconomic analysis is based on specific exergy costing (SPECO) method. Finally, a parametric study is used to show the effect of ambient temperature on important energy, exergy and exergoeconomic parameters of the CHP system. Also, effects of change in compressor pressure ratio and turbine inlet temperature on these parameters are investigated in different environment temperatures. The results show that increasing ambient temperature increases the work output, heating power and exergoeconomic factor and decreases the exergetic efficiency and cost of exergy destruction. Increasing compressor pressure ratio leads to increase in the work output, heating power, exergetic efficiency, and exergy destruction cost and exergoeconomic factor of the CHP system in all environment temperatures. Also increasing turbine inlet temperature decreases the work output, exergetic efficiency and exergoeconomic factor, while increases the heating power as well as exergy destruction cost in all environment temperatures.

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NOMENCLATURE

A	heat transfer area (m^2)	$y^*_{D,k}$	component exergy destruction over total exergy destruction
c	cost per exergy unit ($/kJ)	Z	capital cost of a component ($)
$\dot{C}$	cost rate ($/s)	$\dot{Z}$	capital cost rate ($/s)
e	specific exergy (kJ/kg)	**Subscripts**	
$\dot{E}$	exergy rate (kW)	0	dead (environmental) state
f	exergoeconomic factor	a	air
h	specific enthalpy (kJ/kg)	ch	chemical exergy
$\dot{m}$	mass flow rate (kg/s)	D	destruction
P	pressure (bar)	e	outlet
Q	rate of heat transfer (kW)	f	fuel
R	gas constant (kJ/kg K)	i	inlet
s	specific entropy (kJ/kg K)	j	jth stream
T	temperature (K)	k	kth component
$\dot{W}$	power (kW)	L	loss
X	mole fraction	ph	physical exergy
$y_{D,k}$	component exergy destruction over total exergy input		

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1. INTRODUCTION

Recently, worldwide concern about energy crisis and climate changes has provided continuous opportunities to extend energy efficient technologies. On the other hand, economic constraints and environmental considerations make it necessary to improve the performance of energy conversion systems [1]. Combined Heat and Power (CHP) systems have emerged as an effective procedure of energy conversion because of involving both production of electricity and useful thermal energy in one operation. These systems utilize the waste heat produced during electricity generation and allow more efficient fuel consumption. Therefore, these systems are more economical than production of electricity and useful heat in separate systems [2]. Because CHP systems produce both useful thermal energy and electricity, the efficiency of energy production can be increased from current value of 35% to 55% in the conventional power plants to over 80% in the combined heat and power systems [3].

Internal combustion engine based CHP systems are broadly used because of their cost effectiveness, mobility, and high efficiency [4]. Diesel engines are among the most efficient power generation options. Efficiency levels increase with engine size and vary from about 30% for small high speed engines up to 42–48% for the large slow speed engines [5].

The second law of thermodynamics combined with economics provides a very powerful tool for the systematic study of energy systems. This combination forms the basis of the relatively new field of thermoeconomics or exergoeconomics. Recently, exergy and exergoeconomic analyses have been used for analysis, design, performance improvement and optimization of thermal systems, including combined heat and power systems. It is well known that exergy can be used as a powerful tool to specify the location, type and true magnitude of exergy destruction (or loss). Therefore, it can play an important role in expanding strategies and providing guidelines for more effective use of energy in the existing power plants [6]. Exergoeconomics combines exergy analysis with conventional cost analysis in order to evaluate and optimize the performance of energy systems. The main contribution of exergy analysis to the assessment of energy systems comes through an exergoeconomic evaluation, which considers not only the inefficiencies, but also the costs associated with these inefficiencies and the investment costs required to reduce them [7].

In the literature, there exist a number of papers concerning exergetic and exergoeconomic analysis, and also optimization of CHP systems. One of the most interesting works was a problem called CGAM [8]. The CGAM problem refers to a gas turbine CHP plant, which produces 30 MW of electricity and delivers 14 kg/s of saturated steam at 20 bars. Valero et al. [9] studied application of the exergetic cost theory to the CGAM problem and presented an optimization strategy for complex thermal systems. Cardona and Piacentino [10] presented a new method to exergoeconomic assessment and design of variable demand energy systems. The proposed approach was applied to a trigeneration plant serving a 300-bed hospital placed in a Mediterranean area and results were compared with the optimal solution previously obtained by means of demand cumulative curves and plant running simulations. Colpan and Yesin [11] analyzed the energetic, exergetic and thermoeconomic aspects of the Bilkent combined cycle CHP plant. The electrical power unit exergy cost was determined to be 18.89 US$GW-1 in their work. Kanoglu et al. [12] carried out the exergoeconomic analysis of a geothermal assisted high temperature steam electrolysis system. They also studied effect of the second-law efficiency on exergetic cost parameters.

