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EXERGETIC ANALYSIS OF A SINGLE PRESSURE HEAT RECOVERY STEAM GENERATOR

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Abstract
In this study, a comprehensive exergy analysis is done on a One pressure level (single pressure) heat recovery steam generator of a Combined cycle power plant (CCPP) consisting of two gas turbine cycles as topping cycle and a steam turbine with single pressure HRSG as bottoming cycle. The role and impact of both first and second law efficiencies are analysed to understand the performance of HRSG. The exergy destruction rate and exergetic efficiency are the two terms to judge the quality of net available energy and losses passing through the particular component and whole system so done with HRSG in this paper.A program code is established using MATLAB software to perform the calculations required for the exergy plant analysis considering real variation ranges of the main operating parameters such as pressure ratio, air fuel ratio and inlet temperature. The effects of theses parameters on the system performances are investigated.

Keywords: *Heat recovery steam generator, Combined cycle power plant, Exergy Analysis, 2nd law efficiency, Brayton Cycle, Steam Turbine.*

1. Introduction:

Combined-cycle power plant (CCPP) is one of the most widespread energy conversion systems used around the world today. Because the demand for energy is growing, optimization of energy conversion systems is indispensable. In combined cycle power plant (CCPP) system, Brayton cycle as topping and one Rankine cycle as bottoming cycle is used in synchronisation through HRSG (Heat Recovery steam generator) to achieve maximum power output by utilizing the exhaust of gas turbine. Combined-cycle systems using Brayton Cycle gas turbine and Rankine Cycle steam system with air and water/steam as working fluids can achieve efficient, reliable, and economic power generation.

Efficiency of CCPP depends upon various factors as exhaust temperature from gas turbine, effectiveness of Heat Exchangers (Combustion chamber, HRSG and Condenser) and power consumed by air compressor.

2. Exergy Analysis:

In order to have an idea of the present methodology development in the area of performance and optimization of combined cycle gas turbine power plant, a brief survey of available literature was made. However, this paper is concerned with a review of literature on optimization performed on various thermal systems. In general, some authors focus on the gas turbine operating parameters (topping cycle), others optimize the steam plant (bottoming cycle) on the basis of a given gas turbine, whereas others propose appropriate optimization methods for the whole combined cycle power plant.Furthermore, the optimization can be analysed from a thermodynamic point of view, according to the first and/or second law analysis, or using a thermo economic or environmental-economic strategy (Kaviri et al [1], Ahmadi and Dincer [2], Boyano et al [3] and Petrakopoulou et al [4]). From the point of view of optimization methodology, there are many types of analyses. In this work, the review will highlight most common methodology: the exergy destruction method, and the exergoeconomic method.Fiaschi and Giampaolo [5] investigated an exergy analysis of the semi-closed gas turbine combined cycle. They concluded that combustion, heat recovery steam generator, water injection/mixing, and water recovery system are the main sources of the losses, representing globally more than 80% of the overall exergy destruction. Cihan et al [6] carried out energy and exergy analyses for a combined cycle located in Turkey, and suggested modifications to decrease the exergy destruction in CCPPs. Their results showed that combustion chambers, gas turbines, and HRSGs are the main sources of irreversibilities, representing over 85% of the overall exergy losses. Butcher and Reddy [7] carried out exergy analysis for waste heat recovery based power generation system. The performance of the waste heat recovery power generation systems based on second law analysis was investigated for various operating conditions. The temperature profiles across the heat recovery steam generator (HRSG), network output, second law efficiency, and entropy generation number were simulated for various operating conditions. The variation in specific heat with exhaust gas composition and temperature were accounted in the analysis and results. The effect of pinch point on the performance of HRSG, entropy generation rate and second law efficiency were also investigated.Ibrahim and Rahman [8] performed a parametric thermodynamic analysis of a combined cycle gas turbine. They investigated the effect of operating parameters, compression ratio, gas-turbine peak temperature ratio, isentropic compressor and efficiency and air fuel ratio on the overall plant performance. Their results show that the compression ratios, air to fuel ratio as well as the isentropic efficiencies are strongly influenced by the overall thermal efficiency of the combined cycle gas turbine power plant. The overall thermal efficiency increases with compression ratio as well as isentropic compressor and turbine efficiency. However, the variation of overall thermal efficiency is minor at the lower compression ratio while it is very significant at the higher compression ratio for both isentropic compressor and turbine efficiency. The overall efficiencies for combined cycle gas turbine are much higher than the efficiencies of gas turbine plants. Efficiency quoted range is about 61%. In addition, the overall thermal efficiency increases and total power output decreases linearly with the increase of the compression ratio with constant turbine inlet temperature. The peak overall efficiency occurs at the higher compression ratio with the higher cycle peak temperature ratio as well as higher isentropic compressor and turbine efficiencies. Kamate and Gangavati [9] analysed cogeneration power plants in sugar industries through exergy destruction method for various steam inlet condition. The result shows that, at optimal steam inlet conditions of 61 bar and 475 C, the backpressure steam turbine cogeneration plant perform with energy and exergy efficiency of 0.863 and 0.307, while the condensing steam turbine plant perform with energy and exergy efficiency of 0.682 and 0.26, respectively. Boiler is the least efficient component and turbine is the most efficient component of the plant.Aljundi [10] studied energy and exergy analysis of a steam power plant in Jordan using exergy destruction method. A component wise modelling and a detailed break-up of energy and exergy losses estimated the performance of the plant. The modelling shows that the thermal efficiency (26%) is low compared to modern power plants, because this efficiency was not based on the specific heat input to the steam; rather, it was based on the lower heating value of the fuel to incorporate the losses occurring in the furnace-boiler system due to energy lost with hot gases, incomplete combustion, etc. It was also observed that the maximum exergy destruction is in boiler and maximum exergy loss in condenser.

