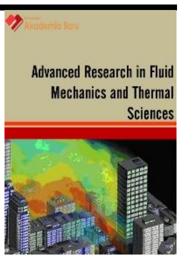
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Exergy and Energy Analysis of 150 MW Gas Turbine Unit: A Case Study

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ARTICLE INFO

Article history:
Received 15 June 2019
Received in revised form 4 September 2019
Accepted 13 September 2019
Available online 15 March 2020

ABSTRACT

A study of the energy and exergy analysis of a 150 MW gas turbine plant was performed using Dataflow sheet Kirkuk unit. Applying the first and second law of thermodynamics across each component of the unit to determine losses have been used. The results showed that the first law efficiency in the compressor, combustion chamber, turbine, and exhaust gases was 93.34%, 85.52%, 94.11%, and 42.32%, respectively. The results were represented by the Sankei diagram, while the second law efficiency in the compressor, combustion chamber, turbine, exhaust gases were 93.3%, 89.52%, 95.57%, and 82.34%, respectively. The outcome of exergy analysis was represented by a Grasmann diagram while the energy analysis was represented by a Sankey diagram. The total thermal efficiency of the unit was 33.069%, while the exergy efficiency was 32.397%.

Keywords:
Exergy; energy; gas turbine

1. Introduction

The recent high energy consumption has pushed researchers to find ways to rationalize energy. To start with any rationalization project, it is necessary to determine the type and quantity of energy losses because the calculation of the losses by quantity does not give a comprehensive impression of the overall efficiency of any power station. Hence the concept of entropy and the second law of thermodynamics on the other hands, the largest function that can be obtained from the system or known as the energy available (Exergy). Recent research has focused on the use of exergy in analytical studies by calculating losses across each component of the plant [1, 2]. When the losses are known, and the reasons are identified, the loss positions of each component can be processed, and therefore, higher efficiency is achieved by determining the maximum expected occupancy [3-5]. The gas turbine often works under different operating conditions, in addition to the specificity of each of its components. Therefore, the effect of these variables on each component is including ambient temperature, maximum temperature, comparison ratio, and load. To obtain a clear impression of the crash sites, each component of the station and corresponding operational conditions [6, 7]. Exergy is

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defined as the maximal useful work obtained from a system while the system interacts with the environment [8]. Nowadays energy and exergy analysis is done for power plants [9] and all the available energy technologies, such as internal combustion engines [10, 11], steam turbines [12, 13], gas turbines [14], as well as for district heating systems [15], technological process [16], etc. Legislation aspects of exergy are reviewed in [17]. This study represents the exergy analysis of the cogeneration plant, which shows the vital points of exergy destruction and might be used for the improvement of operations at plants [18]. A similar study conducted with case studies of the gas turbine power plant the highest exergy occurs in the combustion chamber [19-21]. Several studies have been carried out in this area to determine the losses of the exergy. All these studies confirmed that the losses are the largest possible in the combustion chamber and the lowest in the compressor [22-24], which is a function of the load ratio mainly. The first and the widest spread method for energy transformation efficiency evaluation is energy analysis: combined assessment method, including exergy, energy distraction, and entropy generation concept, is also getting approved [25, 26]. A similar study was conducted to represented energy and exergy analysis of the cogeneration plant by using Sankey and Grassmann diagrams [27].

Most of the researches in this field use the conventional method of energy and exergy analysis across each component of the unit. The direct method of analysis was used by feeding the program with the specifications of the plant and presenting the results for the energy analysis on the Sankey scheme and the results of the exergy analysis on the Grassmann scheme. The objective of the study is to analyze the energy and the exergy of a gas station and determine the locations of the crash and the possibility of improving the performance of the unit in the future.