Power plants and CHP systems based on internal combustion engines are not a new idea, but there have not been many studies on Diesel engine based ones in literature. Diesel engine based CHP and power plants are the best power production option for local applications in some Asian and South European countries [5]. In the present work, the exergetic and exergoeconomic analysis are performed on the Diesel engine based CHP system considered by Aceves et al. [13] for combined power and heating applications. The system is thermodynamically analyzed through energy and exergy. Then, cost balances and auxiliary equations are applied to subsystems. Moreover, a parametric study is used to show the effect of ambient temperature on important energy, exergy and exergoeconomic parameters and effects of change in compressor pressure ratio and turbine inlet temperature on these parameters in Tehran, the capital city of Iranfor four environmental temperatures, namely: spring temperature (21˚C), summer temperature (29˚C), autumn temperature (14˚C) and winter temperature (6˚C).

2. SYSTEM DESCRIPTION AND ASSUMPTIONS MADE

A schematic diagram of the system is shown in Figure 1. The main equipment consists of compressor, Diesel engine, turbine and heat exchanger. The turbine produced the needed work for the compressor using the exhaust gases. The cooling water loop goes from the engine to a heat exchanger being heated by exhaust gases. Process heat generated in the CHP system is recovered from this hot water and then the water is circulated into the engine [13]. The main data of the system are summarized in Table 1. The steady state equations governing the model are constructed as follows:

TABLE 1. The main data of the CHP system

Fuel used in the engine	Diesel fuel
Engine compression ratio	15:1
Engine equivalence ratio	0.7
Fuel heating power into the engine (kW)	600
Compressor and turbine pressure ratio	3
Heat exchanger effectiveness	0.8
Cooling water inlet temperature (°C)	80
Cooling water inlet pressure (bar)	2
Cooling water mass flow rate (kg/s)	1.75

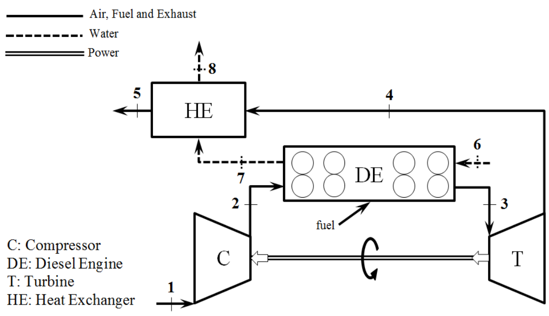

Figure 1. A schematic diagram of the Diesel engine based CHP system

The following assumptions are made in this study:

- The CHP system operates in a steady state condition.
- The air and exhaust gases are considered to be ideal gases.
- For analysis of the Diesel engine, the air standard dual cycle formulation is used.
- The potential and kinetic energy changes are insignificant.
- The dead (environmental) state conditions are P_0=1 bar and T_0=27 °C.
- All components are considered adiabatic, except the Diesel engine.

3. EXERGOECONOMICANALYSIS

Exergoeconomics is the branch of engineering that properly combines the exergy based thermodynamic evaluations with economic principles, in order to present information useful to the design and operation of a cost effective system, and cannot be obtained through thermodynamic analysis and economic analysis [14].

There are different exergoeconomic approaches in the literature. We used specific exergy costing method (SPECO) in this study. This method is based on specific exergies and costs per exergy unit, exergetic efficiencies, and the auxiliary costing equations for components of thermal systems [15].

3. 1. Application of SPECO Method to the System

SPECO method consists of three main steps: (i) quantifying energy and exergy streams, (ii) fuel and product definition for the components of system and (iii) developing cost equations [15]. In the following sections, these steps are applied to the Diesel engine based CHP system.

3. 1. 1. Identification and Analysis of Energy and Exergy Streams Mass, energy and exergy balances for any steady state system can be written as [16]:

$$\sum \dot{m}_i = \sum \dot{m}_e \quad (1)$$

$$\dot{Q} + \sum \dot{m}_i h_i = \dot{W} + \sum \dot{m}_e h_e \quad (2)$$

$$\dot{E}_Q + \sum \dot{m}_i e_i = \dot{E}_W + \sum \dot{m}_e e_e + \dot{E}_D \quad (3)$$

where $\dot{E}_D$ is the exergy destruction. Other terms in this equation are:

$$\dot{E}_Q = \sum (1 - \frac{T_0}{T_i}) \dot{Q}_i \quad (4)$$

$$\dot{E}_W = \sum \dot{W} \quad (5)$$

In the absence of nuclear, magnetic, electrical, and surface tension effects, the total exergy of a system can be divided into four different components. The two important ones are the physical exergy and chemical exergy [17]. In this study, the two other components which are kinetic exergy and potential exergy are considered negligible due to negligible changes of the elevation and speed. Physical exergy is due to temperature and pressure differences with respect to the reference point, and chemical exergy is due to reactions [18]. Thus, the total exergy rate becomes:

$$\dot{E} = \dot{E}_{ph} + \dot{E}_{ch} \quad (6)$$

$$\dot{E} = \dot{m} e \quad (7)$$

The physical exergy can be expressed as [19]:

$$e_{ph} = (h - h_0) - T_0 (s - s_0) \quad (8)$$

The chemical exergy of the mixture may be defined as [20]:

$$e_{ch}^{mix} = \left[\sum_{i=1}^{n} X_i e_{ch_i} + RT_0 \sum_{i=1}^{n} X_i Ln(X_i) \right] \quad (9)$$

The chemical exergies of liquid fuels (LF) as C_aH_b can be determined from [21]:

$$\frac{e_{ch,LF}}{LHV_{LF}} = \gamma_{LF} \cong 1.04224 + 0.011925 \frac{b}{a} - \frac{0.042}{a} \quad (10)$$

where γ denotes the fuel exergy grade function.