The scope and purpose of this research is to develop effective methodology to achieve exergetic optimizations of CCGT power plants. Therefore, the aim of the work is to improve the performance of the power plant by means of proposing an exergy optimization method. With the help of this method, it would be possible to:
a) Provide information about the exergy destruction.
b) Suggest ways of improving the exergetic efficiency.
c) Find the optimal realistic values of operating parameters, which gives the maximum possible power output and efficiency. Additionally, is would be possible to calculate minimum possible exergy destructions.

1.1 3. Nomenclature

X	Exergy	KJ
γ	Heat capacity ratio	-
Ψ	Specific exergy	kJ/kg
H	Efficiency	-
H	Specific Enthalpy	kJ/kg
M	Mass flow rate	Kg/s
T	Absolute Temperature	K
S	Specific Entropy	kJ/kg.K

Subscripts

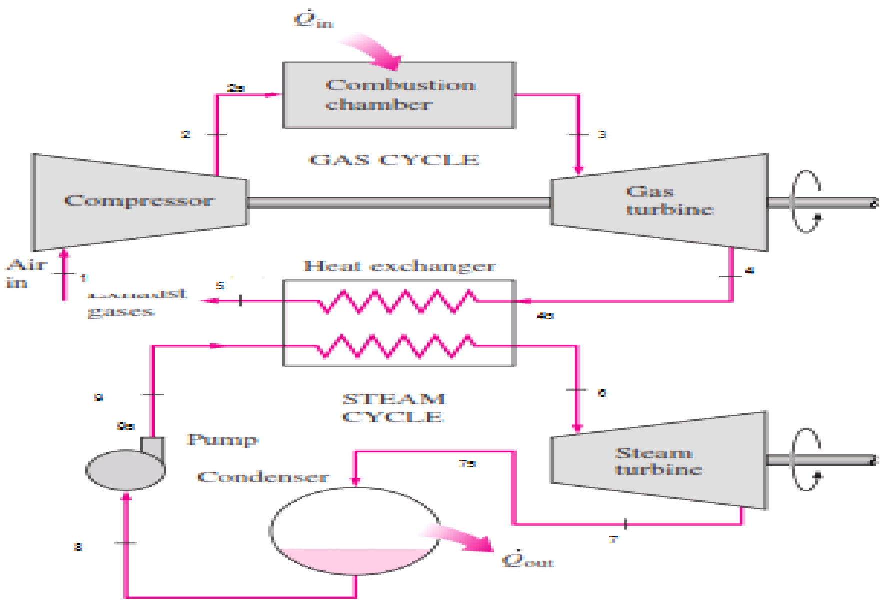
1,2,3…..	Various State Points (Theoretical)
1s,**2s**,3s……	Various State Points (Actual)
A	Air
F	Fuel

W	Water
0	Ambient condition
dest.	Destruction Rate
In	At Entry Point
Out	At Exit Point

