iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 Issue: X Month of publication: October 2018

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue X, Oct 2018- Available at www.ijraset.com

Exergy Analysis of Combined Cycle Power Plant using Second Law of Thermodynamics

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Abstract: Maximum useful work that can be obtained from a system regarding dead state conditions is defined as exergy. Nowadays exergy analysis is a widely used tool for thermo dynamical analysis of the systems because thanks to exergy analys is possible improvements on the efficiency of the systems can be asserted. Exergy, basically consists of four terms. These constituents are physical, chemical, potential and kinetic exergy. In this paper, potential and kinetic exergies are neglected, only physical and chemical exergies are considered for calculations. The equations of exergy analysis are presented in the following parts. Physical exergy shows maximum work potential of system at initial conditions while chemical exergy is related with the change of chemical composition of a system from its equilibrium conditions. This all analysis is done on a combined cycle power plant to calculate the exergy.
Keywords: Exergy, Energy, second law, Combined cycle power plant, Gas Turbine

I. INTRODUCTION

There are two gas turbines, each is having capacity 110MW. But currently due to limiting supply of Natural gas, Only one GT is operating and generating approx. 73 MW of power, while other one is out of service. 1:50 gas-air ratio is used. Gas turbines are aero derivative in nature

It is consisting of following components:

1) *Two air filters* are equipped with each gas turbine. air filters do not allow unwanted suspended particles to enter which could reduce GT efficiency. It is derived with powerful motor. It consisting of electrostatic prefilter, bag filter and charcoal filter. These air filters are aimed to reduce temperature of air during summers by cooling it with evaporative cooling method. These are also designed to control moisture content .
2) *The compressor*, which draws air into the engine, pressurizes it, and feeds it to the combustion chamber at speeds of hundreds of miles per hour.19 stage compressor is equipped in GT.
3) *The combustion chamber*, typically made up of a ring of fuel injectors that inject a steady stream of fuel into combustion chambers where it mixes with the air. The mixture is burned at temperatures of more than 1200^0C degrees F. The combustion produces a high temperature, high pressure gas stream that enters and expands through the turbine section.
4) *The turbine* is an intricate array of alternate stationary and rotating aero foil-section blades. As hot combustion gas expands through the turbine, it spins the rotating blades. The rotating blades perform a dual function: they drive the compressor to draw more pressurized air into the combustion section, and they spin a generator to produce electricity
5) stack is associated with Gas turbine for exhaust gases which are coming out of gas turbines at temp 574^0C where as temperature is maintained less than 120^0C so to prevent formation of NOx .This facility is actually for bypassing exhaust gases directly into atmosphere in case HRSG is under maintenance.
6) Water spray Facility present along passage section of exhaust gases to arrest SOx, NOx , HCs and others harmful gases and particulates before letting them go along with flue gases into HRSG.
7) flue gases (exhaust gases from gas turbines having temp 570^0C) of high enthalpy are utilized to convert water into steam and hence power is generated via steam turbine. This whole process of heat recovery takes place in HRSG(Heat Recovery Steam generator) unit. A HRSG generates steam by capturing heat from the turbine exhaust. These boilers are also known as heat recovery steam generators. High-pressure steam from these boilers can be used to generate additional electric power with steam turbines, a configuration called a combined cycle.
8) Another way to boost efficiency is to install a recuperator to recover energy from the turbine's exhaust. A recuperator captures waste heat in the turbine exhaust system to preheat the compressor discharge air before it enters the combustion chamber.

