Thermodynamic Analysis of Simple Gas Turbine Cycle with Multiple Regression Modelling and Optimization

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ABSTRACT

In this study, thermodynamic and statistical analyses were performed on a gas turbine system, to assess the impact of some important operating parameters like CIT (Compressor Inlet Temperature), PR (Pressure Ratio) and TIT (Turbine Inlet Temperature) on its performance characteristics such as net power output, energy efficiency, exergy efficiency and fuel consumption. Each performance characteristic was enunciated as a function of operating parameters, followed by a parametric study and optimization. The results showed that the performance characteristics increase with an increase in the TIT and a decrease in the CIT, except fuel consumption which behaves oppositely. The net power output and efficiencies increase with the PR up to certain initial values and then start to decrease, whereas the fuel consumption always decreases with an increase in the PR. The results of exergy analysis showed the combustion chamber as a major contributor to the exergy destruction, followed by stack gas. Subsequently, multiple regression models were developed to correlate each of the response variables (performance characteristic) with the predictor variables (operating parameters). The regression model equations showed a significant statistical relationship between the predictor and response variables.

Key Words: **Efficiency, Energy, Exergy, Gas Turbine Cycle, Multiple Regression.**

1. INTRODUCTION

The world energy needs rely heavily on fossil fuels. To convert such fuel sources to electricity, gas turbines seem to play an indispensable role. Although the open cycle gas turbines are considered to be less efficient, they are preferred due to their shorter lead time and relatively lower installation and generation costs. The gas turbines are also popular for using them as prime movers in combined cycle and cogeneration power plants. However, there is a continuing need for efficiency improvements of gas turbine cycles to ensure energy security and environmental impact mitigation. In this regard, Kurt, et. al. [1] reported that the performance of open cycle gas turbines is strongly influenced by some parameters like CIT, PR, and TIT. Many researchers consider exergy analysis as a tool for performance assessment of different gas turbine based power cycles. Ghaebi, et. al. [2] showed that the energy and exergy efficiencies of a gas turbine based trigeneration system can be improved with an increase in the PR and TIT values. Balli, et. al. [3] conducted an exergy analysis of a gas turbine cogeneration power plant and revealed that nearly 68% of the overall exergy destruction occurs in the combustion chamber. Investigating the effects of various cycle parameters on the thermodynamic performance of a gas turbine based combined cycle, Sanjay [4] concluded that exergy

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efficiency of the cycle can be enhanced by increasing the TIT and PR and that the major contributor in exergy destruction was combustor followed by gas turbine and compressor. Various studies regarding efficiency improvement of the gas turbine cycles by compressor inlet cooling method have been performed [5-7]. In this method, the compressor inlet air is cooled in order to increase the net power output and efficiency of the cycle which are drastically reduced at elevated ambient temperatures. As other methods of efficiency improvement, multistage air compression with intercooling, multistage gas expansion with reheating and regeneration have been discussed by Polyzakis, et. al. [8]. Both the design point and off design point performances were investigated in the paper in order to obtain the best option from the performance standpoint. Fang and Xu [9] discussed the importance of empirical models for simulation and analysis of turbine performance in different applications. An empirical model is developed in the paper which correlates the turbine efficiency with the expansion and velocity ratios by using the Taylor series and regression analysis. The proposed model was appended with a very high value of corrected coefficient of determination. Memon, et. al. [10] performed parametric study of simple and regenerative gas turbine cycles to show the variation of different performance, economic and environmental parameters with change in operating parameters. They also conducted regression analysis of the cycles with optimization.

In this paper, a detailed analysis is performed on a gas turbine cycle as against to treat it merely as topping cycle. From this perspective net power output, energy efficiency, exergy efficiency and fuel consumption have been considered as performance characteristics, while CIT, PR, and TIT are nominated as the operating parameters of the cycle. Through parametric study, the impact of operating parameters on performance characteristics is investigated and then optimal operating parameters are calculated for maximum performance values. In this regard a code in the EES (Engineering Equation Solver) software [11] is developed to model the cycle followed by the parametric study and optimization. Moreover, the multiple-linear and polynomial regression models are developed to evaluate the strength of the correlation exists between the performance characteristics (response variables) and operating parameters (predictor variables). To verify the models, statistical parameters like R^2(adj), the T- and F- values are also calculated. In this respect, a free version of the OriginPro software [12] is used. The regression models developed in this study have rarely been found in the literature related to gas turbine system analysis.

