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Energy and Exergy Analysis of high Pressure stem Boiler

[1]Vijay.D. Shimpi, [2]Mr. Mandhata Yadav
[1]M.E. Student, Department Of Mechanical Engineering, MIT, Piludara, Gujarat, India
[2]Professor in Mechanical Engineering Department, MIT, Piludara, Gujarat, India

Abstract-*Effective energy utilization and its management for minimizing irreversibility has made human to look for efficient energy consumption & conversion. In this research, the useful concept of energy and exergy utilization is analyzed, and applied to the boiler system of 690 TPH boiler in 210 MW coal based thermal power plant. In a boiler, the energy and exergy efficiencies are found to be 73.96% and 39.85%, respectively. A boiler energy and exergy efficiencies are compared with others work as well and parametric analysis of the exergy destruction and efficiencies in relation with reference state temperature indicates that exergy destruction increases with increasing reference state temperature as exergy efficiencies were decreasing. It has been found that the combustion chamber is the major contributor for exergy destruction followed by heat exchanger of a boiler system.*

Key word - *Thermal Power Plant, Energy analysis, Exergy analysis, Irreversibility.*

1. Introduction

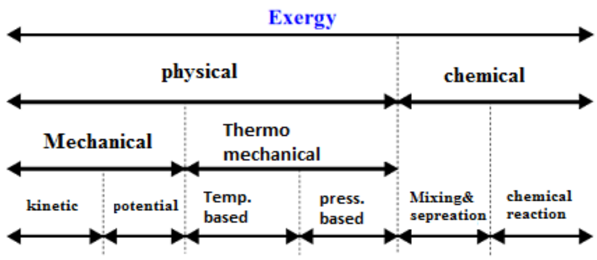
Power generation industry plays the major role in the economic growth of the any Country. Now, 80% of total electricity in the world is approximately produced from fossil fuels (coal, petroleum, fuel-oil, natural gas) fired thermal power Plants [7]. The total power generating capacity of India are 163304.99MW (Feb 2014), out of that coal fired thermal power plants have the generation capacity140723.39MW and natural gas fired thermal power plants have the generation capacity of 20359.85MW and reaming 22580MW include Gas and Diesel plant[CEA-2014].

To assist in improving the efficiency of boiler, their thermodynamic characteristics performances are usually investigated. Boilers are normally examined using energy analysis but better understanding is attained when a more complete thermodynamic view is taken, which uses the second law of thermodynamics in conjunction with energy analysis via exergy methods. Efficiency is one of the most frequently used terms in thermodynamics, and it indicates how well an energy conversion or process is accomplished. Efficiency is also one of the most frequently misused term in thermodynamics and often source of misunderstanding this is because efficiency is often used without being properly defined first (Cengel and Boles, 2006)

In case of coal fired power plant, the first law indicates that the condenser greatly effects the power plant efficiency as large amount of heat is transferred to the cooling water without providing any clue on the real usefulness of this relatively low temperature fluid. Also, energy balances do not provide information about the internal losses such as throttling valve and heat exchanger. Second law or exergy balance, however indicates that there is hardly 1% exergy loss in the condenser and maximum losses in the boiler. The contribution in the boiler exergy loss accounts for irreversibility associated with combustion and finite temperature differences. Hence, analysis of exergy plays a deterministic role in identification of processes and rectifying the components. [4]

The term Exergy was used for the first time by Rant in 1956, and refers to the Greek Words ex (external) and ergos (work). Another term describing the same is Available Energy or simply Availability. “Exergy is maximum useful work obtained from the system at a given state in a specified environment”.Exergy is based on second law of thermodynamics which has proved to be very powerful tool in optimization of complex thermodynamic system. For any thermodynamic system energy supplied is equal to work done plus heat rejected ,in this work done term is referred as the Exergy (available energy) and heat rejected is referred as unavailable energy(Anergy).

