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Thermal efficiency of pulverized fuel boiler

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Abstract: Boiler is an important practical application in heat transfer devices.Its function is to transfer the heat produced by the combustion of fuel to water, and ultimately to generate steam.This paper was carried out by taking data of Pulverized fuel boiler which is a water tube boiler having pressure 138 bar and temperature 540^0C.The fuel used in this boiler is low grade bituminous coal having a calorific value of 4204kcal/kg.The performance of this boiler was conducted by calculating thermal efficiency and heat losses of pulverized fuel boiler by indirect method. Gross calorific value of fuel, wind velocity, surface temperature of boiler shell, and ambient temperature, humidity of air, fuel firing rate, specific heat of flue gas and steam are taken as input parameters. Thermal efficiency, heat losses such as heat losses due to dry flue gas, evaporation of water formed due to H_2 in fuel, moisture present in fuel, moisture present in air, incomplete combustion, radiation and convection and unburntfuel in fly ash and bottom are calculated.

Keywords: boiler, pulverized fuel boiler, heat losses, Thermal efficiency, GCV of coal.

I. INTRODUCTION

Boiler is an energy conversion deviceIt is usually, a closed vessel made of steel and it is a place where the heat produced due to burning of coal in the furnace is used to convert the feed water into steam. The steam produced may be supplied to an external combustion engine of steam engines and turbines, at low pressures for industrial process work in cotton mills, sugar factories, breweries etc., and for producing hot water, which can be used for heating installations at much lower pressures. Boilers are commonly used in industries to generate utility steam used for various purposes like heating or drying chemical compounds in a reactor.

The primary function of boiler is to maintain the steam energy in balance with the load demand while maintaining the internal variables such as pressure, level in a desired range. Steam pressure is one of the most important parameters for power plant efficiency.

Krishnanunni et al. [1]calculated efficiency of oil fired fire tube boiler by evaluating the heat losses.Kurkiya and Chaudhary [2]discussed energy analysis helps designers to find ways to improve the performance of a system in a many way.

The energy losses from individual components in the plant are calculated to determine the true system losses. Arunkumar et al. [3]discussed industry steam generators about 4% of hot water is wasted as blow down. To prevent heat losses, a heat recovery system is used. So, in this a heat recovery system was designed to minimize the losses. Longnathan and Sivakumar [4]focused thus installation of a Waste Heat Recovery Steam Generator (WHRSG)instead of gas cooler for both gas cooling by heat recovery and steam generation. Gulhane and Thakur [5]find out amount and source of irreversibility's generated in boiler of 35 TPH boiler in 6 MW captive power plant.Kumar and Reddy [6]investigated on boiler to extract maximum amount of heat from the flue gases and increase the heat pick up rate of the feed water outlet into the boiler by incorporating the additional bank of tubes in the space below the lower bank of tubes.Costa et al. [7]reported data on local mean gas species concentrations of O_2, CO, CO_2, NO_X, and gas temperatures measured at several ports in the boiler and burner region and incident wall heat fluxes taken around the boiler periphery at 39 ports.Kapooria et al. [8]dealt steam cycles used in power plants, Enhancement of efficiency and reliability of steam power plants are studied.Jou et al. [9]said the practical benefits for reducing energy consumption and greenhouse gas emission to the use of waste hydrogen rich refinery gas (RG) to partially replace the natural gas (NG). Chakraborty et al. [10] discussed design aspects and installation requirements of boiler drum level control for safe and economic operation of thermal power plants.

II.DESCRIPTION OF PULVERIZED FUEL BOILER

A pulverized fuel boiler is an industrial or utility boiler that generates thermal energy by burning pulverized coal. Exhaust gases from the pulverized fuel boiler contain a large quantity of dust and flow very fast.

The coal is ground (pulverised) to a fine powder, so that less than 2% is +300 micro metre (μm) and 70-75% is below 75 microns, for a bituminous coal. Combustion takes place attemperatures from 1300-1700°C, depending largely on coal grade.

This system has many advantages such as ability to fire varying quality of coal, quick responses to changes in load, use of high pre-heat air temperatures etc. One of the most popular systems for firing pulverized coal is thetangential firing using four burners corner to corner to create a fireball at the center of the furnace.