1.1 Process Description and Assumptions Made

An open cycle gas turbine system is depicted in Fig. 1. The fresh atmospheric air is drawn in the air compressor and compressed during a1-a2, followed by the combustion process in the combustion chamber during a2-g3. The hot combustion gas thus produced is expanded in the turbine, generating power during g3-g4. A part of the power produced is supplied to the air compressor. The hot exhaust gas is finally discharged to the atmosphere. The main assumptions made for the analysis are:

- Steady-state operation of system components.
- Ideal gas behavior by air and combustion gas constituents.
- Complete Combustion of natural gas (i.e. methane, CH_4) with chemical exergy only.
- Change in kinetic energy and potential energy of fluid streams neglected.

1.2 Thermodynamic Model Equations

In order to perform the cycle analysis, basic energy and exergy balances are used to establish the system model. Accordingly, the energy efficiency and exergy efficiency of the system are given respectively by:

$$EnE = \left[\frac{\eta_G \left(\dot{m}_g \left(h_{g3} - h_{g4} \right) - \dot{m}_a \left(h_{a2} - -h_{a1} \right) \right)}{\dot{m}_F \left(LHV \right)_F} \right] \qquad (1)$$

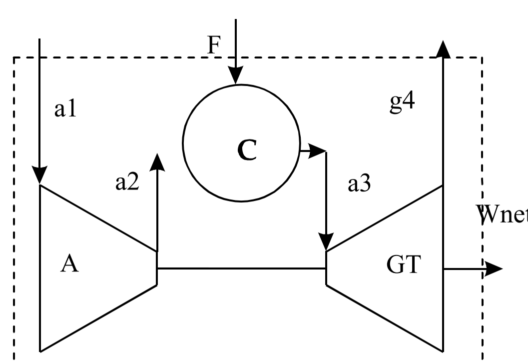

FIG. 1. A SIMPLE OPEN CYCLE GAS TURBINE SYSTEM

$$EnE = \left[\frac{\eta_G \left(\dot{m}_g \left(h_{g3} - h_{g4} \right) - \dot{m}_a \left(h_{a2} - - h_{a1} \right) \right)}{\dot{m}_F X_F} \right] \tag{2}$$

An approximate value for specific chemical exergy of gaseous hydrocarbon fuels C_jH_k is determined from [2] which is given as:

$$X_F = \left(1.033 + 0.0169 \frac{k}{j} - \frac{0.0698}{j} \right) \left(LVH \right)_F \tag{3}$$

The fuel consumption is calculated from:

$$\dot{m}_F = \left(\frac{M_F \bar{\bar{\lambda}}}{M_a} \right) \dot{m}_a \tag{4}$$

The fuel-to-air ratio is calculated from the chemical equation of complete combustion given as:

$$\bar{\lambda} CH_4 + \left(0.7748 N_2 + 0.2059 O_2 + 0.0003 CO_2 + 0.019 H_2O \right) \tag{5}$$

$$\rightarrow \left(1 + \bar{\lambda} \right) \left(\alpha_{O2} N_2 + \alpha_{CO2} CO_2 + \alpha_{HO2} H_2O \right)$$

$$\alpha_{N2} = \frac{0.7748}{1 + \bar{\lambda}}, \alpha_{O2} = \frac{0.2059}{1 + \bar{\lambda}}, \alpha_{CO2} = \frac{0.003}{1 + \bar{\lambda}}, \alpha_{H2O} = \frac{0.019 + 2\bar{\lambda}}{1 + \bar{\lambda}}$$

The rate of exergy destruction of different system components is determined from:

$$\dot{X}_{D,i} = \dot{X}_Q - \dot{X}_W + \sum \dot{X}_{in} - \sum \dot{X}_{out} \tag{6}$$

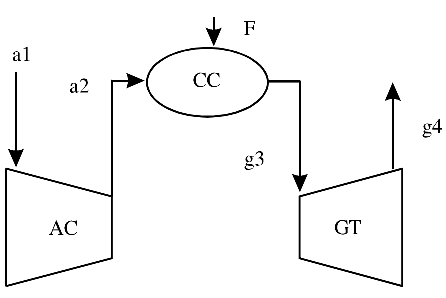

FIG. 1. A SIMPLE OPEN CYCLE GAS TURBINE SYSTEM

2. RESULTS AND DISCUSSION

In this section thermodynamic and regression analyses of the gas turbine system are presented, including assessments of the effects of varying operating parameters on the performance characteristics using the parametric study and development of model equations relating the response variables with predictor variables. The change in CIT, PR and TIT are considered in the ranges 288-328K, 4-36 and 900-1600K, respectively. The ranges of PR and TIT values selected for analysis have been adopted from the design values of leading gas turbine manufacturers, like General Electric (MS Model Series) and Siemens (SGT Model Series) for power generation [13,14].