1.1 Types of Exergy:



The exergy efficiency of the boiler may be defined in two ways. The first one is the physical exergy and the second one is the chemical exergy. In this study the kinetic and potential part of exergy are negligible. The chemical exergy of fuel is computed from the stoichiometric combustion chemical reactions. The chemical exergy is associated with the departure of the chemical composition of a system from its chemical equilibrium which is important in processes involving combustion.[6]

1.2 Different between Energy and Exergy:

- Energy is ability to produce motion
- Energy is always conserved in a process.
- Exergy is always conserved in a reversible process, but is always consumed in an irreversible process.
- Energy is never destroyed during a process, it changes from one form to another.
- Exergy is destroyed by irreversibilities.The destroyed exergy has been called Anergy.

- Exergy can be regarded as property of the system-environment combination because it is measure of the departure of the state of system from that of the environment.
- Energy is find out using first law efficiency.
- Exergy is find out using second law efficiency

1.3 Exergy Analysis Method

A. Exergy destruction method (EDM)

B. Entropy generation method (EGM)

In this paper exergy destruction method is used

A. Exergy Destruction Method

For any thermal system under consideration for the analysis we need some input, which is referred as fuel and out of this is referred as a product. Here exergy input in terms of fuel exergy (E_F) and this input transfers in process of conversion into the output that is produced of exergy, in this some exergy be destroyed (E_D) and the remaining is loss of exergy (E_L). There is a difference between the terms exergy destruction and exergy loss, exergy destructions is the amount of exergy lost due to irreversible and cannot be used anywhere, while exergy lost is the amount of exergy that is wasted from the system under consideration but can be useful to other system.

2. Literature Review

The literature on various investigations using exergy analysis based on second law analysis high pressure steam boiler

Mehmet Kanoglu et al. In 2007[1] conducted the **"Understanding energy and exergy efficiencies for improved energy management in power plants"** in which various energy and exergy-based efficiencies used in the analysis of power cycles. Vapor and gas power cycles, cogeneration cycles and geothermal power cycles are examined, and consideration is given to different cycle designs. [1]

S.K.Som et al. In 2008 [2] **"Thermodynamic irreversibility and exergy balance in combustion processes."** pointed out that, in almost all situations, the major source of irreversibility is the internal thermal energy exchange associated with high temperature gradients caused by heat release in combustion reactions and the primary way of keeping the exergy destruction in a combustion process within a reasonable limit is to reduce the irreversibility in heat conduction. [2]

R. Saidur in 2010 [3]**, "Energy, exergy and economic analysis of industrial boilers"** Conceptualized about Energy, exergy and economic analysis of industrial boilers, Energy and Exergy efficiencies are found to be 72.46% and 24.89%,combustion chamber is major source of exergy destruction and major losses through flue gases. Variable speed drive (VSD) used in boiler fan motor for energy saving. [3]

P. Regulagadda et al, in 2010 [4]**, "Exergy analysis of a thermal power plant with measured boiler and turbine losses"** conducted thermodynamic analysis of a subcritical boiler–turbine generator for a 32 MW coal-fired power plant and concluded that the boiler and turbine irreversibility yield the highest exergy losses in the power plant compare with highest energy losses in condenser. Plant is designed to operate with an air cooled condenser that shows environmental benefits since the water consumption is reduced and also the water rejection from the power plants is reduced.[4]

Ankit Patel et al, in 2012[5] **Energy And Exergy Analysis Of A Boiler With Different Fuels Like Indian Coal, Imported Coal And L.S.H.S. Oil** Compare different types of coal like Indian coal, Imported coal, Mixture of both(60% imported+40%indian) and L.S.H.S Oil and conclude that first law efficiency is 76.54%, 83.03%, 80.60%, and 88.20% respectively and as well as exergetic efficiency of the Boiler Plant are 37%, 37.7%, 37.8% and 40.1% respectively.[5]

Idehai O. Ohijeagbon et al, in 2012[6]**, "Methodology for the physical and chemical exergetic analysis of steam boilers"**energy and exergy efficiencies obtained for the entire boiler was 69.56% and 38.57% at standard reference state temperature of 25^{0}C for an evaporation ratio of 12 all the calculation were based on the analytical method.[6]

