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Exergy Analysis of Rice Straw Fired Boiler

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ABSTRACT

Exergy analysis is great tool to identify the inefficient energy utilization in a system. Effective energy utilization and its management for minimizing losses has made researchers to look for efficient energy consumption & conversion. Based on several research activity and visit to a rice straw fired power plant, some key observation has made and is presented in this paper The aim of this paper is to be find out amount and source of irreversibility's generated in boiler of 33 TPH boiler in 8 MW AFBC boiler power plant so that any process in the system that having largest energy destruction can be identified.
Keywords: *Exergy Analysis, Rice straw, AFBC Boiler, Biomass, Boiler Exergy analysis.*

INTRODUCTION

The general energy supply and environmental situation requires an improved utilization of energy sources. Complexity of power generating units has been increased considerably. There is increasing demand of strictly guaranteed performance, which require thermodynamic calculation of high accuracy. [1] The most commonly used method for evaluating the efficiency of an energy conversion process is the first law analysis. However, there is increasing interest in the combined utilization of the first and second laws of thermodynamics, using such concept as exergy analysis, entropy generation and irreversibility (exergy destruction) in order to evaluate the efficiency with which the available energy is consumed. [2]

Exergetic analysis is a useful tool for more efficient use of energy because it enables the locations type and true magnitude of wastes and losses to be determined. An exergy analysis usually aimed to determine the maximum performance of the system and identify the sites of exergy destruction. Exergy analysis of a complex system can be performed by analyzing the main sites of exergy destruction shows the direction for potential improvements.

In this study an exergy analysis of biomass fired boiler from India is carried out. This exergy analysis will help us to track the maximum losses in power plant in an efficient way. The biomass used as fuel is rice straw which is plenty in northern states of India once harvesting is done. Rice straw fired boilers have high maintenance due high ash contain. Also it has low calorific value so any even small percentage increase in efficiency will make a difference in economic point of view. Also rice straw after harvesting is open burned in fields which causes lot of air pollution. Promotion of rice straw as fuel in these biomass power plants could reduce the air pollution occurring every year. The power plant is 8 MW capacity situated in Abohar town from Punjab State.

1. Plant Description:

This thermal power plant is situated in Punjab state near Abohar town. Currently the plant uses mixed fuel such as rice straw, cotton straw, wheat straw, mustard straw etc. The electricity generation capacity of this plant is 8 MW. The combustion technology used in this plant is atmospheric fluidized bed combustion (AFBC). The steam flow rate is 33 TPH with super heater outlet pressure of 66 kg/cm^2 and temperature of 460 ^{o}C.

Feed water is supplied to economizer through deaerator at pressure of 90 kg/cm^2 and temperature 102 ^{o}C. This water gets heated up to 250 ^{o}C and is supplied to steam drum. The level of steam drum is maintained around 40 %. The saturated steam is supplied to series of super heaters and its pressure and temperature is raised till 469 ^{o}C at outlet of main steam stop valve (MSSV). Shredded biomass is supplied with the help of four screw feeders (2 on each side) as shown in fig 2.1. Fuel is supplied up to feeders with the help of belt conveyors and also one return conveyor is provided to return excess shredded fuel. All of the screw feeders are controlled automatically with respect to load on turbine. As the load decreases so the required steam flow rate also need to be decreased, this is achieved by reducing fuel feed rate i.e by controlling screw feeders. The feed water used in boiler is treated in a water treatment plant. The hardness of the water is checked and controlled to avoid deposition due to scaling. Raw water coming from different sources contains dissolved salts and undissolved or suspended impurities. This salts and suspended particles will from scale inside the heat exchanger tubes eventually and thus they will create excessive pressure and thermal stress inside the heat exchanger, which may lead to explosion and serious hazards for boilers. Also the salts can corrode various parts of boilers such as tubes and turbine blades. There is demineralization and reverse osmosis to remove this salts. This water after treating is supplied to deaerator where it is heated by mixing with low pressure steam to remove dissolved oxygen. Deaerator is a contact type open heater in which dissolved oxygen in the feed water is removed by mechanical means.

The feed water from deaerator which is at 102 ^{o}C is pumped to economizer up to 90 kg/cm^2. The air is supplied at pressure of 730 mm of WC at under the bed material which is sand. After combustion in bed of boiler the flue gas temperature at exit of furnace is reached up to 720 ^{o}C. This flue gas first passes through series of super heaters to super heat the water up to 420 ^{o}C. Then it passes through economizer to heat the water up to 213 ^{o}C from 102 ^{o}C. And finally it passes through air preheater to heat the air. The layout of power plant with air, flue gas path and water/steam flow path is shown in the picture below (Fig. 2.1) taken from power plant operating room. This flue gas which mainly contains fly ash particles is treated in electro precipitator (ESP) and then left out to environment through chimney.

