EXERGETIC EVALUATION OF DOUBLE HRSG COMBINED CYCLE GAS POWER PLANT

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***Abstract*:** Of late the scientists are concerned about the growing demand for power and trying to find the solution for it. Generally, power plants are outlined on the basis of exergetic performance criteria based on the first law of thermodynamics. The extremely valuable energy loss can't be defended by the first law of thermodynamics since it doesn't transform between the quality and quantity of energy. The analysis of exergy is for gaining information about the losses along with their locations qualitatively and quantitatively. The exergetic (thermodynamic) advancement enhances the exhibition of a framework by decreasing the exergy dest. and exergy losses(exergetic inefficiencies) and expanding exergy efficiency. This study indicates exergy efficiency is less at every stage of unit equipment. It also exhibits significant losses of accessible energy at the combustor, HRSG and gas turbine. The main purpose of this work is to examine the framework parts independently and to recognize and measure the areas possessing the greatest exergy and energy losses at different loads. Program code is set up utilizing EES software to present the estimations required for the exergy plant study considering actual variation scopes of the principle working parameters, for instance, AFR, and inlet temp. The impacts of these parameters on the framework exhibitions are explored.
Keywords: combined cycle, heat recovery steam generator, exergy, thermodynamic, Gas turbine.

1. INTRODUCTION

Energy systems contain an extremely large no. and some coordinated efforts with the outside world changing viewpoint, changing the technological and social ambiance in which various designs are feasibly going to be accepted, are the challenges faced by today's engineers. Wide particular energy and economy are some issues that ought to be addressed by the engineers. Because of the energy efficiency, waste which lowers poison releases ozone-depleting substances and operational flexibility, the CPP cycle has got an important consideration. A GPPC (topping cycle) and an SPPC (bottoming cycle) joined together through an HRSG are the main constituents of a combined cycle. Normally, first law analysis gives out energy applications regarding the conservation of energy. Both independently and quantitatively it cannot lead out the data with respect to the losses and cannot deduce the extent of losses. These situations drive us out to bring about exergy investigation from the viewpoint of the 2nd law of thermodynamics.

According to a particular sequence, thought of today's technological advancement in the field of execution and improvement of combined cycle GTPP, a short review of accessible writing was made. From the viewpoint of the optimization technique, numerous types of investigations. In this study, the survey shall feature the best basic technique: the exergo-economic method and the exergy dest. method. The gas turbine utilizing variables that affect the combined cycle gas turbine performance is as follows: the environment states turbine inlet temp. and compressor. The environment states, specifically environment temp., ambient pressure and the relative humidity of the air are the main factors that impact the gas turbine performance. In Iran, Ameri and hejazi[1] observed that the loss of 20% of the rated capacity of the 170MW Gas turbine units can be changed by a slight difference in the environment temp. To upgrade the gas turbine performance they preferred cooling the compressor's intake environment temp.and they came to know that for every 1^{o}C advancement in environment temp., the power output was decremented by .74%. Hosseini et al.[2] compared that if there is an increment in the environment temp. additionally decrements the compressors output pressure, which decreases the gas turbine cycle performance. They indicated that the decrement in the electric power output of the Gas turbine of about .5% and .90% and of about .27% for the combined cycle can be achieved by 1^{o}C advancement in the environment temp 1^{o}C.

NOMENCLATURE

X	Exergy
X_{dest}.	Exergy destruction
h	Specific Enthalpy
s	Specific Entropy
LCV	Low Calorific Value
$\dot{m}_a$	Mass Flow Rate of air
$\dot{m}_f$	Mass Flow Rate of fuel
CCGT	Combined cycle gas turbine
SPP	Steam power plant
HRSG	Heat Recovery Steam generator
Dest.	Destruction
Comb.	Combustion Chamber
AFR	Air Fuel Ratio

Temp	Temperature
AFR	Air Fuel Ratio
CCGT	Combined cycle gas turbine
CPPC	Combined power plant cycle
GPPC	Gas power plant cycle
SBCC	Supercharged boiler combined cycle