Heat Recovery Steam Generator: In the present innovation, the most efficient energy conversion systems to deliver electrical and thermal energy are the combined cycle power plants. In a run of the millCCPP, exhaust heat from the gas turbine GT is recuperated in a heat recovery steam generator to create steam in the steam cycle. HRSG execution larger affects the general execution of a combined cycle power plant. Steam generated in HRSG with different pressure levels depend on the design. HRSG consist of three heat exchanger packages (economizer, evaporator, and superheated). Combustion gases enter superheater, evaporator, and economizer package respectively. The heat recovery from gas side to the water-steam is achieved in three steps:
In the economizer, the feed water is heated to temperature close to its saturation temperature. In the evaporator, the water vanishes at a consistent temperature and pressure and ends up plainly immersed steam. In the superheater, the high esteem heat from the exhaust is utilized for superheating the steam created in the evaporator. Superheated steam is fed to the steam turbine.
Figure a shows a typical model (schematic diagram) of a combined cycle with a single pressure HRSG. Topping cycle is a conventional gas turbine based on Brayton cycle; exhaust gases from gas turbine, crossing the boiler, release heat in opposite current to the sections of the super heater, the evaporator and the economizer. Those sections are crossed by water that is pressurized by a pump and absorbs heat from exhaust gases through various heat exchangers. Water turns into superheated steam and goes into the steam turbine generating

power. The steam finally approaches to condenser in which is driven back to liquid state.

5. Combined Cycle power plant



Description

Figure a : Schematic Diagram of CCPP

Point number	Specification
1	Inlet air entering compressor
2	Outlet air from compressor
3	Combustion gases exiting combustion chamber
4	Outlet hot gases exiting gas turbine
5	Outlet gases exiting HRSG
6	Superheated steam entering steam turbine
7	Outlet steam from steam turbine
8	Saturated liquid entering feed water pump
9	Supplied water entering HRSG

6. Methodology

$$\Delta X_{dest.} = X_{in} - X_{out} \quad (1)$$

Where,

$$X_{4s} = (\dot{m}_a + \dot{m}_f)\psi_{4s} \quad (2)$$

$$X_{9s} = \dot{m}_w \psi_{9s} \quad (3)$$

$$X_{in} = X_{4s} + X_{9s} \quad (4)$$

$$X_5 = (\dot{m}_a + \dot{m}_f)\psi_5 \quad (5)$$

$$X_6 = \dot{m}_w \psi_6 \quad (6)$$

$$X_{out} = X_5 + X_6 \quad (7)$$

$$\eta_{II} = \frac{X_{9s} - X_6}{X_{4s} - X_5} \quad (8)$$

$$(X_{4s} - X_5) = (\dot{m}_a + \dot{m}_f)[(h_{4s} - h_5) - T_0(s_{4s} - s_5)] \quad (9)$$

$$(X_{9s} - X_6) = (\dot{m}_w)[(h_{9s} - h_6) - T_0(s_{9s} - s_6)] \quad (10)$$

Exergy Destruction Rate

$$X_{Dest.} = (X_{4s} + X_{9s}) - (X_5 + X_6) \quad (11)$$

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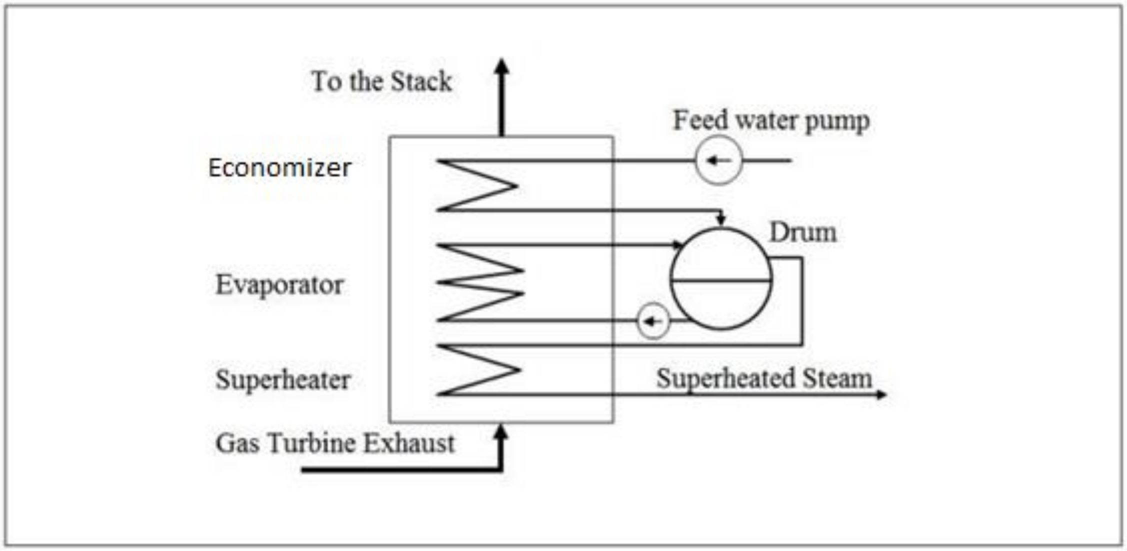

Figure b: Schematic Diagram of Single pressure HRSG

Figure c represents a typical model of one pressure level heat recovery steam generator. It consists of entry from gas turbine exhaust, super heater, evaporator (boiler drum), economizer, feed water pump and exit to stack.