II. LITERATURE REVIEW

Polyzakis et al, shown that the power output decreases as TIT is reduced. Sanjay et al. [8], shows the effect of TIT on blade coolant requirement for various cooling means for an allowable blade surface temperature of 1123 K. As expected for all cooling means coolant requirement increases with increase in TIT. It shows clearly that if TIT is increased beyond 1700 K (temperature level in modern turbines), steam cooling is the best coolant option whereas, for air-cooling, ATC, followed by AFC (Automatic Flow Control)are the next best options. Sanjay et al, shows the effect of turbine inlet temperature (TIT) on coolant mass flow rate for different values of compressor pressure ratio and for a fixed value of maximum blade surface temperature and reheat pressure ratio of 2.8. The coolant (steam) flow requirement increases with increase in TIT expectedly. The quantity of coolant flow requirement in case of steam coolant is significantly less than that when compressor bled air is used. Ibrahim et al, found overall thermal efficiency for regenerative gas turbine configuration very significance with lower compression ratio it reaches to 64.6% at compression ratio 6.4. But when the compression ratio increases the overall thermal efficiency of combined cycle with regenerative gas turbine configuration decreases, because, when compression ratio increases, temperature of the exhaust gases from the turbine decrease and temperature of air in outlet of compressor increases, so, the recovered thermal energy in regenerative heat exchanger falls until zero.

III. DIFFERENT OPERATING PARAMETERS AFFECTING PERFORMANCE OF CCPP

The major operating parameters which influence the combined

A. Cycle performance
B. Turbine inlet temperature
C. Compressor pressure ratio
D. Pinch point
E. Ambient Temperature
F. Pressure levels

IV. PERFORMANCE ANALYSIS OF DCCPP

In this study. Currently GT 1 and HRSG#1 are active while GT 2 and HRSG#2 are both inactive, so thermo-physical properties is available only for GT1 and HRSG#1. Energy analysis of an active CCPP (Combined Cycle Power Plant) is performed with the help of the actual operating data taken from the computer control unit of the plant. For the thermo dynamical performance assessment of the plant, energy analysis, related with the first law of thermodynamics is performed.
Some assumptions are made during the calculations. These assumptions can be given as,

1) The flow is steady state.
2) Air and combustion products are assumed as ideal gas. Molar fractions of the components of air and combustion products are shown in Tables2 and 3 respectively.
3) Dead state conditions are taken as P_0 =101.325kPaand T_0=298.15K.
4) Heat transfer between the components of plant and environment is negligible.

In the following section, performance analysis methods are explained. The equations, thermo physical properties of the working fluids and the thermo dynamical analysis of the components of power plant are given in the following parts. Given equations are used for parametric analysis of the system and obtained results are compared with actual operating results.

V. ENERGY ANALYSIS (USING SECOND LAW OF THERMODYNAMICS)

Exergy balance and exergy destruction equations of the system components

A. Compressor

$$\dot{E}_{x,1} + \dot{W}_{comp} = \dot{E}_{x,2} + \dot{I}_{dest,comp}$$

Using data, $\dot{E}_{x,1}$ = 53,125 KW, $\dot{W}_{comp}$ = 50,700KW, $\dot{E}_{x,2}$ = 46,483 KW

$$\dot{I}_{dest,comp} = 4295.12KW$$

$$\eta_{II,Comp} = \frac{\sum E_e}{\sum E_i} = 91.53\%$$

B. Combustion Chamber

$\dot{E}_{x,2} + \dot{E}_{x,22} = \dot{E}_{x,3} + \dot{I}_{dest,CC}$

Using data, $\dot{E}_{x,3} = 146{,}243.3\ KW$, $\dot{E}_{x,22} = 164{,}899\ KW$, $\dot{E}_{x,2} = 46{,}483\ KW$

$\dot{I}_{dest,CC} = 57140 KW$

$\eta_{II,CC} = \frac{\sum E_e}{\sum E_i} = 69.15\%$

C. Gas Turbine

$\dot{E}_{x,3} = \dot{E}_{x,4} + \dot{W}_{GT} + \dot{I}_{dest,GT}$

Using data, $\dot{E}_{x,4} = 70{,}000 KW$, $\dot{W}_{GT} = 74000 KW$, $\dot{E}_{x,3} = 154{,}338\ KW$