Ibrahim and Rahman[3] expressed the parametric thermodynamics examination of the CCGT. The range of efficiency recorded is about 61%. However, the total power output decreases with the increment in compressor ratio with unchangeable turbine inlet temp. and overall efficiency increases. Sanjay [4] concludes that the turbine inlet temp. and the exergy dest. are the main variables that affect the cycle performance so the inlet temp. the turbine should be kept on the higher side. Mansouri et al [5] analyzed the impact of pressure levels of steam production at heat recuperation steam generator HRSG on the exergetic and exergetic effectiveness of HRSG and combined cycle power plants. Their outcome exhibits that advancement in pressure levels of steam production at HRSG gives advancement in the exergy effectiveness of HRSG and CCPP advancement respectively. Furthermore, advancement in pressure levels at HRSG degrades the exergy dest. because of the heat transfer in HRSG. The exergetic efficiency of HRSG upgrades with the advancement in reheating the cycle and in pressure levels of steam generation. Xiang and chen [6] expressed a combined cycle with three pressure HRSG, equipped with the GEPG9351FA gas turbine. Their outcome manifests that upgrading to steam cycle efficiency when it is over 590ºC. Sayed an abdul moneim et al [7] examined the energy and exergy examination of a combined cycle with the supercharged boiler. The consequences specified that the SBCC leads the output power up to 2.1 times that of the traditional combined cycle. The SBCC efficiency was imitated to be lower than the traditional combined cycle. Fiaschi and Giampaolo [8] examined on exergy investigated of the semi-closed CCGT. They coined up that the main source of losses, constituting more than 80% of overall exergy dest. globally are combustion, water injection/mixing, HRSG and water recovery system. Cihan et al [9] brought out energy and exergy examination for a combined cycle in turkey. Their outcome exhibited that the main source of irreversibility's respectively over 85% of the overall exergy losses are combustion chambers, gas turbines and HRSGs Mousafarash and Ameri [10] their research was composed of a classic Gas turbine power plant. The outcome of their research gave out the highest exergy dest. happens in the combustion chamber, where the huge temp. the difference is the major source of irreversibility. They conducted an exergo-economic examination to find out the fuel cost. The outcome manifests that maximum exergy dest. in the combustion chamber.

2. THERMODYNAMIC ANALYSIS AND FORMULATION OF COMBINED CYCLE GAS TURBINE

2.1 Combined Cycle Gas Turbine System Description

Air is entered in Compressor, the air is compressed.Both pressure and temp. of air increase by supplying work input from turbine work on Compressor. The high-pressure air enters into the combustor, where fuel is supplied and burning of fuel at constant pressure, this supply of heat increase the max. cycle temp.(maximum cycle temp.) This maximum temp. gas goes to the turbine, then they expand from temp. and produce power, some produced power is used to run the Compressor. If the temp. of exhaust gases from gas turbine is more than 723K, HRSG- 1 will come in action otherwise HRSG-2 .then flue gases coming from gas turbine goes through HRSG, where exchange of energy from hot gases to feed water take place so that feed water becomes superheated steam by absorbing heat from flues gases then superheated steam goes through steam turbine where expansion of steam takes place and generates the work output (alternator to generate electricity). Steam from the steam turbine is then passed through the condenser where steam is converted into the water after losing its energy.