The energy and exergy efficiencies are generally defined as [12]:

$$\eta = (\frac{energy\ in\ products}{total\ energy\ input}) \quad (11)$$

$$\varepsilon = (\frac{exergy\ in\ products}{total\ exergy\ input}) \quad (12)$$

Energy efficiency for the entire Diesel engine based CHP system may be defined as:

$$\eta_{CHP} = \frac{\dot{W}_{net} + \dot{Q}_{net}}{\dot{Q}_{in}} = \frac{\dot{W}_{net} + \dot{m}_w(h_e - h_i)}{\dot{m}_f LHV} \quad (13)$$

where $\dot{Q}_{net}$ is the rate of the heat generated in the CHP plant. Also, exergy efficiency for the system may be expressed as:

$$\varepsilon_{CHP} = \frac{\dot{W}_{net} + \dot{E}_{Q,net}}{\dot{E}_{in}} \quad (14)$$

Similarly, $\dot{E}$Qnet is the exergy rate of the heat generated in the CHP plant. The exergy destruction in steady state operation of a component may be calculated from Equation (3). The rate of exergy destruction in a system for the *k*th component can be compared to the exergy rate of the fuel supplied to the overall system as [22]:

$$y_{D,k} = \frac{\dot{E}_{D,k}}{\dot{E}_f} \quad (15)$$

Also, the component exergy destruction rate can be compared to the total exergy destruction rate within the system as:

$$y^*_{D,k} = \frac{\dot{E}_{D,k}}{\dot{E}_{D,total}} \quad (16)$$

Table 2 shows the thermodynamic data of the CHP plant according to the nomenclature shown in Figure 1. These data are obtained from developed EES (Engineering Equation Solver) thermodynamic model for the system [23].

3. 1. 2. Definition of Fuel (F) and Product (P) for the Components of the CHP System In exergy costing method, fuel and product terms must be defined for components. The fuel represents the resources required to generate the product and the product represents the desirable result produced by the system.

TABLE 3. Definitions of the exergies of fuels $\dot{E}_F$ and products $\dot{E}_P$ for the components of the system

Component	$\dot{E}_F$	$\dot{E}_P$
Compressor	$\dot{W}_C$	$\dot{E}_2 - \dot{E}_1$
Diesel engine	$\dot{E}_f + \dot{E}_2 + \dot{E}_6$	$\dot{E}_3 + \dot{E}_7 +$ DE
Turbine	$\dot{E}_3 - \dot{E}_4$	$\dot{W}_T$
Heat Exchanger	$\dot{E}_4 - \dot{E}_5$	$\dot{E}_8 - \dot{E}_7$

Both the fuel and the product are represented in terms of exergy [24]. Definitions of the exergies of fuels $\dot{E}_F$ and products $\dot{E}_P$ for the components of the system are given in Table 3.

3. 1. 3. Cost-Balance Equations Exergy costing involves cost balance for each component of the system. A cost balance equation applied to the kth component expresses that the sum of cost rates associated with all exiting exergy streams equals the sum of cost rates of all entering exergy streams plus the cost rate because of capital investment and operating and maintenance costs ($\dot{Z}_k$) [24].Equations for calculating capital investment of the components are as follow: Diesel engine [25]

$$Z_{DE} = -69.355 \times \mathrm{Ln}(\dot{W}_{DE}) + 863.55 \quad [\$ / kW] \quad (17)$$

Heat exchanger [26]

$$Z_{HE} = 130(\frac{A_{HE}}{0.093})^{0.78} [\$] \quad (18)$$

Turbocharger unit

The purchase cost of the turbocharger unit is assumed to be the sum of the purchase cost for the compressor and turbine of this unit. These costs are as follow [27]:

Compressor:

$$Z_C = (\frac{75\dot{m}_a}{0.9 - \eta_C})(\frac{P_e}{P_i})Ln(\frac{P_e}{P_i}) \quad [\$] \quad (19)$$

Turbine:

$$Z_T = (\frac{1536\dot{m}_{a+f}}{0.92 - \eta_T})Ln(\frac{P_i}{P_e})(1 + \exp(0.036T_i - 54.4))[\$] \quad (20)$$