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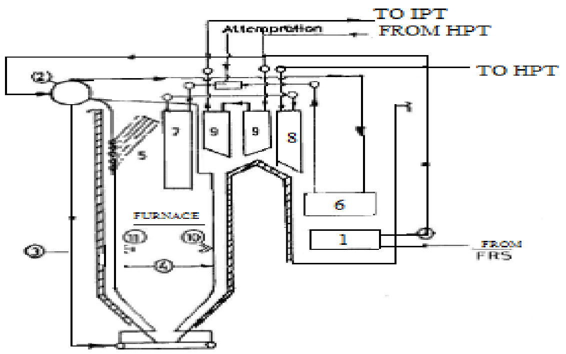

Fig.1 construction ofPulverized Fuel Boiler

This boiler (Fig.1) consists of

1. Economizer,2. Boiler drum, 3. Down Comers, 4.Water walls, 5.Water wall platen, 6. Primary super heater,7. Platen super heater,8. Final super heater ,9. Reheater, 10.Burners and11.Igniters

Furnace: The Sizing of furnace (Fig.4) has the highest influence on the performance of the boiler. With high heat inputs of the modern burners, the furnace must be fully water cooled with a minimums amount of refractory. The furnace plan area must be adequate for full development of flames. Heat release in the plan area is around 3.15 MW/m^2 or 2.7×10^6 $kcal/m^2/h$. The furnace height from the centre of the heat input (with upper burners) to the middle of the furnace exit plane should give a residence time at full load exceeding the minimum residence time requirement of 1-2 seconds (depending on the coal properties). In furnace, coal is pulverized and fired and the flame temperatures are high, the slagging of ash is to be expected. Wall blowers or wall deslaggers are essential.

Economizer (1): The purpose of economizer (Fig.4) is to preheat the boiler feed water before it is introduced into the steam drum by recovering heat from the flue gases leaving the boiler. The economiser is located in the boiler rear gas pass below the rear horizontal superheater. The economizer is continuous unpinned loop type and water flows in upward direction and gas in the downward direction.

Boiler Drum (2): The function of boiler drum (Fig.4) is to separate the water from the steam generated in the furnace walls and to reduce the dissolved solid contents of the steam to below the prescribed limit of 1 ppm(part per million). The drum is located on the upper front of boiler.

Down comers (3): It is like a pipe (Fig.4). This pipe leads the hot gases from the top of a blast furnace downward to the boilers.

Water walls (4): The entire furnace is enclosed by water walls (Fig.4). The function of water walls absorbs the intense heat radiation from the combustion zone. And these walls consist of tubes of about 50mm in diameter linked together by narrow bars welded to the tubes.

Water wall platen (5): It consists of bundle of water tubes (Fig.4). The water from the feed pump circulates in tubes around which flue gases flows from the furnace. It is placed above the furnace at top of the boiler.

Superheater (6) (7) and (8): There are three stages of superheaters besides the side walls and extended sidewalls. The first stage consists of primary superheater of convection mixed flow type with upper and lower banks located above economizer assembly in the rear pass. The saturated steam from the furnace enters the primary superheater (6). The upper bank terminates into hanger tubes, which are connected to outlet header of the first stage superheater (6). The second stage superheater (7) consists of pendant platen which is of radiant parallel flow type. The third stage superheater (8) is final super heater it is in placed middle of the boiler. The outlet temperature and pressure of the steam coming out from the final superheater are 540°C and 138 Kg (f)/Cm^2 respectively.

Reheater (9): The function of reheater (Fig.4) is to reheat the steam coming out from high pressure turbine to a temperature of 540°C. Reheater is composed of two sections, the front pendant section and the rear pendant section. The rear pendant section is located above the furnace arc and the rear water wall and front pendant section is located between the rear water hanger tubes and the superheater platen section.

Burners (10): There are totally twenty four pulverized coal burners (Fig.4) for pulverized fuel type boilers and twelve oil burners provided each in between two pulverized fuel burner.The pulverized coal burners are arranged in such a way that six mills supply the coal to the burners at 4 corners, of the furnace. All the nozzles of the burners are inter linked and can be tilted as a single unit from +30° to - 30°.The oil burners are fed with heavy fuel oil till boiler load reaches to about 25%.

Igniters (11): There are twelve side eddy plate oil/HEA (High Energy Arc type igniter) igniters (Fig.4) per boiler. The atomizing air for igniters is taken from plant air compressors at 7 Kg/cm^2 (gauge). The burners are located at three elevations. Each elevation has four oil burners and igniters. These elevations are normally known as AB elevation, CD elevation and EF elevation. Igniters are used for lighting the main oil gun. There are two igniter air fans which supply air for combustion of igniter oil. Mainly two types of igniters are used.