2. Methodology

The specific exergy on a mass basis, ψ, express as the sum of thermo-mechanical and chemical contributions, is given as [1, 5]:

$$\psi = (h - h_o) - T_o(s - s_o) + \frac{V^2}{2} + gz_1 + \psi^{CH} \tag{1}$$

where h,s and ψ^{CH} are the specific enthalpy, entropy and, chemical exergy, respectively, assume velocity and elevation zero then Eq. (1) can rewrite as:

$$\psi = (h - h_o) - T_o(s - s_o) + \psi^{CH} \tag{2}$$

Eq. (2) is used to extract the value of the exergy through each component of the station by feeding the program with the data from the Dataflow sheet [28] and specification of fuel [29]. The analysis Sequence is consisting of initial data that necessary for calculation, and graphical illustration of the results are shown in the methodology scheme (Figure 1).

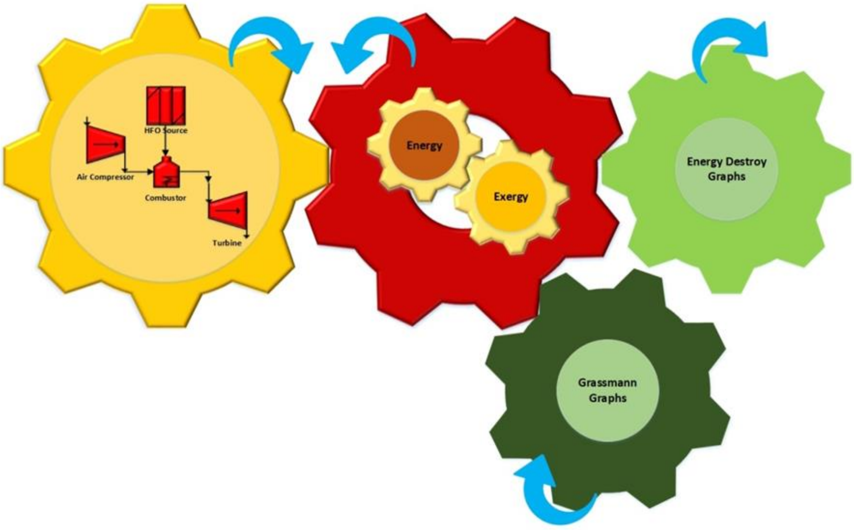

Fig. 1. Algorithm of methodology

3. Plant Description and Initial Data

The unit is equipped with the open-cycle system, which operates in a single axis. Thus, the unit includes the following parts: axial compressor, double ring combustion chamber, gas turbine operating system to cool the blades by air and the electric generator. Working fluid specifications such as pressure, temperature, enthalpy, and mass flow rate across the unit components have been installed, as shown in Figure 2, Table 1, shows the characteristics and specifications of the unit studied .The air compressed through the compressor by the adiabatic or isentropic process, heat added through the combustion chamber. Therefore gas has higher enthalpy then expand through a turbine to initial pressure.