TABLE 2. Thermodynamic properties of fluids of the CHP system

State no.	Fluid	T (°C)	P (bar)	h (kJ/kg)	s (kJ/kg K)	$\dot{m}$ (kg/s)	e_{ph}(kJ/kg)	e_{ch} (kJ/kg)	$\dot{E}$ (kW)
1	Air	27	1	300.6	5.706	0.2935	0	0	0
2	Air	156.5	3	431.3	5.753	0.2935	116.7	0	34.26
3	Exhaust	635.5	3	942.7	6.547	0.3075	389.7	51.15	135.6
4	Exhaust	443.1	1	730.8	6.601	0.3075	161.7	51.15	65.46
5	Exhaust	165	1	439.9	6.088	0.3075	24.73	51.15	23.34
6	Water	80	2	335	1.075	1.75	17.65	0	30.88
7	Water	106.1	2	444.9	1.375	1.75	37.42	0	65.49
8	Water	118.2	2	496	1.508	1.75	48.72	0	85.26

TABLE 4. The values of economic parameters for the system

Parameter	Value
φ	1.06
i (%)	10
n (years)	20
N (hour)	7500

To convert the capital investment into the cost per time unit, one can write [27]:

$$\dot{Z}_k = Z_k.CRF.\phi / (N \times 3600) \tag{21}$$

where Z_k is the purchase cost of kth component in dollar. The Capital Recovery Factor (CRF) is determined using the following relation:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{22}$$

here i is the interest rate, and n the total operating period of the system in years. N is the annual number of operation hours of the unit, and φ the maintenance factor. The values of these parameters are listed in Table4.Now, for each flow line in the system, a parameter called flow cost rate $\dot{C}$ (\$/s) is defined and the cost balance equation for a component that receives heat and produces power is written as [27]:

$$\sum_e \dot{C}_{e,k} + \dot{C}_{w,k} = \dot{C}_{q,k} + \sum_i \dot{C}_{i,k} + \dot{Z}_k \tag{23}$$

The cost balance equation is generally written in a way that all terms are positive. One can write:

$$\sum (c_e \dot{E}_e)_k + c_{w,k} \dot{W}_k = c_{q,k} \dot{E}_{q,k} + \sum (c_i \dot{E}_i)_k + \dot{Z}_k \tag{24}$$

$$\dot{C}_j = c_j \dot{E}_j \tag{25}$$

Tocalculate the cost of exergy destruction in the components of the system, first we should solve the cost balance equations. Usually, we have more than one inlet and outlet stream for a component. Thus, we need to formulate auxiliary equations. This is performed with the aid of the F and P principles in the SPECO approach [15]. Developing cost balance equation for each component of the system and auxiliary equations (according to F and P rules) results in the following system of equations:

Compressor

$$\dot{C}_2 = \dot{C}_{W_C} + \dot{C}_1 + \dot{Z}_C \tag{26}$$

Diesel engine

$$\dot{C}_7 + \dot{C}_3 + \dot{C}_{W_{DE}} = \dot{C}_2 + \dot{C}_6 + \dot{C}_{fuel} + \dot{Z}_{DE} \tag{27}$$

$$\frac{\dot{C}_6}{\dot{E}_6} = \frac{\dot{C}_7}{\dot{E}_7} \tag{28}$$

Turbine

$$\dot{C}_4 + \dot{C}_{W_T} = \dot{C}_3 + \dot{Z}_T \tag{29}$$

$$\frac{\dot{C}_4}{\dot{E}_4} = \frac{\dot{C}_3}{\dot{E}_3} \tag{30}$$

Heat exchanger

$$\dot{C}_8 + \dot{C}_5 = \dot{C}_4 + \dot{C}_7 + \dot{Z}_{HE} \tag{31}$$

$$\frac{\dot{C}_4}{\dot{E}_4} = \frac{\dot{C}_5}{\dot{E}_5} \tag{32}$$

$$\frac{\dot{C}_7}{\dot{E}_7} = \frac{\dot{C}_8}{\dot{E}_8} \tag{33}$$

Also, by assuming the same unit cost of exergy for the work supplied to, or produced by the system, one can write [28]:

$$\frac{\dot{C}_{W_{DE}}}{\dot{W}_{DE}} = \frac{\dot{C}_{W_T}}{\dot{W}_T} \tag{34}$$

$$\frac{\dot{C}_{W_T}}{\dot{W}_T} = \frac{\dot{C}_{W_C}}{\dot{W}_C} \tag{35}$$

By solving the system of 10 equations and 10 unknowns, the costs of unknown streams are obtained. In exergoeconomic assessment of thermal systems, certain quantities, known as exergoeconomic variables play a significant role. These variables include the average cost per exergy unit of fuel ($c_{F,k}$), the average cost per exergy unit of product ($c_{P,k}$), the exergoeconomic factor (f_k), and the cost flow rate associated with the exergy destruction ($\dot{C}_D$) and exergy loss ($\dot{C}_L$).Mathematically, exergoeconomic variables are expressed as [29]:

$$c_{F,k} = \frac{\dot{C}_{F,k}}{\dot{E}_{F,k}} \tag{36}$$

$$c_{P,k} = \frac{\dot{C}_{P,k}}{\dot{E}_{P,k}} \tag{37}$$

$$\dot{C}_{D,k} = c_{F,k} \dot{E}_{D,k} \tag{38}$$

$$\dot{C}_{L,k} = c_{F,k} \dot{E}_{L,k} \tag{39}$$

The exergoeconomic factor f_k is defined by:

$$f_k = \frac{\dot{Z}_k}{\dot{Z}_k + \dot{C}_{D,k} + \dot{C}_{L,k}} \tag{40}$$

TABLE 6. Exergy and exergoeconomic parameters of the system

Components	$\dot{E}_F$(kW)	$\dot{E}_P$(kW)	$\dot{E}_D$(kW)	y*(%)	y (%)	ε (%)	$\dot{C}_{D,k}$($/h)	$\dot{Z}_k$($/h)	$\dot{Z}_k+\dot{C}_{D,k}+\dot{C}_{L,k}$($/h)	f (%)
Compressor	38.38	34.27	4.12	1.46	0.62	89.28	0.30	1.94	2.24	86.56
Diesel Engine	702.1	451.5	250.6	88.86	37.53	39.31	6.46	12.65	19.11	66.19
Turbine	70.12	65.18	4.94	1.75	0.74	92.95	0.11	3.27	3.38	96.84
Heat Exchanger	42.14	19.77	22.37	7.93	3.35	46.92	0.48	1.94	2.42	80.11
Overall System	667.8	362.5	282	100	42.24	54.28	7.35	19.8	27.15	71.61

This factor is an important exergoeconomic parameter that shows the relative importance of a component cost to the associated cost of exergy destruction and loss in that component [27].

4. RESULTS AND DISCUSSION

4. 1. Exergoeconomic Analysis By solving the system of cost balance and auxiliary equations, the cost of unknown streams of the system are obtained. These values are given in Table 5.The values of important exergy and exergoeconomic parameters for the system are given in Table 6.The components having the highest value of the sum of $\dot{Z}_k+\dot{C}_{D,k}+\dot{C}_{L,k}$ are the most important components from the exergoeconomic viewpoint. The Diesel engine has the highest value of the sum $\dot{Z}_k+\dot{C}_{D,k}+\dot{C}_{L,k}$ and the lowest value of the exergoeconomic factor, *f.* This means that the cost rate of exergy destruction is noticeable for this component. Total exergy destruction in Diesel engine is 250.6 kW which comprises 37.53% of the total exergy input and 88.86% of the total exergy destruction in the system. High exergy destruction in the engine is mainly because of the irreversible combustion process in the engine. Although increasing the investment cost can lead to a decrease in the cost of the exergy destruction of the engine, in any other configuration of the system, the engine will have the highest cost of the exergy destruction due to the combustion process. The turbine has the highest value of the exergoeconomic factor, *f.* In addition, this value is 86.56% for the compressor. This means that the owning and operating cost of the turbocharger unit is significantly higher than that of the exergy destruction in it. High value of the exergy efficiency for the turbine and compressor confirms this.

Exergoeconomic improvement of this unit can be achieved by decreasing the capital investment of the unit. Also, relatively high *f* value for the heat exchanger suggests that it can be cost effective to reduce the investment cost by decreasing the surface area. Exergy loss from the system is equal to the exergy of stream leaving the heat exchanger and exhaust to the environment. This value is calculated to be 23.34 kW and the cost flow rate associated with the exergy loss is 0.5 $/h. The energy efficiency and exergy efficiency of the overall CHP system are found to be 93.16% and 54.28%, respectively. Also, work output and heating power of the system are calculated as 277.1 kW and 281.7 kW, respectively.

4. 2. Parametric Study In this section, effect of the ambient temperature on important energy, exergy and exergoeconomic parameters of the system is investigated. The effects of change in compressor pressure ratio and turbine inlet temperature on these parameters are investigated in different environment temperatures as well. Figure 2 shows the effect of the ambient temperature on the work output and heating power of the system. Ambient temperature has little effect on the heating power but the work output increases with increasing ambient temperature. This is mostly due to increasing the work produced by the engine because of rising engine inlet temperature with increasing ambient temperature.

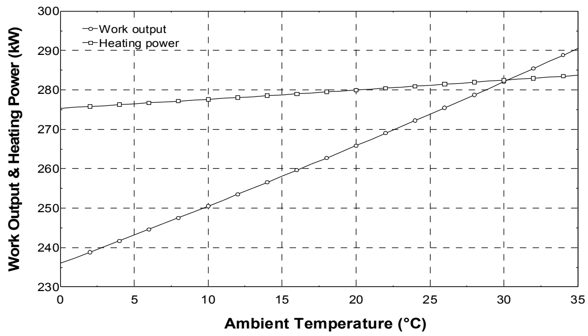

Figure 2. Effect of ambient temperature on the work output and heating power

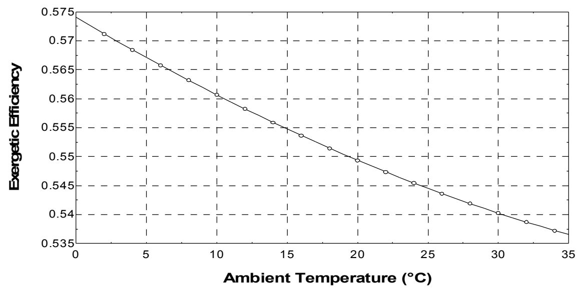

Figure 3. Exergetic efficiency of the system as a function of ambient temperature

