ENERGY AND EXERGY ANALYSIS OF DIESEL ENGINE IN TEKNECIK THERMAL POWER PLANT

M. RUSO, G.BEKTAŞ
Civil Engineering Department, Eastern Mediterranean University
Corresponding author: Asist. Prof. Dr. Gülsün BEKTAŞ, e-mail: gulsum.bektas@emu.edu.tr

REFERENCE NO

EXGY-03

ABSTRACT

In this work, the exergy analysis of Teknecik Thermal Power Plant at Kyrenia, Turkish Republic of Northern Cyprus was conducted to calculate the energy and exergy efficiencies of the system. Energy and exergy analyses of the Thermal Power Plant were performed using actual plant operational data. The heat and exergy losses were determined in each systems; *Water Jacket Cooling System, Starting Air System, Fuel System, Lubrication Oil System and Turbocharger System* of diesel engine n^o 3.
In Teknecik Thermal Power Plant there are 8 Wartsila medium speed four stroke diesel engines and each power of is 17000 kW.
In each diesel machine V-type 18 cylinder is located. Thermal efficiency in a standard medium speed diesel engine is between 0.37 – 0.43. .

Keywords:
energy, exergy analysis, exergy efficiency, thermal power plant

1. INTRODUCTION

Engineers and scientists have been using enthalpy balances for more than a century to quantify the loss of efficiency in a process due to the loss of energy. An exergy assessment allows one to quantify the loss of efficiency in a process due to the loss of the quality of the energy.

Energy is indestructible and exists everywhere, because it is connected with matter in all forms. Two meanings of the word *exergy* can be observed: one, scientifically exact, relates to the indestructibility of energy; the other, applied in practice, and is connected with the ability of some kinds of energy to feed and drive machines and energy processes.

The notion of *maximum work* has been introduced and investigated since the mathematical formulation of the second law of the thermodynamics. Before introduce of *maximum work* subject; ı would like to remind 1st and 2nd law of thermodynamics. The first law of thermodynamics, amount of energy in a closed system, that energy will remain constant, though it will change form. As evolutionist Willard Young says in defining the first law, *Energy can be neither created nor destroyed, but can only be converted from one to another* [7].

Two interpretations of word *energy*, it was necessary to introduce another name for the notion expressing the quality of energy, its ability to be converted into other kinds of energy, and especially to perform work in the conditions of technical processes. The word *exergy* was proposed by Z.Rant in 1956 for this purpose. Other terms are available *energy*, *availability*, and *essergy* [6].

The main purpose of exergy analysis is to detect and evaluate quantitatively the causes of the thermodynamic imperfection of thermal processes. Exergy analysis can give information about the possibilities of improving thermal processes.

During the past decade, many studies have been undertaken by the researchers to investigate thermodynamic aspects of thermal systems and processes.

Gemci T. And Öztürk A. conducted energy and exergy analyses of the sulphide-pulp preparation process used at the SEKA-Izmit Pulp and Paper Mill in Turkey. The energy and exergy analysis of pyrite reactor, waste heat recovery boiler, washing tower and gas cooler are performed [14].

Muangnoi and et al. used an exergy analysis to indicate exergy and exergy destruction of water and air flowing through the cooling tower. One important observation from this study is that the choice of the ambient conditions (dry and wet bulb temperatures) affects the results of exergy analysis quite strongly [2].

G. Bektaş and F. Balkan performed energy and exergy analysis of a Sulfation Unit in a Powder Detergent Plant. The effect of some system parameters on both energy and exergy efficiencies investigated. Overall exergy efficiencies are found 0.73 and 0.56 respectively [12].

Regulagadda et al. [3] performed a thermodynamic analysis of a subcritical boiler-turbine generator for a 32 MW coal fired power plant. Energy and exergy equation governing the cycle are established. A parametric study is conducted for a range of operating variables. That permits to define the optimum parameters leading to the best plant performances. The boiler and turbine engender the maximum exergy destruction rates in the power plant. The identification of the exergy losses in the different cycles has permitted to develop an environmental impact and sustainability analysis.