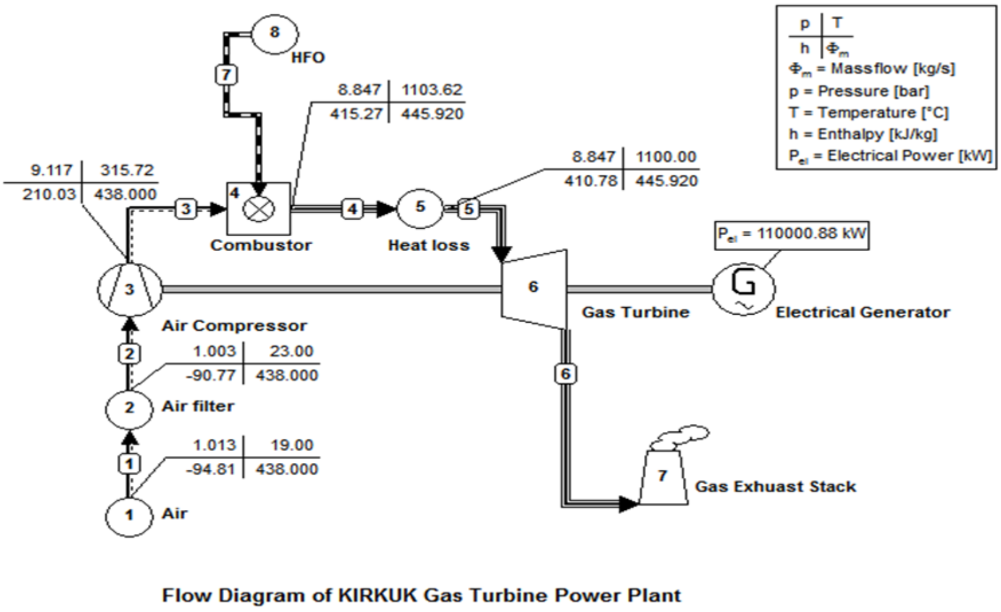

Fig. 2. Flow diagram of Kirkuk gas turbine power plant

Table 1
Characteristics of gas turbine unit

Properties	Symbol	Value	Unit
Pressure ratio	r_p	12	-
Maximum temperature	T_4	1100	°C
Exhaust temperature	T_{ex}	500	°C
Ambient temperature	T_1	19	°C
Outlet compressor temperature	T_3	315.7	^{0}C
Heating value	Q_{hv}	43000	kJ/kg
By-product energy	W	150	MW
Design Efficiency	η	34	%
Fuel type	-	HFO	-

4. Results and Discussion

The results are given in Table 2 and shown in Figure 3 and Figure 4 by Sankey and Grassmann diagrams for energy and exergy analysis respectively at 110 MW load.

Table 2
First and second law analysis results

Equipment	(%)First law efficiency	(%)Second law efficiency	Exergy destroyed(MW)	(%)Relative Exergy Loss
Compressor	93.34	93.32	8.7892	2.59
Combustion Chamber	85.52	89.52	48.43944	14.26
Turbine	94.11	95.57	18.27425	5.38
Stack (Exhuast Gases)	42.326	82.34	101.88051	30.55
Plant	33.069	32.397	177.3834	52.78