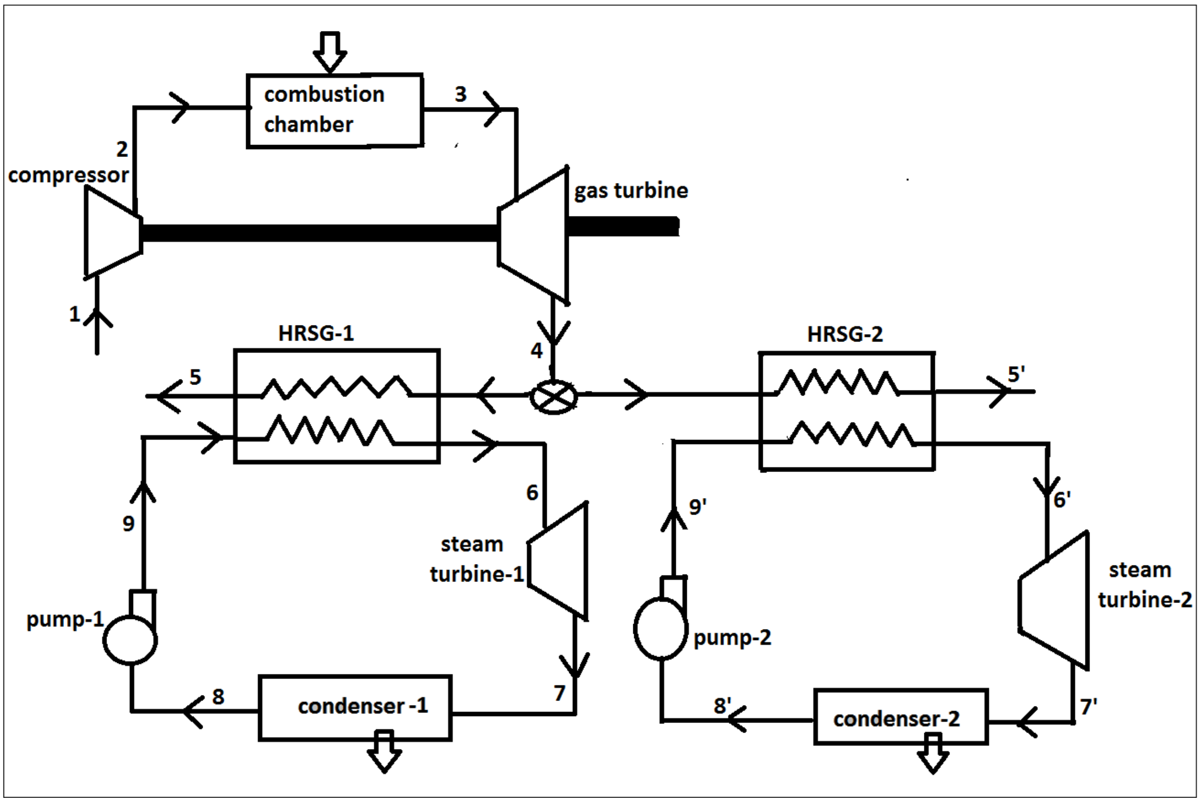

Figure 1: Combined cycle gas power plant

Table 1:Table indicating various points of schematic diagram

Point Number	Specification
1	Compressor inlet air
2	Compressor Outlet air
3	Gases coming from Combustion chamber
4	exhaust gas coming from the Gas turbine
5	Gases coming from HRSG -1
5’	Gases coming from HRSG -2
6	Steam enters Steam turbine -1
6’	steam enters Steam turbine -2
7	Steam coming from the Steam turbine -1
7’	Steam coming from the Steam turbine -2
8	liquid enters the feed water pump -1
8’	liquid enters the feed water pump -2
9	water coming HRSG – 1
9’	water coming HRSG – 2

3. MATHEMATICAL FORMULATION

Now, the analysis of CCGT depends on the following assumptions.

1. It operates at a steady state.
2. In the air and combustion products, ideal gas laws are applied.
3. CNG is used as fuel which is considered as an ideal gas.
4. The combustion process should be complete in the CC (combustion chamber)
5. Neglect the Pressure drop in all components of CCGT.
6. HRSG works on single pressure.

3.1 Compressor

Comp. work is given by $W_C = m_a(h_2 - h_1)$ 3.1

Exergy at point 1 is given by $X_1 = m_a[h_1 - h_O - T_O(s_1 - s_O)]$ 3.2

Exergy at point 2 is given by $X_2 = m_a[h_2 - h_O - T_O(s_2 - s_O)]$ 3.3

Exergetic destruction rate in a compressor is given by $\triangle X_{dest} = X_1 - X_2 + W_c$ 3.3

Exergetic efficiency of the compressor $\eta_{ex\,comp} = \frac{X_2 - X_1}{W_C}$ 3.4

3.2 Combustion Chamber

Exergetic destruction rate in the combustion chamber is given by $\Delta X_{dest} = X_2 + X_f - X_3$ 3.5

Exergetic efficiency of the compressor is given by $\eta_{ex\prime\,cc} = \frac{X_3}{X_2 + X_f}$ 3.6

Exergy of fuel is given by $X_f = X_{ph} + X_{ch}$ 3.6

Physical exergy of fuel is given by $X_{ph} = m_a[h_f - h_O - T_O(s_f - s_O)]$ 3.7

Chemical exergy of fuel is given by

$X_{ch} = \dot{m}_f e_{ch}$ 3.8

Where, $e_{ch} = \dot{x}_i e_{chi} + RT_O \sum x_i \log x_i + Ge$ 3.9

Where G_e is Gibbs free energy which is a neglected quantity in a gas mixture operated at lower pressure. Thus, the fuel exergy can be calculated as the ratio fuel exergy to low value of heating value of for fuel.

$\Omega = \frac{e_f}{LCV}$ 3.10

e_f is specific exergy of the fuel.

For gaseous fuel with creation $\boldsymbol{CxHy}$, the estimation of Ω can be determined as

$\Omega = 1.033 + 0.0169\frac{Y}{X} - \frac{0.0698}{X}$ 3.11

For Methane (CH4) X=1, Y=4

Then $\Omega = 1.06$ $X_f = \dot{m}_f(1.06 * LCV)$ 3.12

3.3 Gas Turbine

Exergy at point 3 is given by $X_4 = (\dot{m}_a + \dot{m}_f)[h_3 - h_O - T_O(s_3 - s_o)]$ 3.13

Exergy at point 4 is given by $X_4 = (\dot{m}_a + \dot{m}_f)[h_4 - h_O - T_O(S_4 - S_O)]$ 3.14

Turbine work is given by $W_{GT} = (\dot{m}_a + \dot{m}_f)[h_3 - h_4]$ 3.15

Exergetic destruction rate in a Gas turbine is given by $\triangle X_{dest} = X_3 - X_4 - W_{GT}$ 3.16

Exergetic efficiency of the compressor is given by $\eta_{ex'\,GT} = \frac{W_{GT}}{X_3 - X_4}$ 3.17

3.4 HRSG-1

Exergy at point 4 is given by $X_4 = (m_a + m_f)[(h_4 - h_0) - T_O(S_4 - S_O)]$ 3.18

Exergy at point 9 is given by $X_9 = (m_s)[(h_9 - h'_o) - T_O(S_9 - S_O)]$ 3.19

Exergy at point 5 is given by $X_5 = (m_a + m_f)[(h_5 - h_O) - T_O(S_5 - S_O)]$ 3.20

Exergy at point 6 is given by $X_6 = (m_s)[(h_6 - h'_O) - T_O(S_6 - S_O)]$ 3.21

Exergetic destruction rate in HRSG-1 is given $\Delta X_{dest} = (X_4 + X_9) - (X_5 + X_6)$ 3.22

Exergetic efficiency of HRSG-1 is given by $\eta_{HRSG-1} = \frac{X_9 - X_6}{X_4 - X_5}$ 3.23