A comparison between nine coal-fired power plants in Turkey is conducted by [4]. For each plant a calculation model is proposed and the mass, energy and exergy balances are established. That permits to determine the energy and exergy efficiency as well the exergy destruction rate of each component. A comparison is then accomplished between the considered power plants. The obtained results may constitute helpful tools for further investigations in the field of energetic and exergetic industrial power plant analysis.

In this project, theoretical and quantitatively information about *exergy analysis of thermal power plant* was studied and applied on *Diesel Generator n^o 3.*

2. THEORATICAL ANALYSIS

In this work, there are three balance equations, namely mass, energy and exergy balance equations which are used to find the work and heat interactions, exergy destructions, and energy and exergy efficiencies. Using these equations exergy and energy efficiencies were calculated each systems. *Water Jacket Cooling System, Starting Air System, Fuel System, Lubrication Oil System and Turbocharger System* of diesel engine n^{o} 3. Also overall thermal power plant in diesel engine part efficiencies was calculated.

2.1 Mass Balance Equation

$$\sum \dot{m}_{in} - \sum \dot{m}_{out} = 0 \quad (1)$$

2.2 Energy Balance Equation

$$\dot{E} = \dot{m}h \quad (2)$$

$$\sum \dot{E}_{in} - \sum \dot{E}_{out} - \sum \dot{W} - \sum \Delta H_{rxn} + \sum \dot{Q} = 0 \quad (3)$$

2.3 Total Exergy Equation and Exergy Balance Equation

$$\dot{E}x = \dot{E}x_{KN} + \dot{E}x_{PT} + \dot{E}x_{TH} \quad (4)$$

$$\dot{E}x_{TH} = \dot{E}x_{PH} + \dot{E}x_{CH} \quad (5)$$

$$\dot{E}x_{KN} = \dot{m}\frac{v^2}{2} \quad (6)$$

$$\dot{E}x_{PT} = \dot{m}gz \quad (7)$$

$$\dot{E}x_{PH} = \dot{m}[(h-h_0)+T_o(s-s_0)] = \dot{m}\left(\sum_i x_i Cp_i^e (T-T_0)\right) \quad (8)$$

$$\dot{E}x_{CH} = \dot{m}\left[\sum_i x_i e_i^0 + RT_0 \sum_i x_i \ln(x_i)\right] \quad (9)$$

$$\sum \dot{E}x_{in} - \sum \dot{E}x_{out} - \dot{E}x_W + \dot{E}x_Q = \dot{E}x_{dest} \quad (10)$$

$$\dot{E}x_Q = \left(1-\frac{T_0}{T}\right)\dot{Q} \quad (11)$$

$$\dot{E}x_W = \dot{W} \quad (12)$$

2.4 Energy and Exergy Efficiencies

Based on the first law of thermodynamics the energy efficiency of a system (η_{en}) can be defined as;

$$\eta_{en} = \frac{\dot{E}_{out}}{\dot{E}_{in} + \dot{W}} \quad (13)$$

The conventional exergy efficiency ($\eta_{ex,P}$), can be defined as;

$$\eta_{ex} = \frac{\dot{E}x_{out}}{\dot{E}x_{in} + \dot{W}} \quad (14)$$

3. CASE STUDY

The general view of the diesel engine generator is shown in Figures 1,2.

Figure 1. Diesel Generator Section of Teknecik Thermal Power Plant.

Figure 2. Diesel Generator n^0 3.

3.1. Starting Air System

The starting air system is the preheating system of the air to prepare for the burning shown in figure 3.

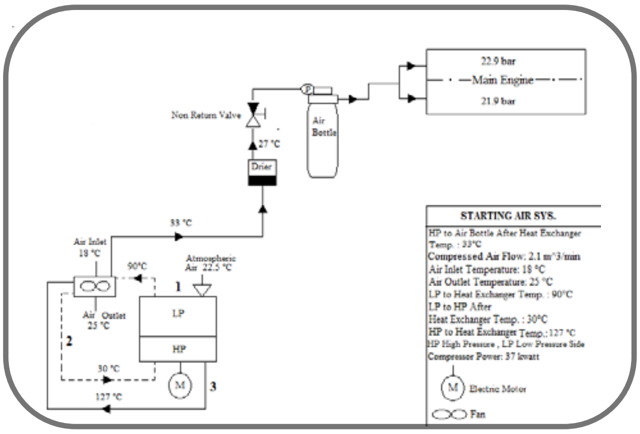

Figure 3. Starting Air System

The first movement is given by the compressor electric motor. Air is compressed in the low pressure side of compressor. Compressed air is sent to the heat exchangers and is cooled by fan and return to the high pressure side. It is compressed again and then is cooled by heat exchangers. The moisture in air is dried in the drier. Air is stored in the air bottle to be fed into Main Engine.