2.1 Impacts of CIT and PR on Performance Characteristics

The variation of the selected performance characteristics with respect to CIT and PR are shown in Figs. 2-5 at TIT=1200K. Fig. 2 exhibits the variation in net power output with a variation in CIT and PR. The net power output increases as the CIT decreases for a given value of PR. This is due to an increase in air density as CIT increases; then at constant air mass flow rate, this lowers the compressor work and ultimately gives a higher net power output. For a given value of CIT, the net power output increases with an increase in the PR till it reaches 8, afterwards it starts to decrease, mainly due to rapid increase in the compressor work. It is also noted that the net power output decreases more rapidly with PR (beyond 8) at higher CIT values.

The variation in energy and exergy efficiencies with a change in CIT and PR values is shown in Figs. 3-4, respectively.

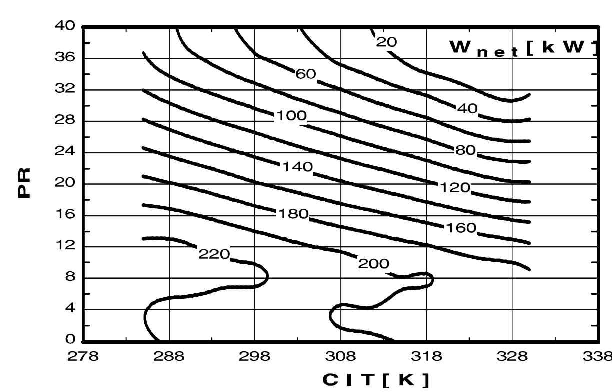

FIG. 2. VARIATION OF NET POWER OUTPUT WITH RESPECT TO CIT AND PR AT TIT=1200K

It is clear that the efficiencies increase as the CIT decreases and PR increases; reaches maximum at PR=16 for CIT=288 K and at PR=12 for CIT>288 K, then start to decrease as PR increases. This is due to reason that the increase in PR beyond its threshold values increases the compressor work more than it decreases the fuel consumption as discussed next.

Fig. 5 illustrates the effects of CIT and PR on the fuel consumption. It is clear that fuel consumption increases with a decrease in the CIT, for a given value of PR. Apparently, it is because the fuel consumption depends on the compressed air temperature which decreases with a decrease in CIT. This necessitates higher fuel-to-air ratio, thus higher fuel supply is required to maintain constant TIT. The fuel consumption tends to decrease with an increase in the PR, for a given value of CIT. This diminution is rapid at lower PR values. In this case, the compressed air temperature increases with an increase in the PR, which requires a lesser fuel supply.

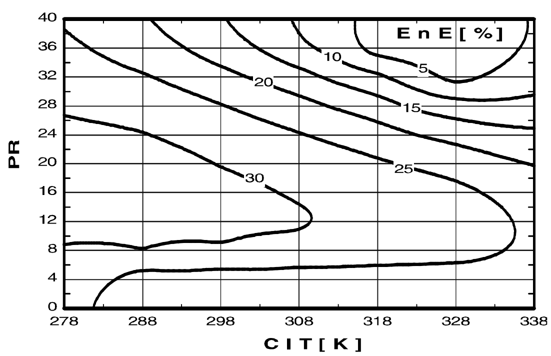

FIG. 3. VARIATION OF ENERGY EFFICIENCY WITH RESPECT TO CIT AND PR AT TIT=1200K

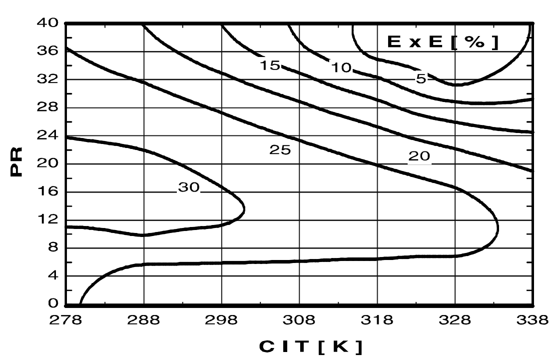

FIG. 4. VARIATION OF EXERGY EFFICIENCY WITH RESPECT TO CIT AND PR AT TIT=1200 K

2.2 Impacts of CIT and TIT on Performance Characteristics

The effects of CIT and TIT at PR=11 on the performance characteristics of the system are exhibited in Figs. 6-9. Fig. 6 exhibits the relationship between the net power output, CIT and TIT. It is apparent that the net power output increases with increase in the TIT, while it decreases with an increase in the CIT.

Figs. 7-8 illustrate the behavior of the energy efficiency and exergy efficiency, respectively, with respect to CIT and TIT. The efficiencies of the system increase with an increase in TIT and decrease in CIT values. The variation in efficiencies with respect to both TIT and CIT is noted more pronounced at lower values.