3.5 HRSG-2

Exergy at point 4 is given by $X_4 = (m_a + m_f)[(h_4 - h_0) - T_O(S_4 - S_O)]$ 3.24

Exergy at point $9'$ is given by $X'_9 = (m'_s)[(h'_9 - h'_o) - T_O(S'_9 - S'_O)]$ 3.25

Exergy at point $5'$ is given by $X'_5 = (m_a + m_f)[(h'_5 - h_O) - T_O(S'_5 - S_O)]$ 3.26

Exergy at point $6'$ is given by $X'_6 = (m'_s)[(h'_6 - h'_O) - T_O(S'_6 - S'_O)]$ 3.27

Exergetic destruction rate in HRSG-2 is given by $\Delta X_{dest} = (X_4 + X'_9) - (X'_5 + X'_6)$ 3.28

Exergetic efficiency of HRSG-2 is given by $\eta_{HRSG-2} = \frac{X'_9 - X'_6}{X_4 - X'_5}$ 3.29

3.6 Steam Turbine-1

Exergy at point 4 is given by $X_6 = m_s[(h_6 - h'_O) - T_O(S_6 - S_O)]$ 3.30

Exergy at point 4 is given by $X_7 = m_s[(h_7 - h'_O) - T_O(S_7 - S_O)]$ 3.31

Steam turbine-1 work done is given by $W_{ST} = m_s(h_6 - h_7)$ 3.32

Exergetic destruction rate in Steam turbine-1 is given by $\Delta X_{dest} = X_6 - X_7 - W_{ST}$ 3.33

Exergetic efficiency of Steam turbine-1 is given by $\eta_{ex'ST} = \frac{W_{ST}}{X_6 - X_7}$ 3.34

3.7 Steam Turbine-2

Exergetic destruction rate in Steam turbine-2 is given by $\Delta' X_{dest} = X'_6 - X'_7 - W'_{ST}$ 3.35

Exergetic efficiency of Steam turbine-2 is given $\eta_{ex'\,ST} = \frac{W'_{ST}}{X'_6 - X'_7}$ 3.36

Exergy at point $6'$ is given by $X'_6 = m'_s[(h'_6 - h'_O) - T_O(S'_6 - S'_O)]$ 3.37

Exergy at point $7'$ is given by $X'_7 = m'_s[(h'_7 - h'_O) - T_O(S'_7 - S'_O)]$ 3.38

Steam turbine-1 work done is given by $W'_{ST} = m'_s(h'_6 - h'_7)$ 3.39

4. RESULTS AND DISCUSSION

Eventually,the study of manifested cycles on which the thermal power plant operates in respect of exergy losses of the effectiveness of a constituent in CPP network. Exergy dest. manifests a loss that can be regained by proper designing of various sections of the system and it demonstrates the best feasible process of the power plant as stated by the 2nd law of thermodynamics. The exergy dest. unveils a loss which can be resolved by the study mathematically, the energy and exergy are appreciable. In this research, the research is done on the CPPC.

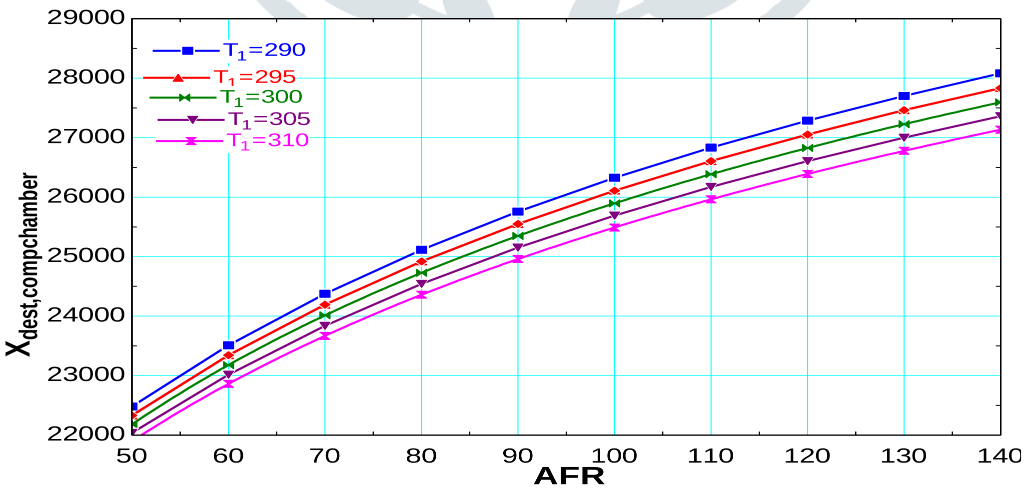

Figure 4.1: Exergy Dest. Rate of Combustion chamber at various inlet temp Vs Air Fuel Ratio

At various inlet temp of the air Compressor, the variation of Exergy dest. rate of the air Combustion Chamber as a function of AFR. In a period of 10, AFR was changed from 50 to 140 as shown in Fig 4.1. In a period of 5, the inlet temp of the compressor was changed from 290 to 310. As the AFR increases the exergy dest. rate of the Combustion Chamber increase. This is because of heat addition in the combustion chamber in a huge amount. At a particular AFR, as exergy dest. rate decrease with the increase of inlet temp of the Air Compressor. This occurs because increased in inlet temp, air receives by combustion chamber at a higher temp. so it required lower chemical energy.