3.2. Lubricating Oil System

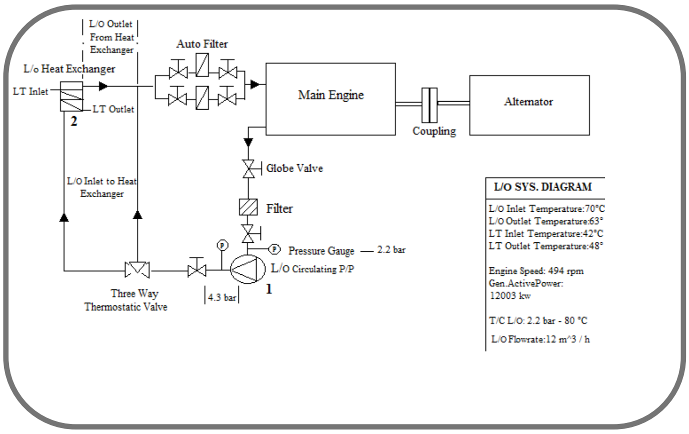

Figure 4. Lubrication Oil System

Used lubrication oil is filtered and pumped to the heat exchanger by circulating pump. It is cooled by water in the heat exchanger. It is filtered in auto filter and sended to the Main Engine for lubrication.

3.3. Turbocharger System

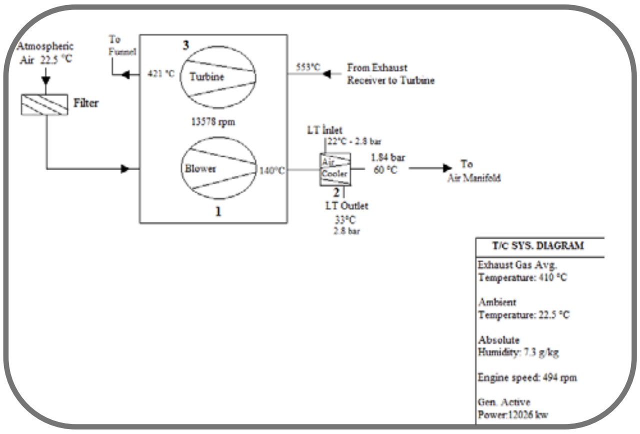

Figure 5. Turbocharger System

Exhaust gases drive the turbine wheel around, which is directly connected via a shaft, to the blower rotor. Blower absorbs air from atmosphere and compresses it . Compressed air is cooled and sent to the Main engine by air manifold. The flowsheet of this system is on figure 5.

3.4. Water Jacket Cooling System

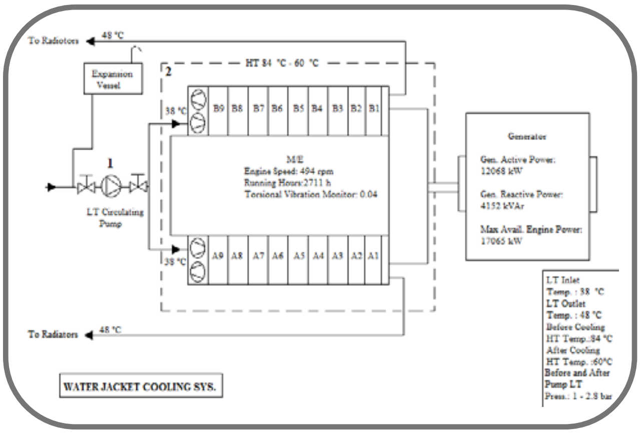

Figure 6. Water Jacket Cooling System

Circulating Pump feeds low temperature water to heat exchanger which locates in the Main Engine (Figure 6).