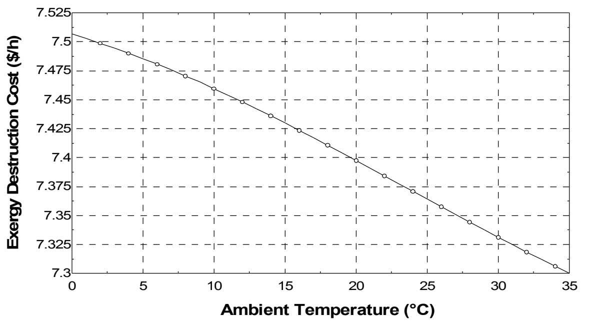

Figure 4. Effect of ambient temperature on the cost of exergy destruction

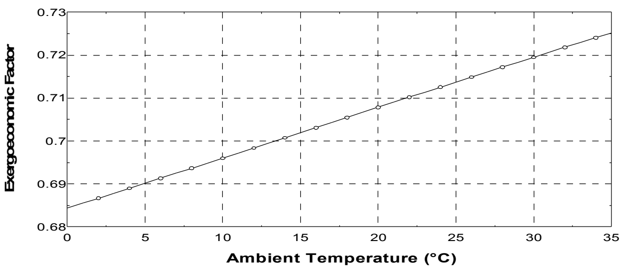

Figure 5. Effect of ambient temperature on the exergoeconomic factor

TABLE 7. Average temperature of Tehran in four seasons of year

Spring	Summer	Autumn	Winter
21 °C	29 °C	14 °C	6 °C

Exergetic efficiency of the system as a function of ambient temperature is given in Figure 3. Increasing the ambient temperature increases the exergy destruction in the components, and as a result, the exergetic efficiency of the system decreases. The ffects of ambient temperature on the cost of exergy destruction and exergoeconomic factor are shown in Figures 4 and 5, respectively. Referring to these figures, increasing ambient temperature leads to a little decrease in the cost of exergy destruction and a little increase in the exergoeconomic factor. Compressor pressure ratio and turbine inlet temperature are two important parameters of the system. In the following, the effects of these parameters on the system are investigated in different environment temperatures in Tehran, Iran. Table 7 shows the average temperature of Tehran in four seasons of year [30]. Figures 6 and 7 show the effect of change in compressor pressure ratio on the work output and heating power of the system for four environment temperatures. These figures indicate that increasing compressor pressure ratio strongly increases the power output and heating power. At constant compressor pressure ratio, increasing ambient temperature increases the power output and heating power of the system.

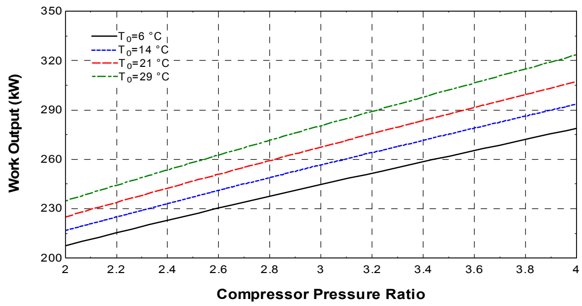

Figure 6. Effect of compressor pressure ratio on the work output for four environment temperatures

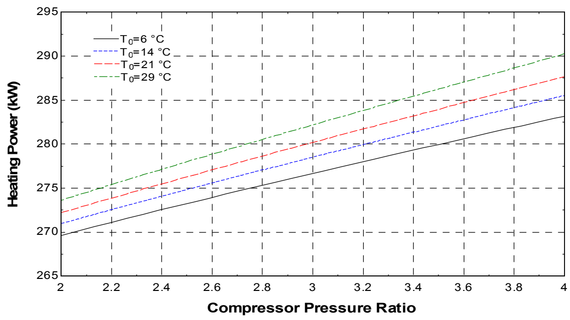

Figure 7. Effect of compressor pressure ratio on the heating power for four environment temperatures

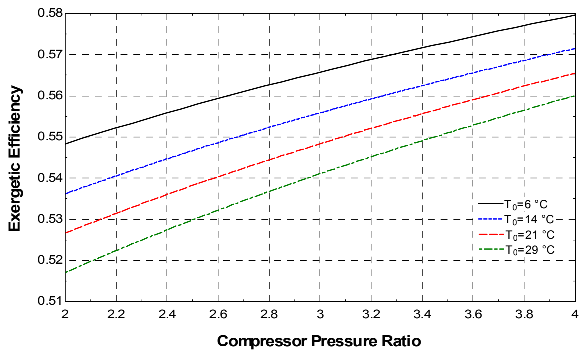

Figure 8. Exergetic efficiency of the system as a function of compressor pressure ratio for four environment temperature