$\dot{I}_{dest,GT} = 10{,}338 KW$

$\dot{\eta}_{II,GT} = \frac{\sum E_e}{\sum E_i} = 92\%$

D. HRSG

$\dot{E}_{x,4} + \dot{E}_{x,14} + \dot{E}_{x,13} = \dot{E}_{x,9} + \dot{E}_{x,10} + \dot{E}_{x,17} + \dot{I}_{dest,HRSG}$

Using data,$\dot{E}_{x,4} = 70000 KW$, $\dot{E}_{x,14} = 304.11 KW$, $\dot{E}_{x,13} = 3689.9 KW$, $\dot{E}_{x,9} = 61{,}172.8 KW$, $\dot{E}_{x,10} = 3413.7 KW$

$\dot{E}_{x,17} = 976.37 W$

$\dot{I}_{dest,HRSG} = 8431.14 KW$

$\dot{\eta}_{II,HRSG} = \frac{\sum E_e}{\sum E_i} = 88.6\%$

E. Steam Turbine

$\dot{E}_{x,9} + \dot{E}_{x,10} = \dot{E}_{x,19} + \dot{W}_{ST} + \dot{I}_{dest,ST}$

$\dot{E}_{x,9} = 61{,}172 KW$, $\dot{E}_{x,10} = 3413.7 KW$, $\dot{E}_{x,19} = 177.12$, $\dot{W}_{ST} = 34{,}820 KW$

$\dot{I}_{dest,ST} = 29{,}588$KW

$\dot{\eta}_{II,ST} = \frac{\sum E_e}{\sum E_i} = 54.18$

F. Condensor

$\dot{E}_{x,19} + \dot{W}_{cond} = \dot{E}_{x,20} + \dot{I}_{dest,cond}$

$\dot{E}_{x,19} = 135.75 KW$, $\dot{W}_{cond} = 119 KW$, $\dot{E}_{x,20}$=150.55KW

$\dot{I}_{dest,cond} = 104.2 KW$

$\eta_{II,cond}$ =58.88%

G. H.P. and L.P. Pumps

$\dot{E}_{x,22} + \dot{W}_{HP} = \dot{E}_{x,23} + \dot{I}_{dest,HP}$

$\dot{E}_{x,22} = 292.34 KW$, $\dot{W}_{HP} = 527.46 KW$, $\dot{E}_{x,23} = 806.4 KW$

$\dot{I}_{dest,HP} = 13.422$

$\dot{\eta}_{II,HP} = \frac{\sum E_e}{\sum E_i}$=98.36

$\dot{E}_{x,22'} + \dot{W}_{LP} = \dot{E}_{x,23'} + \dot{I}_{dest,LP}$

$\dot{E}_{x,22'} = 29.43 KW$, $\dot{W}_{LP} = 6.03 KW$, $\dot{E}_{x,23'} = 31.14 KW$

$\dot{I}_{dest,LP}$ =4.32KW

$\dot{\eta}_{II,LP} = \frac{\sum E_e}{\sum E_i}$=87.81%

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VI. RESULTS AND DISCUSSION

The exergy efficiencies of the components of the investigated CCPP and the exergy efficiencies of the equipment's are presented graphically, shows the percentage distribution of exergy destruction rates for the each system component. It is found out that Steam Turbine, condensor and Combustion Chamber were among those having low exergy efficiency which are 54.18%, 58.88% and 69.15%.respectively. While 52% of exergy destruction takes place in the combustion chamber and also the maximum rate of exergy destruction takes place in the combustion chamber with the rate of 57,140kW.