3.5. Fuel System

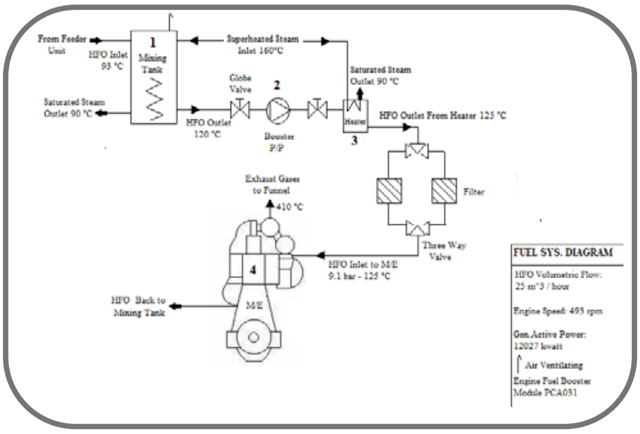

Figure 7. Fuel System

Heavy Fuel Oil heats in mixing tank with steam for decreasing viscosity.

As shown in figure 7, booster pump feeds heavy Fuel Oil(HFO) from mixing tank to main engine. Before Main Engine, HFO is reheated in heater by steam. HFO is filtered in auto filter. In main engine chemical reaction takes place which converts HFO into energy, exhaust gases, water vapor. Unburned fuel oil returns to mixing tank.

4. RESULTS

The data related with the system are obtained by direct measurements and system throwbacks. They are all operational data. By using these data energy and exergy analysis were carried out and the efficiencies were calculated. The results for the system are shown in Table 1 and 2.

Table 2. Energy and Exergy Efficiencies for the Equipments of the System

System	Equipment	Energy efficiency	Exergy efficiency
Lubrication Oil	Circulating Pump	1.00	0.09
	Heat Exchanger	0.97	0.82
Starting Air	Compressor	0.10	0.04
	Heat Exchanger for Low Pressure Compressed Air	0.92	0.40
	Heat Exchanger for High Pressure Compressed Air	0.79	0.39
Water Jacket Cooling	Circulating Pump	1.00	0.34
	Heat Exchanger on Main Engine	0.95	0.49
Turbocharger	Blower	0.93	0.45
	Air Cooler	0.99	0.89
	Turbine	0.75	0.42
Fuel	Mixing Tank	0.99	0.85
	Booster Pump	1.00	0.005
	Heater	0.99	0.91
	Main Engine	0.18	0.49

Table 1. Energy and Exergy Rates in Diesel Generator n° 3 and Systems

		In					Out		$Ex_{destruct}$		
Syst	**Equipment**	**Stream**	$\dot{E}$ **(kJ/s)**	$\dot{E}x_{PH}$ **(kJ/s)**	$\dot{E}x_{CH}$ **(kJ/s)**	$\dot{E}x_{T}$ **(kJ/s)**	**Stream**	$\dot{E}$ **(kJ/s)**	$\dot{E}x_{PH}$ **(kJ/s)**	$\dot{E}x_{CH}$ **(kJ/s)**	$\dot{E}x_{T}$ **(kJ/s)**
Lubrication Oil	Circulating Pump	Oil	444.08	21.95	0	21.95	Oil	444.08	2.043	0	2.043
	Heat Exchanger	Oil	444.08	21.95	0	21.95	Oil	399.67	18.96	0	18.96
	Heat Exchanger	Water	215.93	3.18	0	3.18	Water	246.78	4.21	0	4.21
						Q_{loss} = 13.32 kJ/s			**$Ex_{destruct}$ = 25.21 kJ/s**		
Starting Air	Compressor	Air	37.9	37	0	37	Compressed Air	3.82	1.76	0	1.76
	Heat Exchanger	Air	4.88	0.24	0	0.24	Air	6.78	0.12	0	0.12
	Heat Exchanger	Low Pressure Compressed Air	3.80	0.26	0	0.26	Low Pressure Compressed Air	1.26	0.087	0	0.087
	Heat Exchanger	Air	4.88	0.24	0	0.24	Air	6.78	0.12	0	0.12
	Heat Exchanger	High Pressure Compressed Air	5.37	0.59	0	0.59	High Pressure Compressed Air	1.39	0.21	0	0.21
						Q_{loss} = 36.8 kJ/s			**$Ex_{destruct}$ = 2.29 kJ/s**		