Inboiler (Fig.1), the pulverized coal isejected into afurnace. Coal burns by combustion process with help ofigniters (11) and burners (10) release hot flue gases in furnace. From the economizer (1) the feed water fed into the water wall platen (4). Around the water wall platen (4) hot gases flows and produce saturated steam. The saturated steam enters into superheater (6, 7 and 8) through drum (2) for superheated steam. Where the drum(2) separates the saturated steam and water, due to density of water, water flows downwards and steam flows top of the drum. In superheater the saturated steam

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heated and converted into superheated steam at pressure of 138 kg/cm^2 and temperature 540^{o}C.Than the superheated steam enters into the turbine.

III. ASSUMPTIONS

1. The circulation of water and the water steam mixture takes with the help of an external pump which supplies water at a higher pressure than in a natural circulation boiler.
2. Water flow is fully developed.
3. Properties of water are constant.
4. The coefficient and the fouling factor are constant and uniform.
5. Steady operating conditions exist.

IV.ANALYSIS OF THE BOILER

1) Theoretical air required for combustion
[(11.6xC)+{34.8(H_2-O_2/8)}+(4.35xS)]/100 Kg/Kg of fuel
2)Theoretical CO_2 ((CO_2)$_t$)

$$co_2\ \%: = \frac{moles\ \ of\ c}{moles\ \ of\ N_2 + moles\ \ of\ c}$$

3)Moles of N_2

$$N_2 = \frac{Wt\ of\ N_2\ in\ air}{Mol.Wt\ of\ N_2} + \frac{Wt\ of\ N_2\ in\ fuel}{Mol.Wt\ of\ N_2}$$

4) Moles of C

$$C = \frac{\text{Wt of C in fuel}}{\text{Molecular Wt of C}}$$

5)% Excess air supplied(EA)

$$\frac{7900[(co_2\%)t - (co_2\%)a]}{(co_2\%)a[100 - (co_2\%)t}$$

5)Actual mass of air supplied / kg of fuel (AAS)
{1+EA/100} theoretical air
7)Actual mass of dry flue gas (m)
= Mass of CO_2+ Mass of NO_2 content in the fuel + Mass of N_2 in the combustion air supplied + Mass of oxygen in flue gas.
8) % heat loss in dry flue gas

$$(L_1) = \frac{mc_p(Tf - Ta)}{GCV\ of\ fuel} x100$$

9) % heat due to formation of water from H_2 in fuel

$$(L_2) = \frac{9H_2\{584 + C_P(T_f - T_a)\}}{Gcv\ of\ fuel} x100$$

10) % heat loss due to moisture in fuel

$$(L_3) = \frac{M\{584 + C_P(T_f - T_a)\}}{Gcv\ of\ fuel} x100$$

11) % heat loss due to moisture in air

$$(L_4) = \frac{AASx\,humidity\ \ factorx\ c_{p(T_f - T_a)}}{Gcv\ of fuel} x100$$

12) % heat loss due to partial conversion of C to CO

$$(L_5) = \frac{\%COxC}{\%CO + \%CO_2} \times \frac{5744}{Gcv\ of\ fuel} x100$$

13) Heat loss due to radiation & convection

$(L_6) = 0.548[(T_S/55.55)^4-(T_a/55.55)^4]+1.957\ (T_s\text{-}T_a)^{1.25}$
Sq.rt of [(196.85V_m+68.9)/68.9]

14) % Heat loss due to un burnt in fly ash

$$(L_7) = \frac{\frac{Total\ \ ash\ collected}{kg\ of\ fuel} xgcv\ of\ fly\ ash}{Gcv\ of\ fuel} x100$$

15) % heat loss due to un burnt fuel in bottom ash

$$(L_8) = \frac{\frac{Total\ \ ash\ collected}{kg\ of\ fuel} xgcv\ of\ fly\ ash}{Gcv\ of\ fuel} x100$$

16) Boiler efficiency
(ṅ) =100-(L_1+L_2+L_3+L_4+L_5+L_6+L_7+L_8)

V.RESULTS AND DISCUSSION

The calculated values as results are plotted as is following graphs.

Fig.2 the graph is plotted between losses in (%) V_S GCV of coal (kcal/kg) with constant wind velocity at 4.1 m/s .It was found from graph that as GCV of coal increases there is a decrease in percentage of losses. However the percentage of losses such as heat loss due to moisture present in air (L_4) and radiation and convection loss (L_6) signifies a contributes amount to losses.