Exergetic efficiency of the system as a function of compressor pressure ratio is shown in Figure 8. At lower pressure ratios, effect of change in ambient temperature is higher. Figures 9 and 10 show the effects of environment temperature on the cost of exergy destruction and exergoeconomic factor with respect to the compressor pressure ratio. As Figure 9 shows, increasing compressor pressure ratio leads to a sharp increase in the cost of exergy destruction. On the other hand, increasing compressor pressure ratio strongly increases the components capital costs and the cost of exergy loss. These parameters are changed in a way that the exergoeconomic factor is increased with increasing compressor pressure ratio.

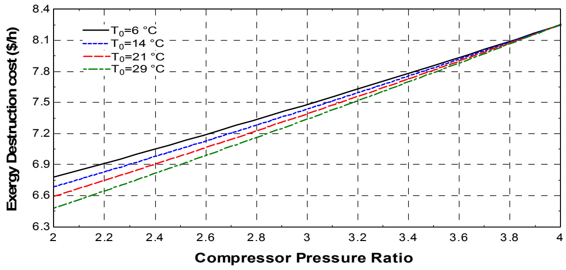

Figure 9. Effect of environment temperature on the cost of exergy destruction with respect to the compressor pressure ratio

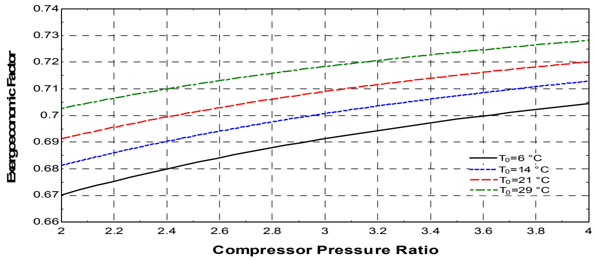

Figure 10. Effect of environment temperature on the exergoeconomic factor with respect to the compressor pressure ratio

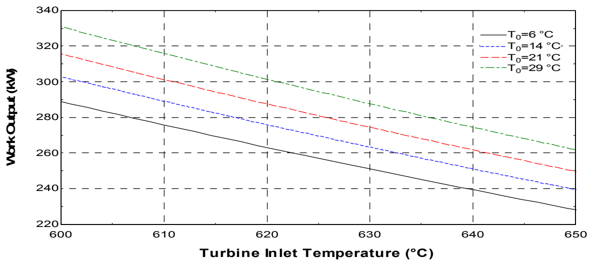

Figure 11. Effect of turbine inlet temperature on the work output for four environment temperatures

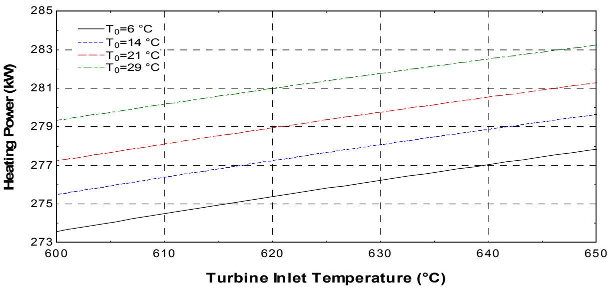

Figure 12. Increasing the heating power with increase of turbine inlet temperature in four environment temperatures

Figure 11 shows the effect of turbine inlet temperature on the work output of the system for four environment temperatures. Increasing turbine inlet temperature decreases the output power of the system. This is mostly due to decreasing the work produced by the engine with increasing turbine inlet temperature.

As Figure 12 shows, the heating power of the system increases with increasing turbine inlet temperature in all environment temperatures. This is due to increasing transferred heat to the water in the heat exchanger.

Exergetic efficiency of the system as a function of turbine inlet temperature is given in Figure 13 for four environment temperatures. As this Figure shows, increasing turbine inlet temperature decreases the exergetic efficiency. Figures 14 and 15 show the effect of environment temperature on the cost of exergy destruction and exergoeconomic factor with respect to the turbine inlet temperature. As Figure 14 shows, increasing turbine inlet temperature leads to a little increase in the cost of exergy destruction. On the other hand, increasing turbine inlet temperature strongly decreases the components capital costs. Also, the cost of exergy loss increases with increasing turbine inlet temperature. As a result, exergoeconomic factor decreases with increasing turbine inlet temperature.