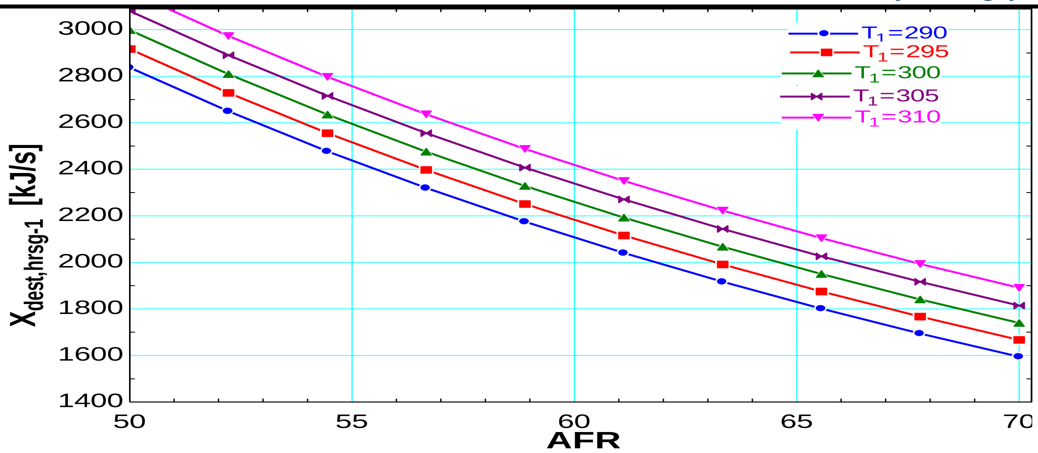

Figure 4.2: Exergy Dest. Rate of HRSG-1 at various inlet temp Vs Air-fuel Ratio

This CPPC uses two HRSG. If exit temp. of the gas turbine is more than 723K than HRSG-1 will come in action otherwise HRSG-2. At various inlet temp of the air Compressor, the variation of Exergy dest. rate of the HRSG-1 as a function of AFR. In a period of 5, AFR was changed from 50 to 70 as shown in Fig 4.2. In a period of 5, the inlet temp of the compressor was changed from 290 to 310. Exergy dest. rate decreases with an increase of AFR because at an initial value of AFR, temp of exhaust gas which enters in HRSG-1is high so that temp of exhaust gas which enters in HRSG-1 is decreasing as the AFR is increasing. At a certain AFR, exergy dest. rate increase with the increase of inlet temp of air Compressor. This is because of an increase in inlet temp. of air compressor, exhaust temp. of the Gas turbines also increase so that chance of exergy dest. rate increase in HRSG-1.

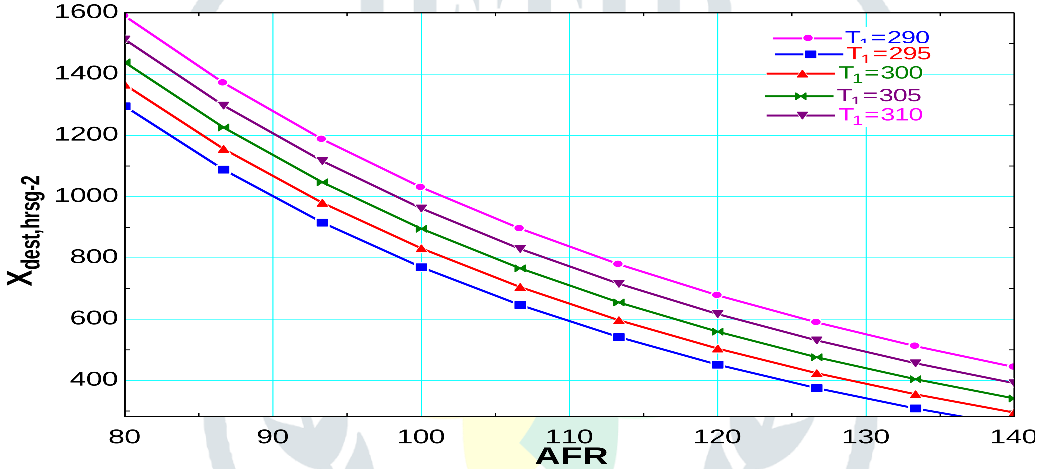

Figure 4.3:Exergy Dest. Rate of HRSG-2 at various inlet temp Vs air-fuel Ratio

At various inlet temp of the air Compressor, the variation of Exergy dest. rate of the HRSG-2 as a function of AFR. In a period of 10, AFR was changed from 80 to 140 as shown in Fig 4.3. In a period of 5, the inlet temp of the compressor was changed from 290 to 310The The variation of exergy dest. rate of HRSG-2 as a function of AFR at a different inlet temp of the air Compressor in Fig 4.3. AFR was changed from 80 to 140. Exergy dest. rate decrease with the increase of AFR similar to what happens in HRSG-1 but the value of dest. rate in HRSG-1 lower as compared to HRSG-2.At a certain AFR exergy dest. rate of HRSG-2 increase with the increase of inlet temp of air Compressor. In HRSG-2 less exergy dest. rate value as compared to HRSG-1 because HRSG-2 works on lower temp as compared to HRSG-2.