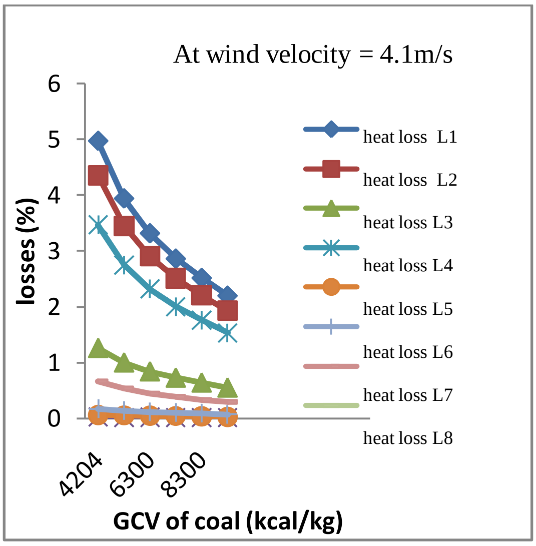

Fig.2 Heat losses with variation in GCV of fuel

Fig.3This figure illulirates the graph plotted for thermal efficiency keeping wind velocity constant at 4.1m/s. It was found that for an increase of Gross calorific value(GCV) of fuel around 4500kcal/kg, thermal efficiency is increased by 9 percent.

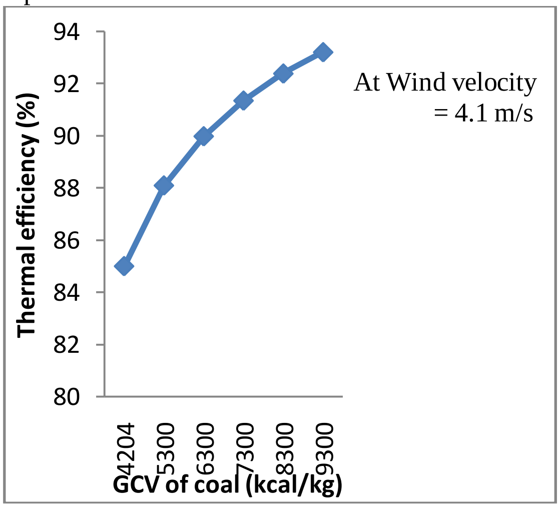

Fig.3 Variations of thermal efficiency with Gross Calorific Value (GCV)

Fig.4 the figure shows the plot with percentage if heat loss due to convection and radiation to wind velocity. It was found that there is significent decrease in percentage of heat loss as wind velocity decreases. However this loss has an effect on thermal efficiency than other losses which has no effected.

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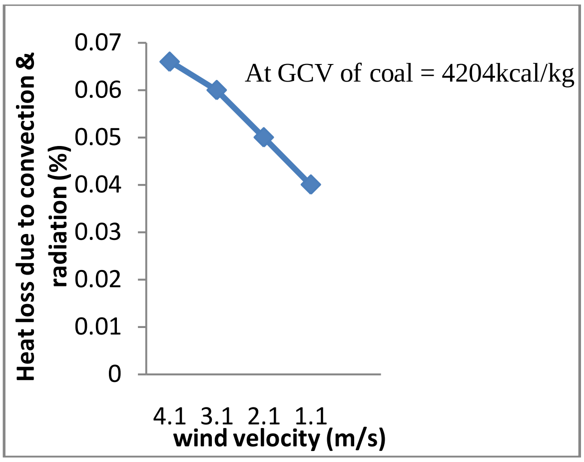

Fig.4 Variations of convection and radiation loss with wind velocity

As seen in Fig.5, there is an increase in thermal efficiency when wind velocity is decreased from 4.1 m/s to 1.1 m/s with constant Gross Calorific Value (GCV) at constant 4204 kcal/kg.

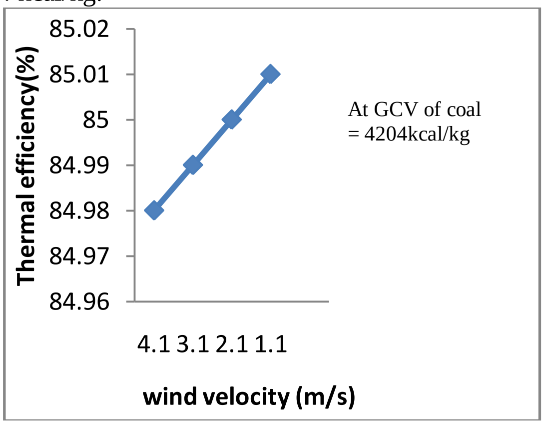

Fig.5 Variations of thermal efficiency with wind velocity

Fig.6This figure shows a plot of a SANKEY diagram where the various heat losses in percentages are shown, for a GCV of fuel of 4204 kcal/kg and wind velocity of 4.1 m/s. The heat output got was 84.9%.