Table 1. Energy and Exergy Rates in Diesel Generator n° 3 and Systems

			In					Out		**$Ex_{destruct}$**	
System	**Equipment**	**Stream**	$\dot{E}$ **(kJ/s)**	$\dot{E}x_{PH}$ **(kJ/s)**	$\dot{E}x_{CH}$ **(kJ/s)**	$\dot{E}x_{T}$ **(kJ/s)**	**Stream**	$\dot{E}$ **(kJ/s)**	$\dot{E}x_{PH}$ **(kJ/s)**	$\dot{E}x_{CH}$ **(kJ/s)**	$\dot{E}x_{T}$ **(kJ/s)**
Water Jacket Cooling	Circulating Pump	Water	195.37	1.68	0	1.68	Water	195.37	0.58	0	0.58
	Main Engine	Low Temperature Water	195.37	1.68	0	1.68	Low Temperature Water	246.78	0.02	0	0.02
	Main Engine	High Temperature Water	122.89	8.47	0	8.47	High Temperature Water	87.78	5.07	0	5.07
						Q_{loss}= 16.35 kJ/s			**$Ex_{destruct}$= 5.67 kJ/s**		
Turbocharger	Blower	Air	144.27	112.03	0	112.03	Air	142.10	50.80	0	50.80
	Air Cooler	Air	142.10	0	0	7.61	Air	60.90	38.57	0	38.57
	Air Cooler	Water	162.76	367.1	0	367.1	Water	244.15	353.96	0	353.96
	Turbine	Exhaust Gases	320.74	528.88	0	528.88	Exhaust Gases	235.76	140.80	0	140.80
		Water Vapor	1034.11	520.95		520.95	Water Vapor	787.27	317.05		317.05
					Q_{loss}= 333.8 kJ/s			**$Ex_{destruct}$= 901.18 kJ/s**			

Table 1. Energy and Exergy Rates in Diesel Generator n^{o} 3 and Systems

			In				**Out**			**$Ex_{destruct}$**	
System	**Equipment**	**Stream**	$\dot{E}$ **(kJ/s)**	$\dot{Ex}_{PH}$ **(kJ/s)**	$\dot{Ex}_{CH}$ **(kJ/s)**	$\dot{Ex}_{T}$ **(kJ/s)**	**Stream**	$\dot{E}$ **(kJ/s)**	$\dot{Ex}_{PH}$ **(kJ/s)**	$\dot{Ex}_{CH}$ **(kJ/s)**	$\dot{Ex}_{T}$ **(kJ/s)**
Fuel	Mixing Tank	Steam	616.35	1609.78	0	1609.78	Steam	346.69	1329.2	0	1329.2
	Mixing Tank	Fuel Oil	1329.49	104.07	0	104.07	Fuel Oil	1715.47	144.09	0	144.09
	Booster Pump	Fuel Oil	1715.47	189.41	0	189.41	Fuel Oil	1715.47	198.27	0	198.27
	Heater	Steam	113.69	296.95	0	296.95	Steam	63.95	245.19	0	245.19
	Heater	Fuel Oil	1715.47	189.41	0	189.41	Fuel Oil	1786.95	198.27	0	198.27
	Main Engine	Fuel Oil	12191.25	24500	0	24500	Exhaust Gases	229.6	3870.66	0	3870.66
							Water Vapor	815.9	7741.33		7741.33
					Q_{loss}= 9962.19 kJ/s			**$Ex_{destruct}$= 13727.01 kJ/s**			

5. CONCLUSIONS

In this work, the energy and exergy analyses of Diesel Generator n° 3 in Thermal Power Plant and systems in plant were performed. Some concluding remarks from this study are as follows:

- The exergy loss is the greatest in the *heat exchanger* of compressor. This is due to the reason: Two section low pressure side and high pressure side are on the compressor however only one heat exchanger uses for cooling air.
- Pumps are used only for pressurization of fluid. Exergy and energy analyses of pumps are minor.
- Air cooler and heater have great exergy and energy efficiencies.
- The exergy destruction in the *Main Engine* is higher than those in the other units. This can be explained by the fact that the chemical reaction in *Main Engine* is highly irreversible.
- The overall energy and exergy efficiencies of the unit were calculated as 0.65 and 0.51, respectively.