7. Results and conclusions

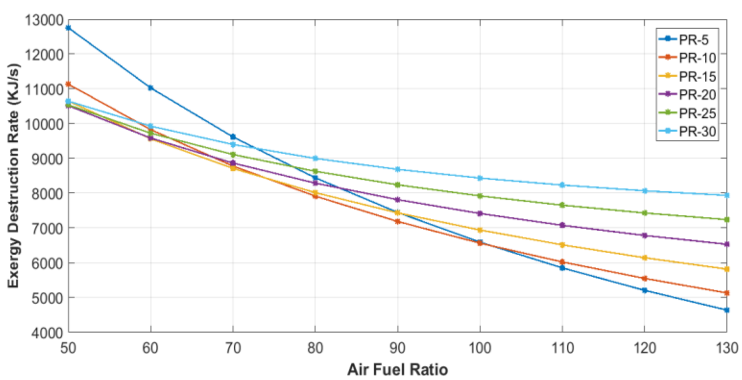

Figure c:Variation of EDR in HRSG vs AFR

Figure d illustrates the variation of Exergy destruction rate of HRSG as a function of air fuel ratio at various pressure ratios. As air fuel ratios increasing, exergy destruction rate is decreasing very rapidly because at lower air fuel ratio, the inflow temperature is high and decreasing with increase in AFR that results in fall of destruction rate.

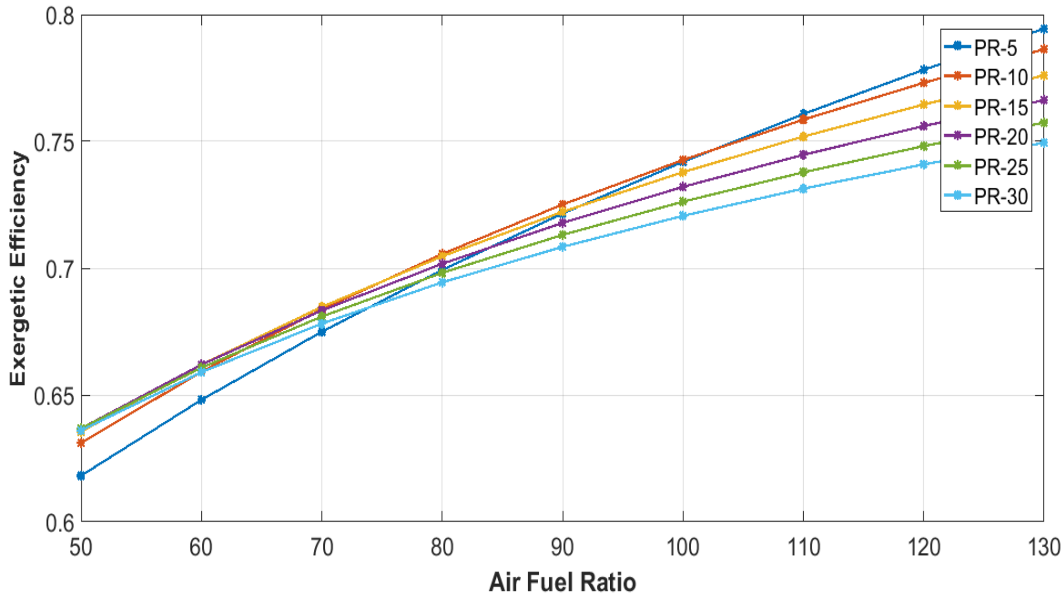

Figure e: Variation of Exergetic Efficiency of HRSG vs AFR

Figure e depicts Exergetic efficiency of HRSG at Various Pressure Ratios as a function of air fuel ratio. It is increasing because as air fuel ratio is increasing the destruction rate is decreasing which makes the overall efficiency increasing. At lower pressure ratio, exergetic efficiency increases very rapidly as compared to higher pressure ratio because temperature of exhaust gases entering to HRSG is low so exergy destruction rate is also low so exergetic efficiency is high as vice versa for higher pressure ratio.
Therefore, for higher exregetic efficiency it is advisable to run power generation unit at lower possible (assuring no major decrement in power output) pressure levels with significant more air fuel ratios ranging 110-130. In this domain, the exergy destruction rate falls which outcomes in higher exergetic efficiency of HRSG.

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