2. Exergy Analysis of Boiler:

3.1. Exergy Analysis of

GCV of fuel = 2984 kcal/kg
= 12473.12 KJ/kg
Ratio of chemical exergy to HHV = 1.05 [5]
Exergy of fuel = 13096.776 KJ/kg

Fuel Feed rate = 240 ton/day
= 2.77 kg/s
X_f = 36379.93 kW
Theorotical air = 11.521 %C + 34.56 %H + 4.32(%S-%O) (using table 3.1)
= 4.53 kg/kg of fuel

3.2. Exergy of feed water

Formula: $X_w = (C_{pw})\ (T_w - T_o) - T_o \ln (T_w/T_a)$ [3]

T_w: temp of inlet feed water after dearator T_o: ambient temp
102 °C
27 °C
375 K
300 K
Water feed rate = 33.5 tph Specific heat of water = 4.187 kJ/kg
= 9.30 kg/s

X_w = 2299.234669 kW

3.3. Exergy change in economizer

Formula: $X_e = C_{pw} (T_{eo} - T_{ei}) - T_o (\ln (T_{eo}/T_{ei}))$ [3]
T_{ei} = Inlet water temp to economizer T_{eo} = Outlet water temp from economizer (using table 3.2)
= 102 °C = 375 K = 213 °C = 486 K
X_e = 3600.991497 kW

3.4. Exergy of supplied air

Formula: $X_a = C_{pa} (T_a - T_o) - T_o (\ln (T_a/T_o))$ [3]
Ta = furnace air inlet temp after APH = 132 °C T_o = 300 K
(using table 3.2)
= 405 K

Theoretical air = 4.53 kg/kg of fuel
C_{pa} = 1.005 kJ/kgK
m_a = 17.607 kg/s (40 % excess air)
X_a = 272.79 kW

3.5. Exergy Change in Drum

Formula: $X_d = (h_{do} - h_{di}) - T_o (s_{do} - s_{di})$ [3]
Properties of steam at inlet of drum

T_{di} = 213 °C p_{di} = 88 kg/cm^2 (assume 2 kg/cm^2 pressure drop in economiser)
h_{di} = 913.63 kJ/kg s_{di} = 2.442 kJ/kgK

Steam flow rate = 34.6 tph

= 9.61 kg/s
Properties of steam at outlet of drum
(using table 3.2)
p_{do} (sat) = 80 kg/cm^2

h_{do} = 2761.5 kJ/kg s_{do} = 5.7568 kJ/kgK
X_d = 8202.410556 kW

3.6. Exergy Change in Super heater

Formula $X_s = (h_{so} - h_{si}) - T_{si} (s_{so} - s_{si})$ [3]

Properties of steam at inlet of superheater
T_{si} = Superheater inlet temp p = 80 kg/cm^2
= 293.79 °C = 566.79 K
h_{si} = 2761.5 kJ/kg s_{si} = 5.7568 kJ/kgK
Properties of steam at outlet of superheater

T_{so} = 460 °C p = 66.7 kg/cm^2

h_{so} = 3318.9 kJ/kg s_{so} 6.7009 kJ/kgK

X_{sh} = 2635.078333 kW

3.7. Exergy change in Air Preheater:

Formula
$X_{aph} = C_{pa} (T_{ao} - T_{ai}) - T_{ai} (\ln (T_{ao}/T_{ai}))$
[3]
m_a = 17.61 kg/s
T_{ai} = 27 °C C_{pa} = 1.005 kJ/kgK

= 300

T_{ao} = air temperature at outlet of APH
= 132 °C

= 405 K

X_{aph} = 272.7926532 k

3.8. Exergy in flue gases leaving APH

Formula $X_{fl} = C_{pg} (T_{fo} - T_o) - T_o (\ln (T_{fo}/T_o))$ [3]

C_{pg} = specific heat of flue gases =1.2 kJ/kgK
T_{fo} = Temperature of flue gas leaving APH (using table 3.2)
= 163 °C = 436 K

T_o= 300 K
Energy Balance in APH: $m_g \times C_{pg} (T_{fi} - T_{fo}) = m_a \times C_{pa} (T_{ao} - T_{ai})$
m_g = mass flow rate of flue gases from APH
= 22.118 kg/s
X_{fl} = 1128.974297 kW

