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Energy and Exergy Analysis of Coal Fired Cogeneration Power Plant

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***Abstract-* In this paper an energy and exergy analysis of cogeneration power plant is presented. Most of the power plants are designed by an energetic performance criteria based on first law of thermodynamics only it gives an amount of energy inlet and outlet but it does not specify the quantity of energy losses in an environment. Real use of energy can justified by second law of thermodynamics which gives quality and quantity of energy at inlet and outlet. In this study an energy and exergy analysis of different components of coal based power plant is carried out and found out that and energy and exergy efficiency of boiler is 84.38% and 58.50% respectively.**

1. INTRODUCTION

Conventional Steam power plants are widely utilized throughout the world for electricity generation, and coal is often used to fuel these plants. Although the world's existing coal reserves are sufficient for about two centuries, the technology largely used today to produce electricity from coal causes significant negative environmental impacts. To use coal more efficiently and effectively efforts are been made to improve an efficiency of thermal power plant. Cogeneration is a technique for producing heat and electricity in one process that can save considerable amounts of energy.

To improve efficiency of thermal power plant, a heat rate improvement of only a few percent appears desirable which is carried out by analyzing an amount of heat loss in different components. Energy technologies are normally examined using energy analysis but for better understanding, complete thermodynamic view is taken by 2nd law of thermodynamics in conjunction with energy analysis, by exergy methods.

An exergy analysis is is a straight forward method for assessing and improving thermal generating stations. An exergy analysis is carried out in different components and identifies that where maximum heat loss occurs so that proper improvement can be done to increase an efficiency of coal based power plant.

2. COGENERATION

Cogeneration, or combined heat and power (CHP), is the simultaneous production of electricity and usable heat. In conventional power plants, a large amount of heat is produced but not used. By proper designing the system maximum amount of heat can be utilized hence the efficiency of energy production can be increased from current levels that range from 35% to 55%, to over 80% (DOE, 2003). New technologies are making cogeneration cost-effective at smaller scales, meaning that electricity and heat can be produced for neighbourhoods or even individual sites. Micro-cogeneration systems produce heat and power at site scale for individual buildings or building complexes.

3. COGENERATION PLANT

In several industries, saturated steam at required temperature and pressure is used for heating purpose. Apart from heating, industries also need electric power for running various machineries and for lightening purpose. Formally in industries moderate pressure of steam was generated for power purpose and saturated steam at required pressure for heating purpose. Having two different units for generating power and for heating purpose is wasteful.

By modifying the initial and exhaust steam pressure required power can be generated and it makes available for process heating. In cogeneration plant, the exhaust steam from the turbine is used for the process heating purpose hence process heaters are kept instead of condensers of the ordinary rankine cycle

4. EXERGY ANALYSIS

Exergy analysis is thermodynamic analysis technique based on the second law of thermodynamics which provides an alternative and illuminating means of assessing and comparing processes and systems meaningfully and rationally. In particular, exergy analysis yields efficiencies which provide a true measure of how nearly actual performance approaches to ideal and the causes and locations of thermodynamic losses can be identified more clearly then energy analysis. Moreover, exergy analysis helps in improving and optimizing designs.

5. DESCRIPTION OF COGENERATION POWER PLANT

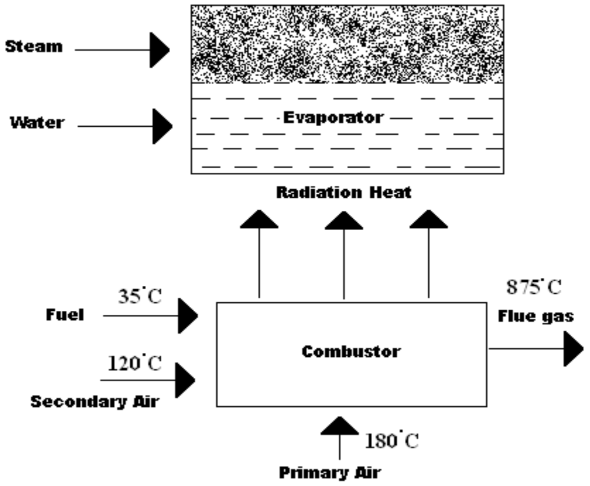
The technical data of a cogeneration power plant is given as below:

25MW Cogeneration Plant Technical Data

Parameters	Value
Nominal power output	9MW
Steam generation rate	120TPH
Pressure, temperature & mass flow rate of main steam	105bar/505°C/ 33.33 kg/s
Pressure, temperature & mass flow rate of Extracted steam	30bar/350°C/ 15.27kg/s
Condenser pressure and temperature	1.6bar/28°C
Flue gas temperature	109°C
Fuel type	Lignite coal
Lower heating value	4226 kcal/kg

Energy and Exergy calculation of combustor considering above data is as follow:

6. SAMPLE CALCULATION FOR COMBUSTOR



Energy part:

$$\dot{E}_{in} = \dot{E}_f + \dot{E}_{pa} + \dot{E}_{sa}$$

$$\dot{E}_{out} = \dot{E}_g + \dot{E}_{sg}$$

Where,

$\dot{E}_f$ = fuel energy in kJ/sec = $\dot{m}_f h_f$

$\dot{E}_{pa}$ =Energy of primary air in kJ/sec = $\dot{m}_{pa} h_{pa}$

$\dot{E}_{sa}$ = Energy of secondary air in kJ/sec= $\dot{m}_{sa} h_{sa}$

$\dot{E}_g$ = Energy of flue gas in kJ/sec = $\dot{m}_g h_g$

$\dot{E}_{sg}$ = Energy required to generate steam from water in kJ/sec = $\dot{m}_{sg} h_{sg}$

1st Law Efficiency $\eta_I = \frac{\dot{E}_{out}}{\dot{E}_{in}}$ =98.93%.