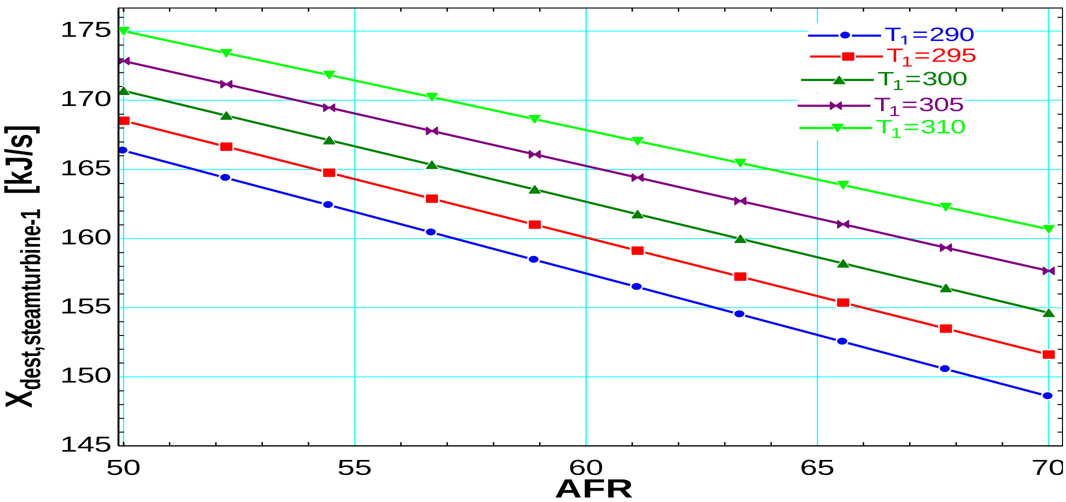

Figure 4.4:Exergy Dest. Rate of Steam turbine-1 at various inlet temp Vs air-fuel Ratio

At various inlet temp of the air Compressor, the variation of Exergy dest. rate of the Steam turbine-1 as a function of AFR. In a period of 5, AFR was changed from 50 to 70 as shown in Fig 4.4. In a period of 5, the inlet temp of the compressor was changed from 290 to 310. As the AFR increases the exergetic efficiency of Steam turbines-1 decrease because of the increase of AFR, mass flow rate of steam decrease so that low quantity of steam flow in Steam turbine-1 that's why exergy dest. of Steam turbines-1 decrease.

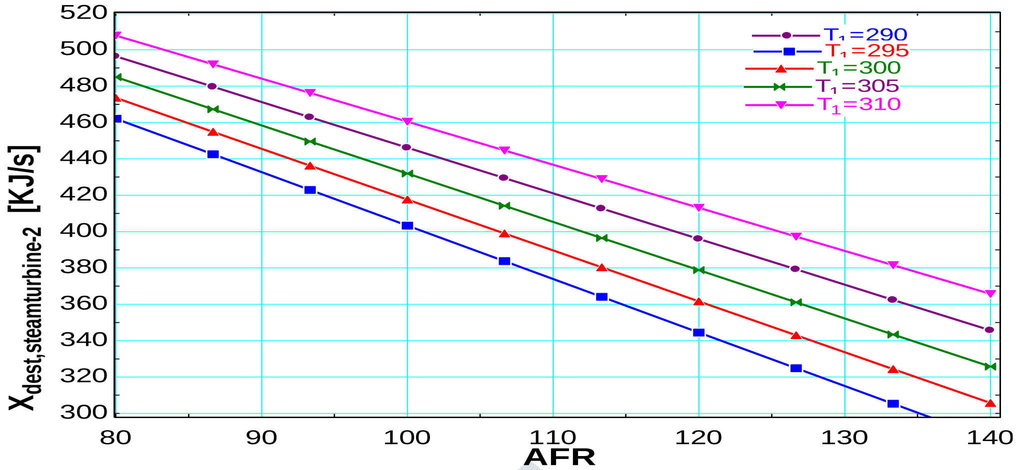

Figure 4.5:Exergy Dest. Rate of Steam turbine-2 at various inlet temp Vs air-fuel Ratio

At various inlet temp of the air Compressor, the variation of Exergy dest. rate of the Steam turbine-2 as a function of AFR. In a period of 10, AFR was changed from 80 to 140 as shown in Fig 4.5. In a period of 5, the inlet temp of the compressor was changed from 290 to 310. As the AFR increases exergy dest. rate of Steam turbines-2 decrease. The reason is the same as Steam turbine-1.