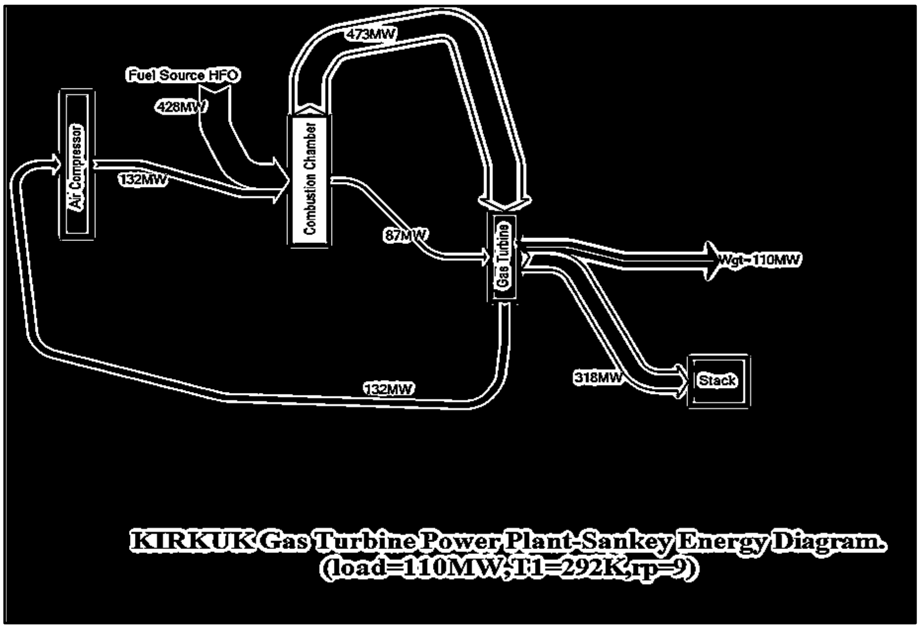

Fig. 3. Sankey diagram for gas turbine unit

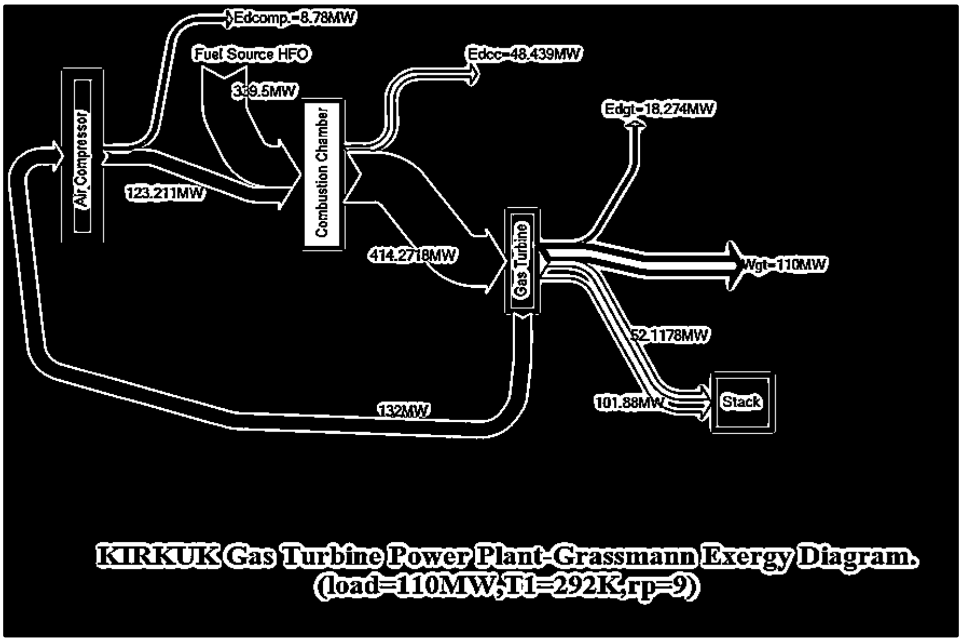

Fig. 4. Grassmann diagram for gas turbine unit

The overall exergy and energetic efficiency of the gas turbine unit were calculated as 32.397% and 33.069% respectively, which are similar to the results [30] which shows exergy and energetic efficiency as 30.81% and 31.05%, respectively,and the results which shows exergy and energetic efficiency as 32.25% and 33.77%, respectively [31]. Exergetic efficiency of the unit is a little bit lower than the energy efficiency. The evaluation of exergetic efficiency involves environment parameters, and exergy is lost because of the irreversibility in the system. The exergy losses are caused by the internal irreversibility resulting from friction losses in both compressor and gas turbine due to high compression ratio in the air compressor and high temperature in turbine thus increase energy and exergy losses. The highest exergy loses, and the lowest exergetic efficiency happens in the combustion chamber due to unburnt fuel, the large difference temperature, incomplete combustion, and heat loss to the surrounding area [32].

5. Conclusions

The exergy and energy analysis gives an actual indicator of the losses which happened in plant components. The energy and exergy performance of the gas turbine unit was analyzed, and the results are exposed to Sanky and Grassmann drawings. Exergy losses were found to be greatest in the exhaust gas and combustion chamber and as low as possible in the turbine and compressor caused by the large difference between ambient temperature and maximum temperature. The exergy efficiency and the thermal efficiency of the plant are 32.397% and 33.069% respectively. The efficiency of the first law is greatest than exergetic efficiency and inversely proportional to the ambient temperature.

Acknowledgements

The authors would like to thank Northern Technical University for providing laboratory facilities and financial support.

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