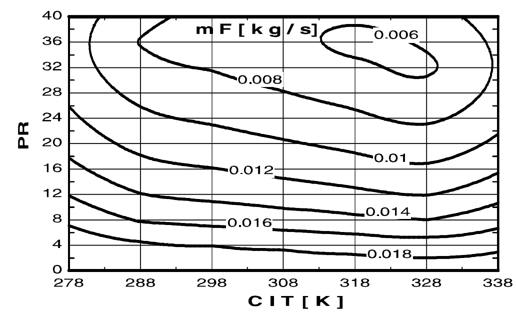

FIG. 5. VARIATION OF FUEL CONSUMPTION WITH RESPECT TO CIT AND PR AT TIT=1200 K

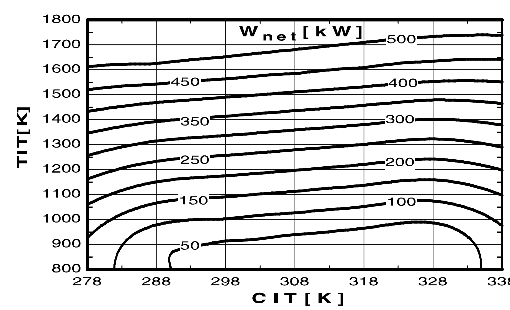

FIG. 6. VARIATION OF NET POWER OUTPUT WITH RESPECT TO CIT AND TIT AT PR=11

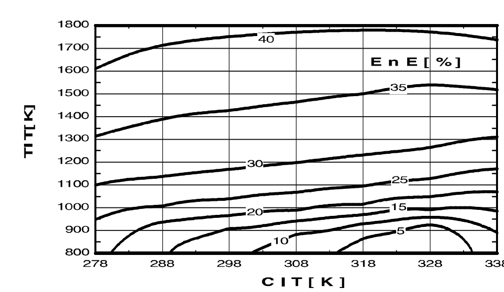

FIG. 7. VARIATION OF ENERGY EFFICIENCY WITH RESPECT TO CIT AND TIT AT PR=11

Fig. 9 exhibits variations in fuel consumption versus CIT and TIT. The fuel consumption increases as the TIT increases, whereas it decreases as the CIT increases. The corresponding variations in fuel consumption with respect to CIT and TIT are almost consistent for all values.

The results showing the effects of CIT have been compared well with the results in the literature. For instance, Farzaneh-Gord and Deymi-Dashtebayaz [7] have reported a decrease in gas turbine cycle thermal efficiency of 0.15% for a rise in the temperature of $1^{O}C$. Similarly, different performance characteristics of MS7001 model from GE have been greatly affected by the ambient temperature with a decrease of 22% of design output for an increase of $34^{O}C$ in the temperature [13].

It is evident from the above discussion that the cooling of inlet air is one of the available methods for performance improvement of gas turbines. Any method of inlet air cooling may be adopted with various configurations for almost all practical gas turbines. The inlet air cooling method has been classified into three groups, namely, evaporative cooling, spray inlet cooling or fogging and vapor compression cooling or absorption chillers. The detailed study of these methods can be found elsewhere [5-7]. The excessive energy loss as waste heat through the hot exhaust gas at higher TIT values can be recovered to reduce CIT by absorption refrigeration method. Another possible method of performance improvement by using the exhaust gas is a hybrid system to operate a steam cycle for power and/or cogeneration.

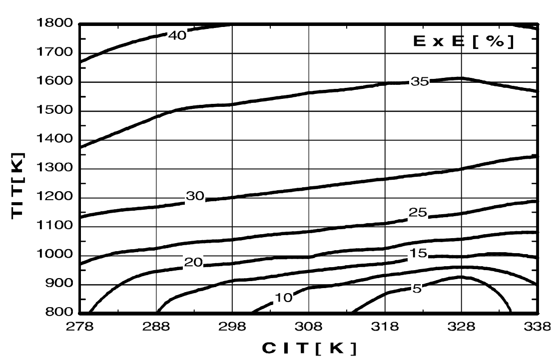

FIG. 8. VARIATION OF EXERGY EFFICIENCY WITH RESPECT TO CIT AND TIT AT PR=11

2.3 Impacts of PR and TIT on Performance Characteristics

Figs. 10-13 illustrate the effects of PR and TIT at CIT=288K on the performance characteristics of the system. Fig. 10 depicts variations in net power output with respect to PR and TIT. Results show that the net power output increases as the TIT increases. This increase is prominent at higher PR values. The net power output increases as the PR increases from 4-12 with TIT values between 1300 and 1600K, and from 4-8 with TIT between 1000 and 1300K, then starts to decrease. However, the net power output always decreases as the PR increases with TIT values between 900 and 1000K, since compressor work increases more than the turbine work as PR increases with lower TIT.