Sarang j gulhane et al. In 2007[7] **"Exergy Analysis of Boiler In cogeneration Thermal Power Plant"** concluded that boiler has exergy destruction at home load 1.1 mw is around 83.35% and as load increases for highest load 5.6 mw the exergy destruction found to be 76.33%thus efficiency of 1st law and 2nd law increases with load, we have to work on the peak load for reduce the irreversibility. [7]

3. Methodology:

This section describes about the method used to estimate the energy and exergy use, energy and exergy efficiencies for a boiler. A boiler can be divided into heat exchanger and combustor as shown in fig 3.1. Data for the boiler has been taken from the plant. Here for exergy analysis Exergy Destruction Method is used.

substance	Flow rate (Kg/Sec	Temp (^{0}C)	Enthalpy (Kj/Kg)	Entropy (Kj / kg.K)
Air(ma)	223.6	330	612.27	2.417
Fuel(mf)	38.647	80	16744	8.883
Hot product (mp)	250	1183	3136.03	2.153
Water (mw)	183.88	241	1041.8	2.710
Steams-(ms)	183.88	541	3567.65	7.3715
Exhaust flue gas,(mg)	250	153	231	2.0516

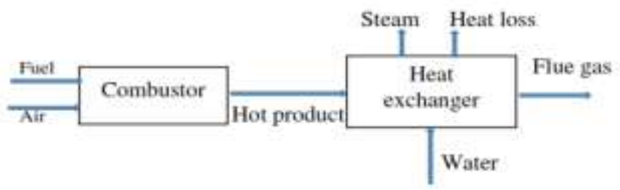


Fig.3.1 Schematic diagram of combustor and heat exchanger

4. Analytical calculation:

4.1 First law analysis on combustor:

The combustor in a boiler is usually well insulated that causes heat dissipation to the surrounding almost zero. It also as no involvement to do any kind of work (w=0). Also, the kinetic and potential energies of the fluid streams are usually negligible. Then only total energies of the incoming streams and the outgoing mixture remained for analysis. The conservation of energy principle requires that these two equal each-others. Besides, the sum of the incoming mass flow rates will be equal to the mass flow rates of the outgoing mixture.

Energy use of combustor

$\dot{E}in = \dot{E}out$

$\dot{m}fhf + \dot{m}aha - \dot{m}php = 0$

$\dot{m}fhf + \dot{m}aha = \dot{m}php$

Where, $\dot{h}f$ = specific enthalpy of fuel, KJ/Kg

$\dot{h}a$ = specific enthalpy of air, KJ/Kg

$\dot{h}p$ = specific enthalpy of hot products of combustion, KJ/Kg

First law efficiency of combustor

$\eta C = \dot{m}php / \dot{m}fhf$

Second law analysis on combustor

The maximum power output or reversible power is determined from the exergy balance applied to the boiler considering boundary with an environment temperature of ($T_0 = 25^0c$) and by assuming the rate of change in exergy in the boiler's system is zero. The exergy balance formulations have been established using methodology developed by

$$X_{in} - X_{out} = X_{destroyed}$$

Exergy destruction in the combustor is given by:

$\dot{I}C = \dot{m}f\varepsilon f + \dot{m}a\varepsilon a - \dot{m}p\varepsilon$

$= \dot{m}f(hf - T0Sa) + \dot{m}(ha - T0Sa) - \dot{m}p(hp - T0Sp)$

Where, Ic = Exergy destruction

$\varepsilon f, \varepsilon a, \varepsilon p$ = Exergy of air, fuel and hot product

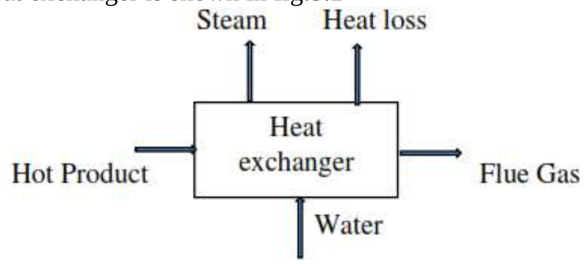
Appropriate second law efficiency for the combustor is analogous to the combustor's energy efficiency and can be written as:

$\Psi_C = \dot{m}_p\varepsilon_p / \dot{m}_f\varepsilon_f$

$= \dot{m}p (hp - T0Sp) / \dot{m}f (hf - T0Sf)$

4.2 First law analysis of heat exchanger:

Heat exchanger is a device where two moving fluid streams exchange heat without mixing. Heat is transferred from the hot fluid to the cold one through the wall separating them. A heat exchanger typically involves no work interactions (w=0) and negligible kinetic and potential energy changes for each fluid streams. Basically, the outer shell of the heat exchanger is usually well insulated to prevent any heat loss to the surrounding medium. However, there is a little amount of heat that will be dissipated. The energy balance for heat exchanger is shown in fig.3.2



By applying mass conservation law, mass flow rate for hot product ($\dot{m}p$) and mass flow rate of flue gas ($\dot{m}g$) assumed to be as a mass flow rate of hot product ($\dot{m}H$), mass flow rate of water ($\dot{m}l$) and mass flow rate of steam ($\dot{m}s$) assumed to be a mass flow rate of cold product ($\dot{m}c$)

$\dot{m}p = \dot{m}g = \dot{m}H$

$\dot{m}l = \dot{m}s = \dot{m}c$

With these assumption energy balance can be expressed as:

$\dot{E}in = \dot{E}out$

$(\dot{m}php + \dot{m}lhl) - (\dot{m}ghg + \dot{m}shs) = \dot{Q}$

$\dot{m}php - \dot{m}ghg + \dot{m}lhl - \dot{m}shs = \dot{Q}$

$\dot{m}H (hp - hg) + \dot{m}c (hs - hl) = \dot{Q}$

The appropriate first law efficiency for heat exchanger is calculated by

$\eta H = \dot{m}c (hs - hl) / \dot{m}h (hp - hg)$

Second law analysis of heat exchanger

By assuming the rate of change in exergy in the boiler's system is zero and the environment temperature at T0 = 250C the exergy balance can be expressed as

Xin = Xout + Xdestroyed

Exergy destruction in heat exchanger network is given by

$\dot{I}H = \dot{m}H (\varepsilon p - \varepsilon g) + \dot{m}C (\varepsilon l - \varepsilon s)$

$= \dot{m}H [(hp - T0Sp) - (hg - T0Sg)] + \dot{m}C [(hl-T0Sl) - (hs - T0SS)]$

Second law efficiency of heat exchanger:

$\Psi H = \dot{m}C (\varepsilon s - \varepsilon l) / \dot{m}h (\varepsilon p - \varepsilon g)$

$= \dot{m}C [(hs - T0SS) - (hl - T0Sl)] / \dot{m}H [(hp - T0Sp)-(hg - T0sg)]$

Over all exergy balance of the boiler is obtain by adding exergy balance of combustor and heat exchanger which is given as below

$\dot{I}B = \dot{I}C + \dot{I}H$

4.3 Over all energy and exergy efficiency of boiler is,

Energy efficiency $\eta B = \dot{m}c (hs - hl) / \dot{m}fhf$

Summary of All Analytical Procedure with Result:

Summary of exergetic parameters of heat exchanging unit

1. Heat Loss 261803 KW

$\dot{Q}H$ (loss) = $\dot{m}H$ (hp - hg) + $\dot{m}c$ (hs – hl)

2. Energy efficiency (%) 63.95%

ηH = $\dot{m}c$ (hs - hl) / $\dot{m}h$ (hp - hg)

3. Exergy destruction (KW) 193021 Kw

$\dot{I}H$ = $\dot{m}H$ [(hp – T0Sp) – (hg – T0Sg)] + $\dot{m}C$ [(hl-T0Sl) – (hs – T0SS)]