Fig 1 : Percentage distribution of exergy distribution rates

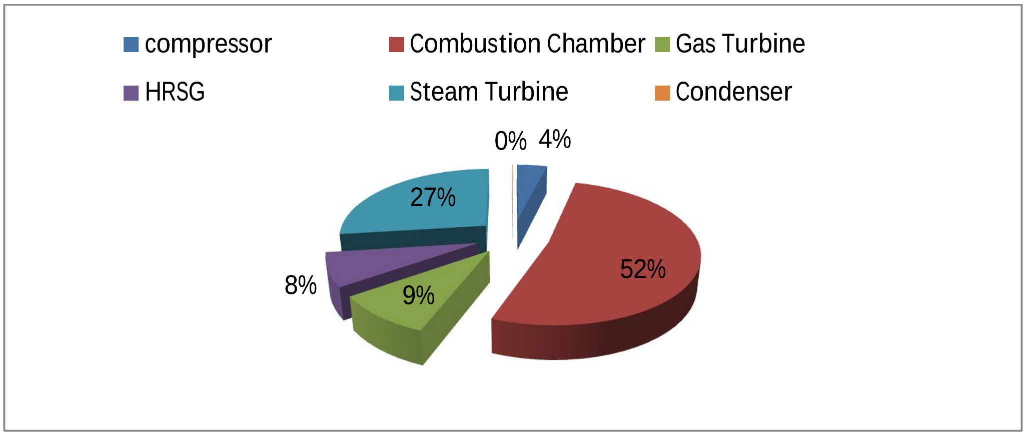
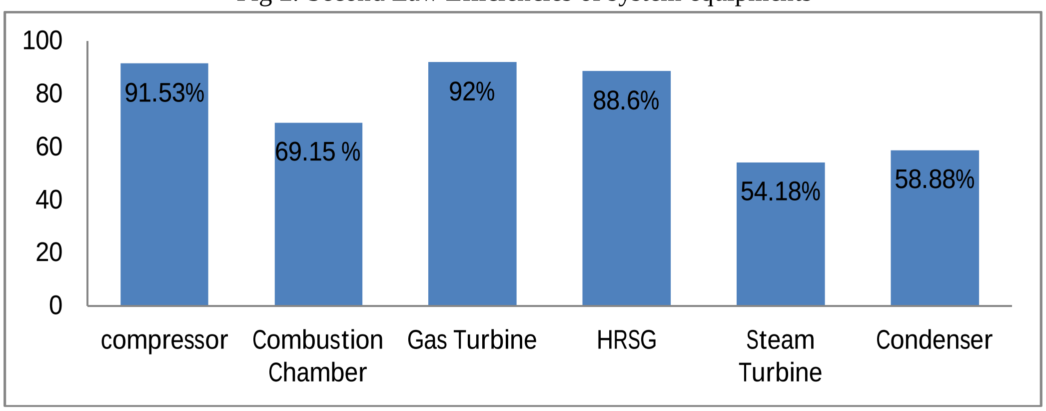


Fig 2: Second Law Efficiencies of system equipments



Exergy analysis of the studied, CCPP is calculated and second law efficiencies of the top cycle and CCPP system are found as 44.08% and 65.84% respectively.

VII. CONCLUSION

Chlorides, nitrates and sulfates can deposit on compressor blades and may result in stress corrosion attack and/or cause corrosion Pitting. Sodium and potassium are alkali metals that can combine with Sulfur to form a highly corrosive agent and that will attack portions of the hot gas path. The contaminants are removed by passing through various types of filters which are present on the way. Gas phase contaminants such as ammonia or sulfur cannot be removed by filtration. Special methods are involved for this purpose. To control the emissions in the exhaust gas so that it remains within permitted levels as it enters the atmosphere, the exhaust gas passes through two catalysts located in the HRSG.

One catalyst controls Carbon Monoxide (CO) emissions and the other catalyst controls Oxides of Nitrogen, (NOx) emissions. Aqueous Ammonia – In addition to the SCR, Aqueous Ammonia (a mixture of 22% ammonia and 78% water) is injected into system to even further reduce levels of NOx.