Figs. 11-12 shows the effects of PR and TIT on the energy and exergy efficiencies of the system at CIT=288K. The efficiencies increase with an increase in the TIT for a given value of PR. The efficiencies increase as PR increases from 4-32 with TIT values between 1500 and 1600K; from 4-28 with TIT values between 1400 and 1500; from 4-24 with TIT values between 1300 and 1400; from 4-20 with TIT values between 1200 and 1300; from 4-16 with TIT values between 1100 and 1200; from 4-12 with TIT values between 1000 and 1100; from 4-8 with TIT values between 900 and 1000; then starts to decrease. The change in efficiencies with respect to PR is significant at lower TIT values. It means that the efficiencies of the system can be improved by increasing both PR and TIT; the selection of optimum values depends upon the safe and economical operation of the system.

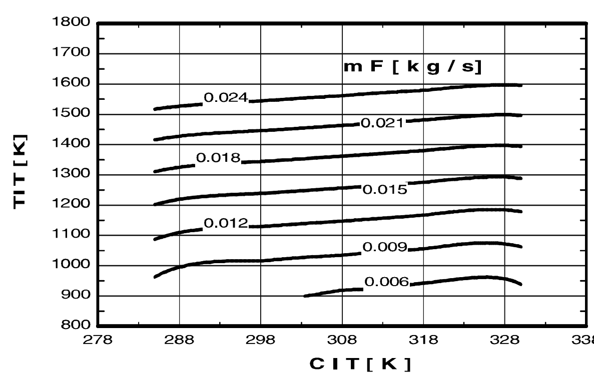

FIG. 9. VARIATION OF EXERGY EFFICIENCY WITH RESPECT TO CIT AND TIT AT PR=11

Fig. 13 exhibits the variation in fuel consumption with respect to PR and TIT. The fuel consumption increases as the TIT increases because extra energy is required to get a higher TIT value at constant PR. On the other hand, the fuel consumption decreases as the PR increases for a given value of TIT. This is because the temperature of compressed air that was increased at higher PR, resulting in a lower fuel supply at constant TIT. In both cases, the tendency of variation is nearly similar.

These results have been found in complete agreement with the literature reviewed. For instance, Sanjay [4] found an increase in the fuel consumption for an increase in the TIT and a decrease in the PR. At the design stage, the weight to output ratio for a gas turbine system depends on the value of PR. The former can be minimized on maximizing the latter. The increase in PR up to certain values also turns into efficiency gains at a given TIT.

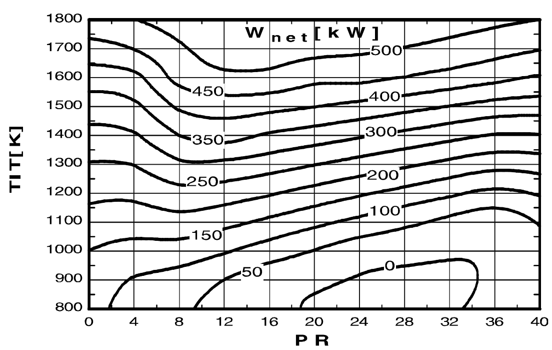

FIG. 10. VARIATION OF NET POWER OUTPUT WITH RESPECT TO PR AND TIT AT CIT=288 K

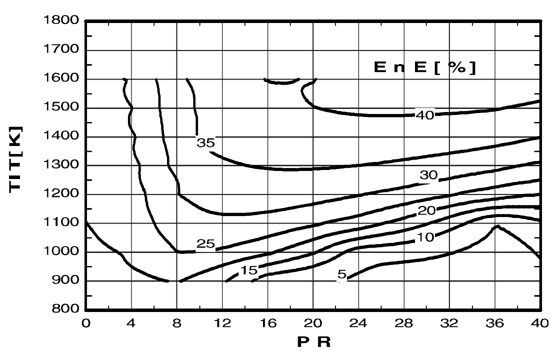

FIG. 11. VARIATION OF ENERGY EFFICIENCY WITH RESPECT TO PR AND TIT AT CIT=288 K

These results have been found in complete agreement with the literature reviewed. For instance, Sanjay [4] found an increase in the fuel consumption for an increase in the TIT and a decrease in the PR. At the design stage, the weight to output ratio for a gas turbine system depends on the value of PR. The former can be minimized on maximizing the latter. The increase in PR up to certain values also turns into efficiency gains at a given TIT.

For a simple cycle gas turbine to operate with safe thermal and mechanical limits of PR and TIT, efficiencies can be improved by the methods of multistage compression with intercooling (by saving work of compression), multistage expansion with reheating (by gaining work of expansion) and regeneration [8]. The trend in variation of different performance characteristics are compared well with similar model studied in [1].