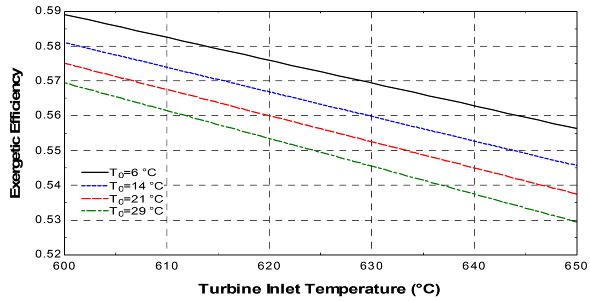

Figure 13. Exergetic efficiency of the system as a function of turbine inlet temperature for four environment temperatures

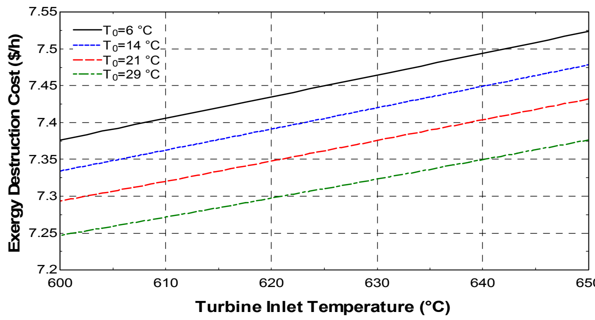

Figure 14. Effect of environment temperature on the cost of exergy destruction with respect to the turbine inlet temperature

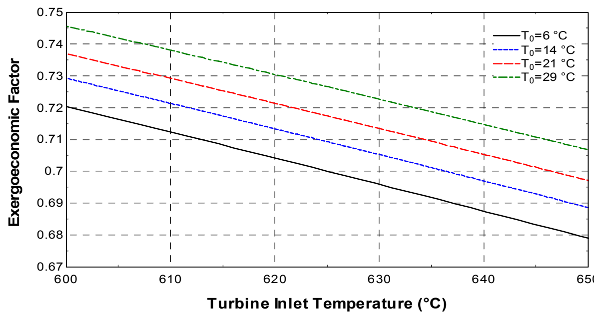

Figure 15. Effect of environment temperature on the exergoeconomic factor with respect to the turbine inlet temperature

5. CONCLUSIONS

The detailed exergy and exergoeconomic analysis of the Diesel engine based Combined Heat and Power (CHP) system are performed. Exergy destruction within the components and exergy efficiencies are calculated and the values of exergoeconomic variables are determined for the components and entire CHP system. Moreover, a parametric study is performed to show effect of ambient temperature on important energy, exergy and exergoeconomic parameters and also effects of change in compressor pressure ratio and turbine inlet temperature on these parameters in different environment temperatures in Tehran, Iran. The results show that increasing ambient temperature decreases the exergetic efficiency of the system but it has a positive effect on the work output, heating power and cost of exergy destruction. At the same time, increasing compressor pressure ratio has a positive effect on the work output, heating power and exergetic efficiency of the system but increases the cost of exergy destruction in four environment temperatures. Also, increasing turbine inlet temperature increases the heating power of the system, whereas it has a negative effect on the work output, exergetic efficiency and exergy destruction cost in four environment temperatures. The results of this study help better understanding of the cost formation process in the plant. In addition, these results can be used as a basis for exergoeconomic optimization of the system.

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A Parametric Study on Exergy and Exergoeconomic Analysis of a Diesel Engine based Combined Heat and Power System

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چکیده

این مقاله تحلیل اگزرژی، اگزرژواکونومیک و بررسی پارامتری یک سیستم تولید همزمان برق و حرارت بر پایه موتور دیزل را که ۲۷۷ kW برق و ۲۸۲ kW گرما تولید می‌کند ارائه می‌نماید. بدین منظور ابتدا تحلیل ترمودینامیکی سیستم تولید همزمان بر پایه انرژی و اگزرژی انجام شده است. سپس تعادل هزینه و معادلات کمکی برای هر یک از اجزا نوشته شده‌اند. تحلیل اگزرژواکونومیک بر پایه روش هزینه‌دهی به اگزرژی ویژه انجام شده است. در نهایت، یک مطالعه پارامتری به منظور نشان دادن اثر تغییر دمای محیط بر پارامترهای مهم انرژی، اگزرژی و اگزرژواکونومیک سیستم انجام شده است. همچنین تاثیر تغییرات نسبت فشار کمپرسور و دمای ورودی توربین در دماهای مختلف محیط بر این پارامترها بررسی شده است. نتایج مطالعه نشان می‌دهد که افزایش دمای محیط باعث افزایش کار و گرمای خروجی و ضریب اگزرژواکونومیک شده و بازده اگزرژی و هزینه تخریب اگزرژی را کاهش می‌دهد. افزایش نسبت فشار کمپرسور منجر به افزایش کار و گرمای خروجی، بازده اگزرژی، هزینه تخریب اگزرژی و ضریب اگزرژواکونومیک سیستم تولید همزمان در همه دماهای محیط می‌شود. همچنین، افزایش دمای ورودی توربین باعث کاهش کار خروجی، بازده اگزرژی و ضریب اگزرژواکونومیک می‌شود، در حالیکه گرمای خروجی و هزینه تخریب اگزرژی را در همه دماها افزایش می‌دهد.

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