Exergy Part:

$$\psi_{in} = \varepsilon_f + \varepsilon_{pa} + \varepsilon_{sa}$$

$$\psi_{out} = \varepsilon_g + \varepsilon_{sg}$$

Where,

ψ_{in} =Exergy in or Availability at inlet to the combustor in kJ/sec.

ψ_{out} =Exergy out or Availability at combustor outlet in kJ/sec.

ε_f =Specific exergy of fuel in kJ/sec. = $\dot{m}_f (h_f - T_0 s_f)$

ε_{pa} =Specific exergy of primary air in kJ/sec. = $\dot{m}_{pa} (h_{pa} - T_0 s_{pa})$

ε_{sa} =Specific exergy of secondary air in kJ/sec. = $\dot{m}_{sa} (h_{sa} - T_0 s_{sa})$

ε_g =Specific exergy of flue gas in kJ/sec. = $\dot{m}_g (h_g - T_0 s_g)$

ε_{sg} =Specific exergy utilized for steam generation in evaporator kJ/sec.= $\dot{m}_{sg} (h_{sg} - T_0 s_{sg})$

$\therefore\ \psi_{destruction} = \psi_{in} - \psi_{out}$ in kJ/sec. in Combustor.

And, 2nd Law Efficiency of Combustor $\eta_{II} = \frac{\psi_{out}}{\psi_{in}}$ =0.5850=58.50%

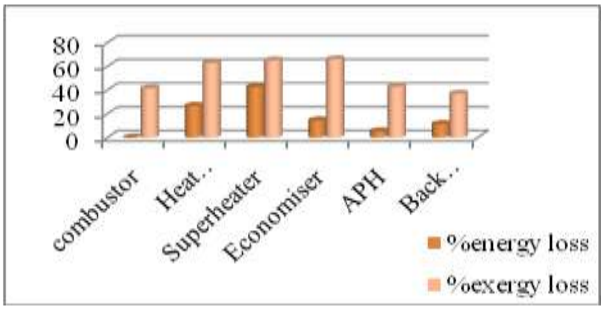
Similarly calculating an efficiencies of boiler, economizer, superheater, airpreheater we get the following result.

7. OVERALL PLANT RESULTS AND DISCUSSION

From energy and exergy analysis maximum exergy loss (68%) occurred in economiser section which leads to damage of certain portion of tubes suffering from fouling of the tubes, corrosive scaling of the tube and insulation leakage. Also whole heat recovery system has 62% of exergy loss which demands for cleaning of damaged tubes and replacing of fouled tube with new one.

Compo-nent	**1st law** η	**2nd Law** η	**% Energy loss**	**% Exergy Destruction**
Combustor	98.93%	58.50%	1.07%	41.50%
Heat Recovery system	73.20%	37.59%	26.8%	62.74%
Super Heater	57.22%	34.86%	42.78%	65.14%
Economiser	85.49%	33.98%	14.51%	68.02%
Air Preheater	94.67%	56.99%	5.33%	43.01%

Comparison between exergy and energy losses



As shown in above figure, the highest exergy loss occurs in an economiser so to increase an efficiency of power plant we have to carry out efforts to decrease exergy losses in the economiser

The lowest exergy loss occurs in back pressure turbine as from tthe graph shown below.In case of energy loss, the highest energy loss occurs in superheater and lowest energy loss occurs in combuster.

8. CONCLUSION:

From above result and discussions following conclusion are listed below:

a) Exergy efficiency of the plant is lower than energy efficiency due to so many losses occur in the plant and energy degradation.

b) It has been found out that 65.14% exergy loss occurs in superheater and 68.02% exergy loss occurs in economiser (heat exchanger). Which are main parts that contribute more loss of exergy.

c) It has been found that 41.50% exergy loss occurs in combustor (furnace) which shows combustor is not fully adiabatic and combustion may not be completed. It is due to the irreversibility within the combustion process. This study indicates that the combustor requires necessary modification like refractory (insulation) modification to reduce exergy destructions thereby plant performance can be improved.

d) The major exergy destruction(62.74%) occurs in the heat recovery system which leads to inefficient heat transfer between hot stream (flue gas) and cold stream (water & air).It indicates that heat exchanger system need to be carefully inspected.

e) Back pressure turbine shows variation in energy and exergy losses which is due to variation in stream flow at extraction and exhaust stage according to variation in plant demand of heat and electricity. It should be optimized between heat load and electrical load at given mass ratio for better operation and to minimize the variation between energy and exergy efficiency.

9. SCOPE OF FUTURE WORK

The exergy method can be a useful tool for furthering the goal of more efficient energy-resource use, for it enables the locations, types and magnitudes of wastes and losses to be identified and meaningful efficiencies to be determined.

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