IInd law efficiency= $\frac{\text{Exergy recoverd}}{\text{Exergy in}}$

$$= \frac{Xeco + Xaph + Xd + Xsh + Xfl}{Xf + Xw + Xa}$$

$$= \quad \mathbf{41\%}$$

3.9. Exergy Gain by Steam:

$X_{gain} = m_s [(h-h_o)-T_o(s-s_o)]$

From steam table

h_0 = 113.16 kJ/kg h_{s1} = 3318.9 kJ/kg

s_{si} = 6.7009 kJ/kgK s_0 = 0.3947 kJ/kgK

X_{gain} = 12627.84 kW

3.10. Exergy Destruction rate:

Exergy destruction rate in boiler can be given by

$I = X_{fuel} + X_{in} - X_{out}$

= 25195 kW

3. Results and Discussions.

After calculating exergy of different components of boilers and its destruction it seems that most of the exergy of fuel is not recovered. Though the precautions to avoid thermal heat loss by adding insulation are taken still exergy destruction is more. Most of exergy gets recovered in super heater which is obvious as the flue gases are at higher temperature than ambient which means it has large work potential. As the flue gases moves further its work potential decreases and it can be seen from table 4.1 that the components which come after super heater has lesser exergy efficiency or exergy utilization percentage.

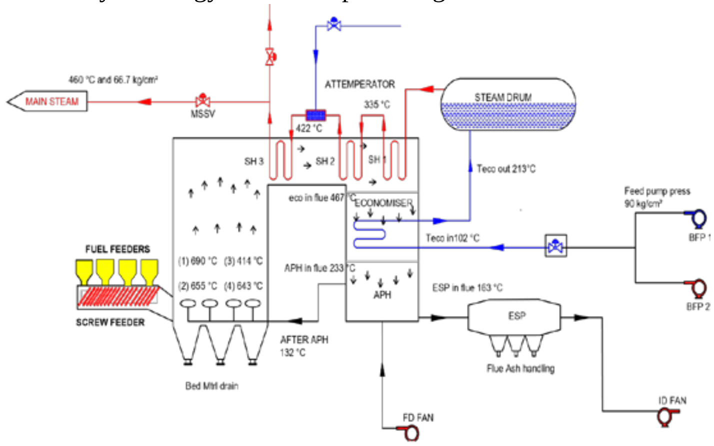

Fig. 2.1 Power Plant Layout

Table 3.1 Ultimate Analysis

Element	C	H	O	N	S	Cl	Ash
%	38%	5%	35%	1%	0%	0%	20%

Table 3.2.Boiler Readings

Sr. No	Parameters	Units	1 p. m
A	Levels		
	1. Drum level	%	39
	2. Deareator level	%	29
B	Pressure		
	1. SH Outlet Pressure	kg/cm^2	66.7
	2. Deareator level	kg/cm^2	0.72
	3. Feed Pump Discharge pressure	kg/cm^2	90
C	Temperature Water and steam		
	1. Main steam Line Temp.	Deg. C	460
	2. SH no. 3 inlet Temp	Deg. C	422
	3. SH no. 2 outlet temp	Deg. C	428
	4. SH no. 1 outlet temp	Deg. C	335
	5. Economiser inlet temp(water)	Deg. C	102
	6. Economiser outlet temp (water)	Deg. C	213
	7. Deareator temp	Deg. C	102
D	Temperature air and flue gases		
	1. Bed no. 1 temp	Deg. C	690
	2. Bed no. 2 temp	Deg. C	655
	3. Bed no. 3 temp	Deg. C	414
	4. Bed no. 4 temp	Deg. C	643
	5. Furnace outlet temp RHS	Deg. C	729
	6. Furnace outlet temp LHS	Deg. C	702
	7. Economiser inet temp.(flue)	Deg. C	467
	8. APH inlet temp. (flue)	Deg. C	233
	9. ESP inlet temp	Deg. C	163
	10. ID inlet temp	Deg. C	147
	11. APH outlet temp	Deg. C	132
E	Air pressure and drafts		

	1. Chamber no. 1 pressure 2. Chamber no. 2 pressure 3. Chamber no. 3 pressure 4. Furnace pressure 5. Economizer inlet pressure 6. APH inlet pressure 7. ESP inlet pressure	mm WC mm WC mm WC mm WC mm WC mm WC mm WC	730 730 730 1.7 -30 -65 -125
F	Flow 1. Water flow 2. Steam flow 3. Generation	 tph tph kWhr	 33.5 34.6 7958

Table 4.1 Exergy Utilization and Percentage Distribution

Exergy Utilized in	Value (kW)	Percentage
Fuel (supplied)	36379.93	100%
APH	272.7927	1%
Economiser	3600.991	10%
Drum	8202.411	23%
Superheater	12627.84	35%
Not recovered	11675.89	32%

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