4. Exergy efficiency (%) 30.87%

Summary of exergetic parameters of combustion unit

1. Energy input (KW) 783883 KW

$\dot{E}in$ = $\dot{m}fhf$ + $\dot{m}aha$

2. Exergy destruction (KW) 509467 KW

$\dot{I}C$ = $\dot{m}f$ (hf – T0Sa) + $\dot{m}a$ (ha – T0Sa) – $\dot{m}p$ (hp – T0Sp)

3. Exergy efficiency (%) 11.44 %

ΨC = $\dot{m}p$ (hp – T0Sp) / $\dot{m}f$ (hf – T0Sf)

Summary of exergetic parameters of entire boiler

1. Energy efficiency (%) 73.96%

ηB = $\dot{m}c$ (hs – hl) / $\dot{m}fhf$

2. Overall exergy destruction (KW) 702480 KW

$\dot{I}B$ = $\dot{I}C$ + $\dot{I}H$

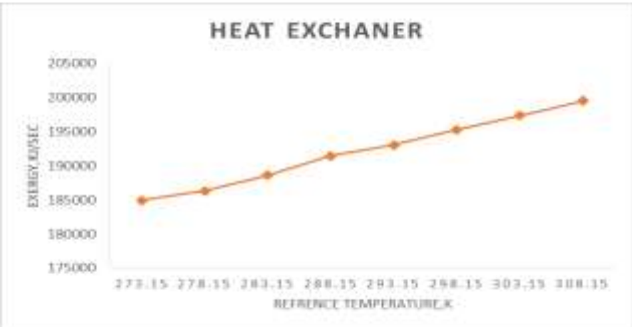
3. Overall exergy efficiency (%) 39.35%

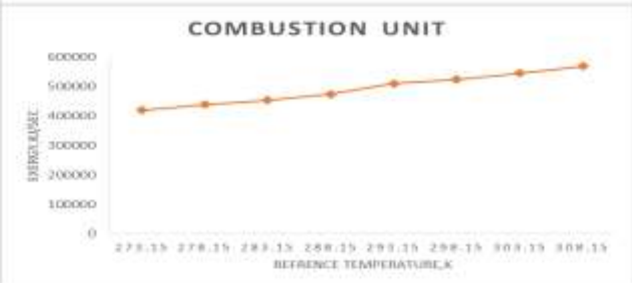
ΨB = $\dot{m}C$ (εS – εl) / $\dot{m}f$εf

5. Results and Discussion:

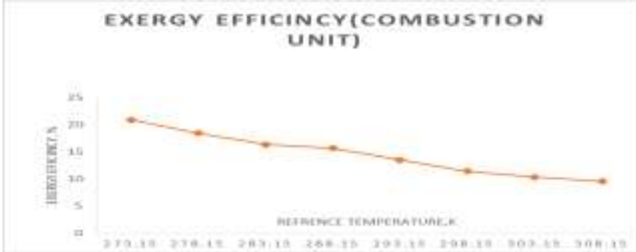
The combustor part contributes the biggest portion of Exergy destruction. Since temperature of the air-fuel during entrance in the combustor and that in the chamber is high and this differences in the temperature causes more Exergy destruction in the combustor.

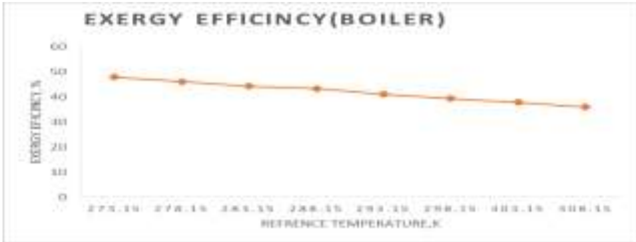
The parametric analysis of the Exergy destruction and efficiencies in relation with reference state temperature indicates that Exergy destruction increases with increasing reference state temperature as shown in graph. reveals that greater amount of Exergy was destroyed in the combustion unit compared with the heat exchanging unit.





Exergy efficiencies were decreasing as shown in graph. the Exergy efficiencies were higher in the heat exchanging unit in comparison with the combustion unit. Lower Exergy efficiencies experienced in the combustion unit was as a result of greater irreversibility occurring in the unit





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