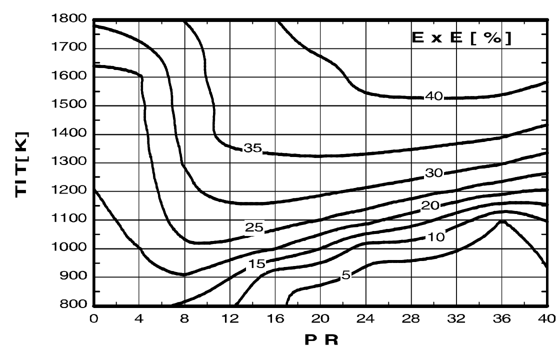

FIG. 12. VARIATION OF EXERGY EFFICIENCY WITH RESPECT TO PR AND TIT AT CIT=288 K

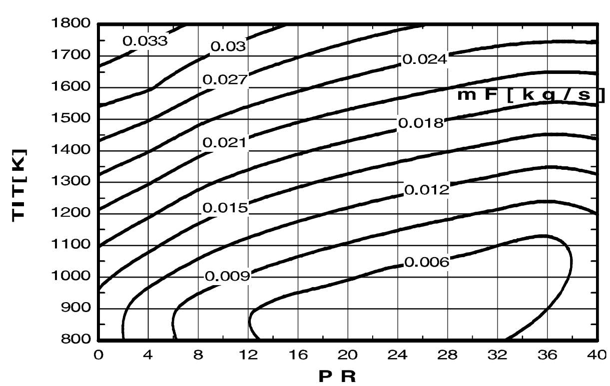

FIG. 13. VARIATION OF FUEL CONSUMPTION WITH RESPECT TO PR AND TIT AT CIT=288 K

3. OPTIMIZATION

Optimization is a process of minimization and/or maximization of objective functions by varying the single or multiple predictor variable(s). Here, net power output, energy and exergy efficiencies are considered as the objective functions with nomination of CIT, TIT and PR as the predictor variables. Such multidimensional optimization is processed by using Nelder-Mead simplex method included in the EES software. The results are tabulated in Table 1 which suggests that for maximum cycle performance, the optimal value of CIT is lowest and that of TIT is highest. Furthermore, the optimal value of PR for maximum net power output is considerably lower than that for maximum efficiencies which happens to be due to larger compressor work at higher PR values. Similarly, at higher PR values the air temperature entering the combustion chamber is higher which reduces the fuel required for a same unit's power output. This lead to an improvement in efficiencies of the cycle and therefore higher optimal PR is obtained for the maximum efficiencies. The optimal values obtained in this study are compared well with values obtained in [1].

4. EXERGY DESTRUCTION OF SYSTEM COMPONENTS

In this part an exergy destruction analysis of the system components is discussed, when the system is operated with optimal operating parameters. Fig. 14 illustrates the rate of exergy destruction and RXDR (Relative Exergy Destruction Ratio) of the system components for maximum efficiencies. According to the figure largest exergy destruction occurs in the combustion chamber, stem mainly from the irreversibilities associated with the combustion reaction, followed by the exergy loss due to stack. The air compressor, gas turbine and gas turbine mechanical shaft contribute only a small towards the total exergy destruction. It is also evident that the exergy destruction rate of the overall system is considerably reduced (mainly due to a reduction in the combustion chamber exergy destruction rate and stack gas exergy loss) when the system operates with maximum exergy efficiency. It is also evident that the quantity of the exergy destruction rate of the combustion chamber, exergy loss due to stack and overall system are decreased at lower CIT, and higher TIT and PR values. These results have been compared with the work in [1,3,4,8,10] and found satisfactory.

5. MULTIPLE REGRESSION MODELS

Multiple regression models are developed to examine how the multiple predictor variables are related to a response variable. For each performance characteristic, a best-fit regression equation is calculated (by the method of least squares), such that the distances between the parametric data points and the predicted values estimated by the equations are minimized. To check the accuracy of the approximation by the model equations, adjusted coefficient of determination is calculated which is defined as:

$$R^2(adj) = 1 - \frac{(n-1)}{n-(k+1)} \times \frac{\Sigma(y-\hat{y})^2}{\Sigma(y-\bar{y})^2} \quad (7)$$

where y is the simulated value, is the value from the approximation, is mean of the parametric data points, n is number of data points and k is total number of regressors (variables) in the model. A high R^2(adj) value indicates that the predictor variables, as a group, are a good estimator of the response variable. The F- and T- values along with their respective probabilities, P(F) and P(T) are also reported to test the significance of the models. The larger absolute F- and T-values, greater than 1.96 (for 95% confidence) with their respective probabilities equal to or less than 0.05 implies a statistically significant model. The analysis is based on the values of CIT, PR and TIT in ranges 288-328K, 4-36 and 900-1600K, respectively.