Acknowledgements

We thank to Chief Engineer Kemal ÖZGÜÇ, Head of Marine Engineering Department, for constant encouragement the construction of this project along.

We would also like to thank Chief Engineer Aytaç TOKEL to host in Thermal Power Plant of Teknecik and giving us relevant technical information.

Nomenclature

C_p	Specific Heat Energy(kJ/kg°C)
e	Formation Exergy (kJ/kg)
$\dot{E}$	Rate of Energy Transfer(kJ/s)
$\dot{E}_{ex}$	Rate of Exergy Transfer(kJ/s)
h	Specific Enthalpy(kJ/kg)
$\dot{m}$	Mass Flowrate(kg/s)
s	Specific Entropy(kJ/kgK)
W	Work(kJ/s)

References

[1] Yunus A. Çengel, Michael A. Boles, 2007, "Thermodynamics: An Engineering Approach ", Literature,.

[2] T. J. Kotas, 1985 "The Exergy Method of Thermal Plant Analysis ", British Library Cataloguing, TJ,163.9,.

[3] Regulagadda P., Dincer I., Naterer G. F. Exergy analysis of a thermal power plant with measured boiler and turbine losses. Appl Therm Eng 2010; 30:970–976.

[4] Erdem H. H., Akkaya A. V., Cetin B., Dagdas A., Sevilgen S. H., Sahin B., Teke I., Gungor C., Atas S, 2009. Comparative energetic and exergetic performance analyses for coal-fired thermal power plants in turkey. Int J Therm Sci; 48:2179–2186.

[5] Ghannadzadeh A., Hetreux R. T., Baudouin O., Baudet. P, Floquet P.,Joulia X. 2012, General methodology for exergy balance in ProSimPlus® process simulator. Energy; 44:38–59.

[6] Molès F. 2015, Thermodynamic analysis of a combined organic Rankine cycle and vapor compression cycle system activated with low temperature heat sources using low GWP fluids. Appl Therm Eng; 87:444–453.

[7] Taner T. 2015 Optimisation processes of energy efficiency for a drying plant: A case of study for Turkey. Appl Therm Eng; 80:247–260.

[8] Ali Bolatturk, Ahmet Coskun, Caglar Geredelioglu. 2015, Thermodynamic and exergoeconomic analysis of Cayırhan thermal power plant. Energy Convers and Manage; 101:371-378.

[9] Taillon J., Blanchard R. E., 2015, Exergy efficiency graphs for thermal power plants, Energy; 88: 57-66.

[10] Omendra Kumar Singh, S. C., 2013, Kaushik. Energy and exergy analysis and optimization of Kalina cycle coupled with a coal fired steam power plant. Appl Therm Eng; 51:787-800.

[11] Jan Szargut, David R. Morris, Frank R. Steward, 1988, " Exergy Analysis of Thermal, Chemical and Metallurgıcal Processes ", Hemısphere Publishing, TJ265.S958,

[12] G. Bektaş and F. Balkan, 2010 "Energy and Exergy Efficiencies of a Sulfation Unit in a Powder Detergent Plant and Effect of System Parameters ", University of Ege.

[13] Teknecik Thermal Power Plant's, System Diagrams, Parameters, Lubrication Oil and Fuel Oil Certificates of Quality.
[14] T. Gemci, A. Öztürk, 1998 Energy Conversion and Management, Volume 39, Issues 16–18, November–December.
[15] Author(s), Title of paper, *International Journal*, Vol. X, No. Y, YEAR, pp.ZZ-ZZ.
[16] Author(s), Title of paper, International Conference, Place, YEAR, Vol. X, pp. YY-YY.
[17] Author(s), *Title of the book*, Xth Ed., Publishing house, YEAR.