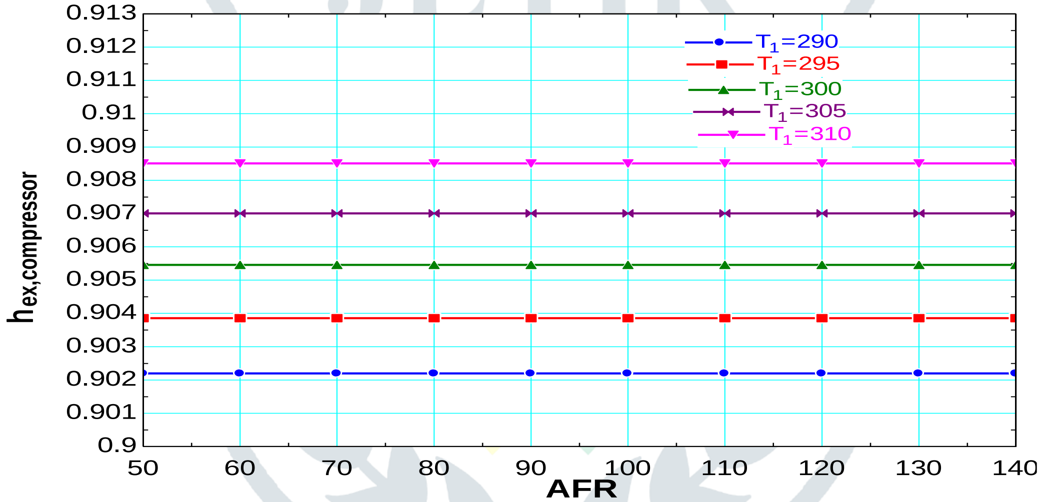

Figure 4.6:Exergetic efficiency of the Compressor at various inlet temp Vs Air Fuel Ratio

At various inlet temp of the air Compressor, the variation of Exergetic efficiency of air Compressor as a function of AFR. In a period of 10, AFR was changed from 80 to 140 as shown in Fig 4.6. In a period of 5, the inlet temp of the compressor was changed from 290 to 310. The mass of fuel is constant and that is equal to 1kg and the mass of air varies as the AFR varies. Exergetic efficiency does not change with the change in the AFR.because there is no addition of fuel in a compressor. Exergetic efficiency of the air Compressor is not a function of the AFR.

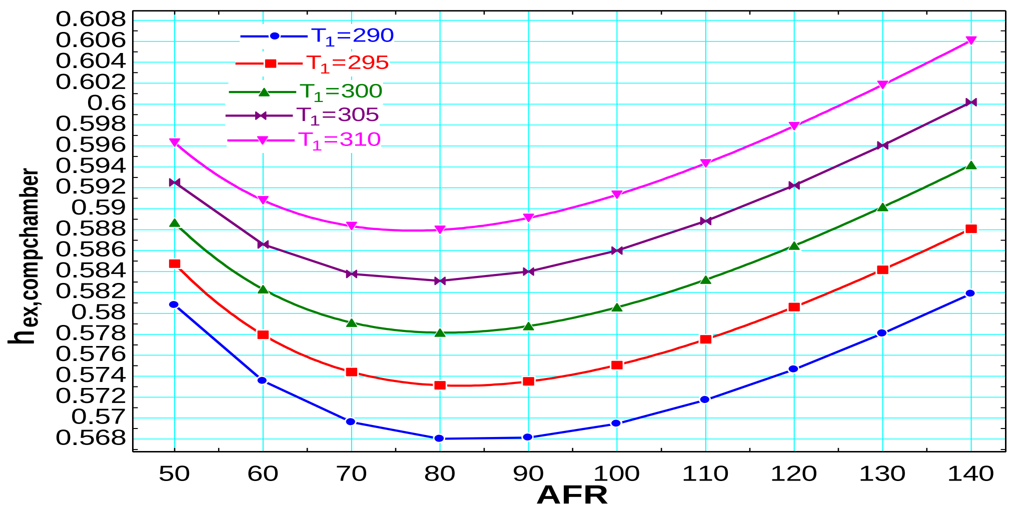

Figure 4.7:Exergetic Efficiency of Combustion Chamber at various inlet temp Vs Air Fuel Ratio

Fig.4.7. The variation of Exergetic efficiency of air Combustion Chamber as a function of AFR at a different inlet temp. of the air Compressor. As the AFR increases the exergetic efficiency of the Combustion Chamber decrease at a certain point after that it starts increasing. At a particular AFR, exergetic efficiency of air Combustion Chamber increase with the increase in inlet temp. of air Compressor because the required amount of heat in the Combustion Chamber is decreased by high temp. coming from the Compressor.