TABLE 1. OPTIMAL OPERATING PARAMETERS FOR MAXIMUM PERFORMANCE CHARACTERISTICS

Objective Functions	Maximum Value	Optimal CIT	Optimal TIT	Optimal PR
W_{net} (kW)	491.4	288 K	1600 K	13.18
EnE (%)	42.7	288 K	1600 K	33.06
ExE (%)	41.4	288 K	1600 K	33.85

Table 2 shows multiple regression models relating response variables to predictor variables at TIT=1200K. In case of net power output and fuel consumption, the MLR (Multiple Linear Regression) models fit the data well and are statistically significant. The MLR models of energy and exergy efficiencies are statistically significant, but appended with a very low R^2(adj) values. For these response variables MPR (Multiple Polynomial Regression) models are developed which produces very high R^2(adj) values. The models presented in Table 2 indicate that each performance characteristic is inversely proportional to CIT and PR at constant TIT.

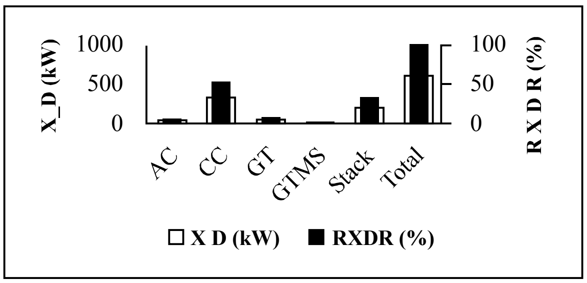

FIG. 14. EXERGY DESTRUCTION RATE AND RXDR OF DIFFERENT SYSTEM COMPONENTS FOR MAXIMUM EFFICIENCIES

Table 3 exhibits multiple regression models of the performance characteristics with respect to CIT and TIT at PR=11. The MLR models of the net power output and fuel consumption deliver a strong evidence of statistical significance with very high R^2(adj) values. In the case of energy and exergy efficiencies, the MPR models are developed which produce very high R^2(adj) value. The models in Table 3 show that each performance characteristic is inversely proportional to the CIT and directly proportional to the TIT at constant PR.

The multiple regression models of performance characteristics with respect to PR and TIT at CIT=288K are given in Table 4. The MLR models are developed to estimate the net power output and fuel consumption, which are statistically significant and appended with a high R^2(adj) values. The full MLR models of the energy and exergy efficiencies are statistically significant but with a very low R^2(adj) value. There is also an evidence of no statistically significant correlation between efficiencies and PR. Therefore, MPR models for these response variables are developed which produce very high R^2(adj) values. According to models exhibited in Table 4, each performance characteristic is inversely proportional to the PR and directly proportional to the TIT at constant CIT.

TABLE 2. MULTIPLE REGRESSION MODELS OF PERFORMANCE CHARACTERISTICS WITH RESPECT TO CIT (RANGE: 288-328 K) AND PR (RANGE: 4-36)

$z=a[CIT(K)]^2 + b[CIT(K)][PR] + c[PR]^2 + d[CIT(K)] + e[PR] + f$, TIT = 1200K										
z	a	b	c	d	e	f	T [P(T)] (CIT)	T [P(T)] (PR)	F [P(F)]	R^2(adj) (%)
$\dot{W}$ (kW)	0	0	0	-1.78	-5.67	799	-10.29 [0.000]	-23.76 [0.000]	323.27 [0.000]	93.7
EnE (%)	0	0	0	-0.238	-0.408	105	-4.43 [0.000]	-5.51 [0.000]	23.77 [0.000]	51.4
EnE (%)	-0.002	-0.0194	-0.0445	1.3877	7.3050	-211.8	-	-	-	96.7
ExE (%)	0	0	0	-0.231	-0.396	102	-4.43 [0.000]	-5.51 [0.000]	23.78 [0.000]	51.4
ExE (%)	-0.002	-0.0188	-0.0432	1.346	7.0856	-205.5	-	-	-	96.7
$\dot{m}_f$ (kg/s)	0	0	0	-6.2E-5	-3.4E-4	0.037	-7.80 [0.000]	-30.80 [0.000]	493.42 [0.000]	95.8

TABLE 3. MULTIPLE REGRESSION MODELS OF PERFORMANCE CHARACTERISTICS WITH RESPECT TO CIT (RANGE: 288-328 K) AND TIT (RANGE: 900-1600 K)

$z=a[CIT(K)]^2 + b[CIT(K)][TIT(K)] + c[TIT(K)]^2 + d[CIT] + e[TIT](K)] + f$, PR = 11										
z	a	b	c	d	e	f	T [P(T)] (CIT)	T [P(T)] (PR)	F [P(F)]	R^2 (adj) (%)
$\dot{W}$ (kW)	0	0	0	-1.39	0.614	-102	-24.9 [0.000]	178.3 [0.000]	16201 [0.000]	99.9
EnE (%)	0	0	0	-0.129	0.034	25.6	-3.1 [0.004]	13 [0.000]	88.5 [0.000]	81.8
EnE (%)	-9.3E-4	4.3E-4	-6.6E-5	-0.094	0.066	3.56	-	-	-	97.2
ExE (%)	0	0	0	-0.125	0.033	24.9	-3.1 [0.004]	13 [0.000]	88.5 [0.000]	81.8
ExE (%)	-9.0E-4	4.2E-4	-6.4E-5	-0.091	0.064	3.31	-	-	-	97.2
$\dot{m}_f$ (kg/s)	0	0	0	-5E-5	2.8E-5	-0.004	-20.9 [0.000]	183.6[0.000]	17071 [0.000]	99.9