The advances in cogeneration-the process of simultaneously producing useful heat and electricity from the same fuel source-which increases the efficiency of fuel burning from 30% to 90%, thereby reducing damage to the environment while increasing economic output through more efficient use of resources

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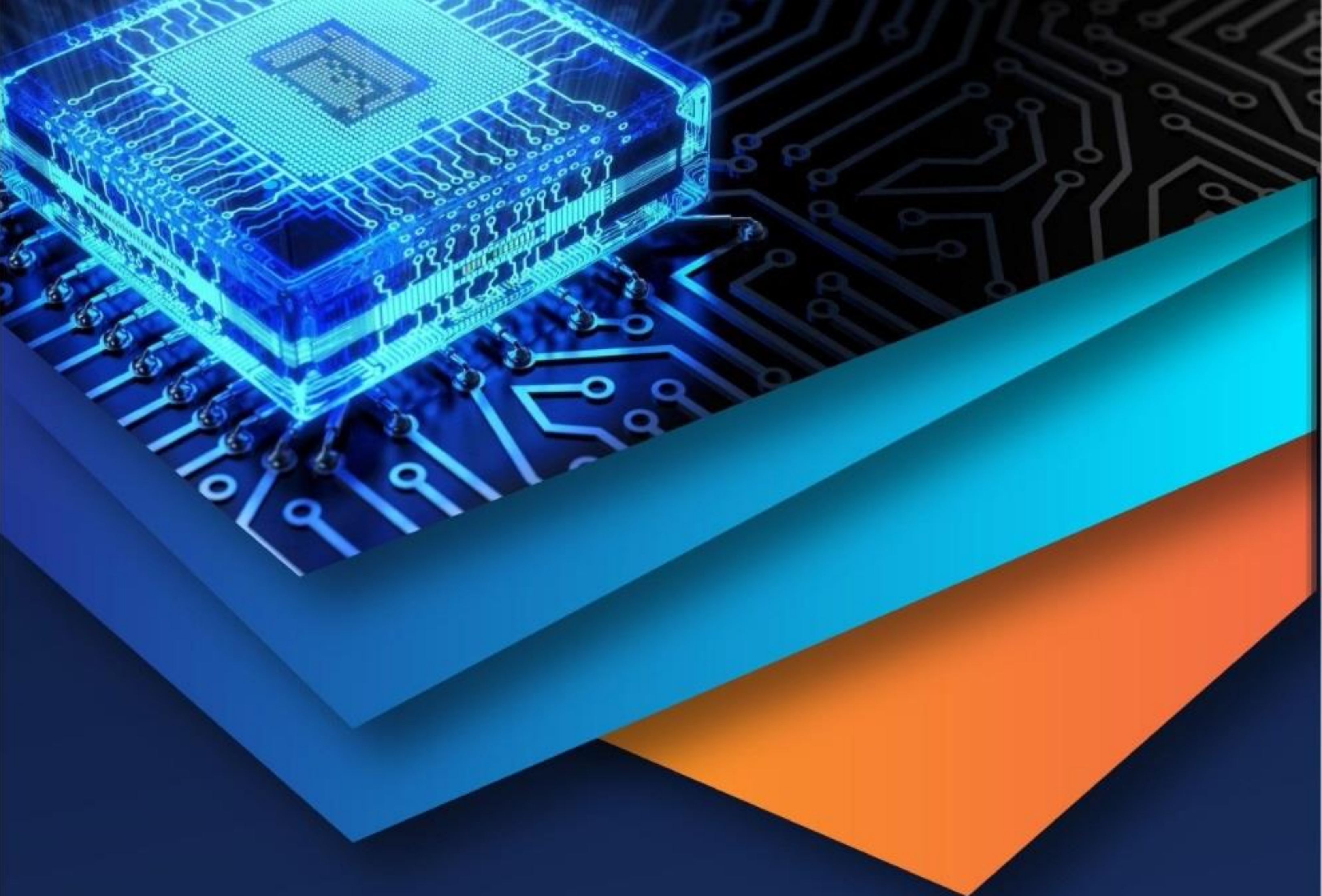

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