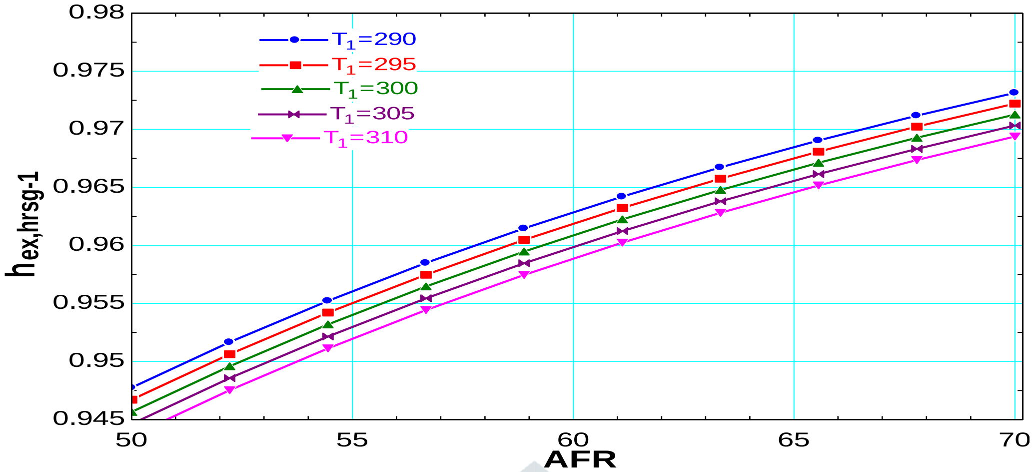

Figure 4.8:Exergetic Efficiency of HRSG-1 at various inlet temp Vs Air Fuel Ratio

At various inlet temp of the air Compressor, the variation of Exergetic efficiency of HRSG-1 as a function of AFR. In a period of 5, AFR was changed from 50 to 70 as shown in Fig 4.8. In a period of 5, the inlet temp of the compressor was changed from 290 to 310. As the AFR increases exergetic efficiency of HRSG-1 increases because of the temp.of hot gases entering will be low at higher AFR.

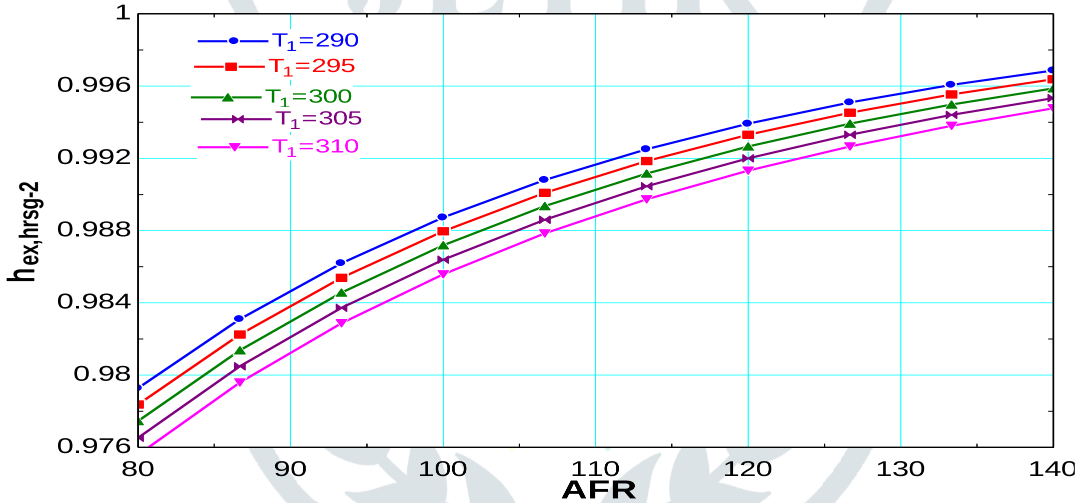

Figure 4.9:Exergetic Efficiency of HRSG-2 at various inlet temp Vs Air Fuel Ratio

At a various inlet temp of the air Compressor, the variation of Exergetic efficiency of HRSG-2 as a function of AFR. In a period of 10, AFR was changed from 80 to 140 as shown in Fig 4.9. In a period of 5, inlet temp of compressor was changed from 290 to 310. As the AFR increases the exergetic efficiency of HRSG-2 increase. The reason is the same as HRSG-1. At a particular AFR, Exergetic efficiency of gas turbine decrease with the increase of inlet temp. of air Compressor. In HRSG-2 value of exergetic efficiency is higher as compared to HRSG-1.

5. CONCLUSION

The key point of the exergy analysis is to differentiate the scope and the range of real energy losses to upgrade the ongoing systems or methods. The effect of different variables namely inlet temp. and pressure of system execution is analyzed in this report parametrically alongside 2nd law of thermodynamics of analysis of a thermal power plant has been performed in this report. CPPC oversee the growing energy requirement therefore, the distinctive analysis must be inclined to distinguish a methodology for the enhancement of these systems. The exergy examination manifested for a CPPC has disposed of statistics on the irreversibilities of each operation. The exergy analysis made for this composite plant exhibited that the prominent exergy losses exist in Combustion Chamber, gas turbine, and HRSG while most of the energy losses occur at the stack. The strategies suggested to enlarge the efficiency of plant is higher gas turbine inlet temp. using usual super compounds in gas turbine hot segments, Compressor inlet air cooling and a progressive strategy for the HRSG working variables.The exergy examination shows that he HRSG has the greatest effect component on the overall system and therefore, these further center of interest this thesis is on variables in optimization notable components were taken into analysis. Thus the and indicates that a decrement in the exergy dest. of HRSG component can enhance system performance.

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