TABLE 4. MULTIPLE REGRESSION MODELS OF PERFORMANCE CHARACTERISTICS WITH RESPECT TO PR (RANGE: 4-36) AND TIT (RANGE: 900-1600 K)

$z=a[PR]^2 + b[PR][TIT(K)] + c[TIT(K)]^2 + d[PR] + e[TIT](K)] + f$, CIT = 288K										
z	a	b	c	d	e	f	T [P(T)] (CIT)	T [P(T)] (PR)	F [P(F)]	R^2 (adj) (%)
$\dot{W}$ (kW)	0	0	0	-3.49	0.639	-513	-8.7 [0.000]	33.3 [0.000]	559.3 [0.000]	94.7
EnE (%)	0	0	0	0.0497	0.0351	-16.2	0.71 [0.479]	10.5 [0.000]	58.5 [0.000]	64.6
EnE (%)	-0.030	0.0023	-6.7E-5	-1.8	0.1685	-81.61	-	-	-	93.4
ExE (%)	0	0	0	0.0482	0.0340	-15.7	0.71 [0.479]	10.5 [0.000]	58.5 [0.000]	64.6
ExE (%)	-0.029	0.0022	-6.5E-5	- 1.75	0.1635	-79.17	-	-	-	93.4

4. CONCLUSIONS

This study conducted a comprehensive thermodynamic and statistical analysis of an open cycle gas turbine system. From a thermodynamic point of view, it is established that the CIT, PR and TIT are the key parameters which directly affects the performance of the system. It is determined that by increasing the TIT, the net power output, energy efficiency, exergy efficiency and fuel consumption tend to increase at given values of CIT and PR. Moreover, the net power output, energy efficiency, exergy efficiency and fuel consumption tend to decrease with an increase in the CIT for given values of PR and TIT. It is also found that the net power output, energy efficiency and exergy efficiency increase as the PR increases up to certain values, whereas the fuel consumption always decreases with PR at given values of CIT and TIT. The maximum value of the net power output is obtained at PR=12 when T=1600 and CIT=288K. The energy efficiency and exergy efficiency are maximum at PR=32 when TIT=1600 and CIT=288K. Hence optimum CIT and TIT values are 288 and 1600K, respectively, while the optimum PR value may be chosen from 12-32, depending upon the size and complexities of the system. It is, therefore, concluded that for attaining maximum performance the CIT should be maintained at lowest possible value whereas the TIT should be chosen at highest possible value. However, the former is restricted by additional energy use and costs in bringing down the inlet air temperature in the chillers and the latter is restricted by the metallurgical limits. From the exergy analysis, it is concluded that the largest exergy destruction occurs in the combustion chamber followed by the stack gas for all operating conditions. From the multiple regression analysis, a statistically significant relationship between the response and predictor variables is evinced. The models thus developed, found estimating each response variable with a great degree of accuracy.

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NOMENCLATURE

EnE	Energy Efficiency (%)
ExE	Exergy Efficiency (%)
h	Specific Enthalpy (kJ kg^{-1})
LHV	Lower Heating Value (kJ kg^{-1})
M	Molar Mass (kg $kmol^{-1}$)
$\dot{m}$	Mass Flow Rate (kg s^{-1})
P	Pressure (MPa)
R^2(adj)	Adjusted Coefficient of Determination(%)
T	Temperature, (K)
$\dot{W}$	Power (kW)
$\dot{x}$	Specific Exergy Flow (kJ kg^{-1})
$\dot{X}$	Exergytransfer Rate (kW)

ABBREVIATIONS

AC	Air Compressor
CC	Combustion Chamber
CIT	Compressor Inlet Temperature
GT	Gas Turbine
PR	Pressure Ratio
RXDR	Relative Exergy Destruction Ratio
TIT	Turbine Inlet Temperature

GREEK LETTERS

α	mole fractions of chemical species
$\bar{\lambda}$	molar fuel-to-air ratio (kmol fuel/kmol air)
η	efficiency

SUBSCRIPTS

α	air
D	destruction
F	fuel
g	combustion gas
i	ith component
in	influx
out	exflux
Q	heat
W	work
j	number of carbon
k	number of hydrogen

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