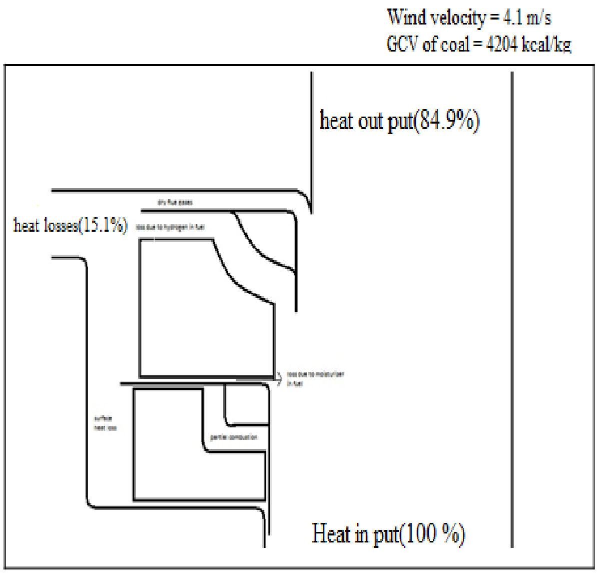

Fig.6 Heat balance sheet

VI. CONCLUSIONS

Varying gross calorific value (GCV) of fuel (Bituminous coal) from 4204kcal/kg to 9300kcal/kg at constant wind velocity at 4.1 m/s. Percentage of heat loss due to dry flue gas shows a decrease of 2.77%, formation of water from H_2 in fuel shows a decrease of 2.43%, moisture in fuel decreases to 0.70% and incomplete combustion decrease of 1.93%. Heat loss due to moisture in fuel, radiation and convection, unburntfuel in fly ash and bottom are negligible. Efficiency of boiler is found to be increase from 84.99% to 93.35 %.Varying wind velocity from 4.1m/s from 1.1m/s at constant gross calorific value (GCV) at 4204 kcal/kg.Percentage of heat loss due to radiation and convection shows a decrease of 0.02%. The remaining losses are not affected. Efficiency of boiler is found to be increase from 84.9 % to 85.1%. Hence, varying the Gross calorific value (GCV) of fuel at constant wind velocity shows an increase of thermal efficiency of boiler when compared to varying wind velocities at constant Gross calorific value (GCV).

VII. NOMENCLATURE

A percentage of ash
AAS actual mass of air supplied, kg
C percentage of fixed carbon
CO percentage of carbon oxide present in fuel
CO_2 percentage of carbon di oxide present in fuel
$(CO_2)_a$actualCO_2
$(CO_2)_t$ theoretical CO_2
C_p specific heat, kcal/kg
EA excess air
H_2 percentage of hydrogen present in fuel
L loss
m mass of dry flue gas, kg/kg of fuel
M percentage of moisture
N_2 percentage of nitrogen present in fuel
O_2 percentage of oxygen present in fuel
S percentage of sulphur present in fuel
T temperature, ^{0}C
V velocity, m/s
VM percentage of volatile meter

Subscripts

a ambient temperature
f flue gas temperature
s surface temperature
1 heat loss due to dry flue gas, %
2 heat loss due to formation of H_2in fuel
3 heat loss due to moisture present in fuel
4 heat loss due to moisture present in fuel
5 heat loss due to incomplete combustion
6 heat loss due to radiation and convection
7 heat loss due to unburntfuel in fly ash
8 heat loss due to unburnt fuel in bottom ash

REFERENCES

1. S.Krishnanunni, C.Josephkunju Paul, MathuPotti, Ernest Markose Mathew, Evaluation of Heat Losses in Fire Tube Boiler,International Journal of Emerging Technology and Advanced Engineering, Vol.2, Issue 12, pp.301-305, December, 2012.
2. RaviprakashKurkiya, SharadChaudhary, Energy Analysis of Thermal Power Plant,International Journal of Scientific and Engineering Research, Vol. 3, Issue 7,PP.83-85, July,2012.

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology
Vol. 2, Issue 1, January 2015

3. S.Arunkumar, R.Prakash, N.Jeeva, M.Muthu, B.Nivas, Boiler Blow down Heat Recovery,Journal of Mechanical and Civil Engineering (IOSR-JMCE),Vol.11, Issue 4, pp.83-85, Jul- Aug, 2014.
4. R. Loganathan , P. Sivakumar, Waste Heat Recovery Steam Generator in Sponge Iron Plant,The Standard International Journals (The SIJ), Vol. 1, No. 1, PP.23-28,March-April, 2013.
5. Sarang J Gulhane, Prof.Amitkumar Thakur, Exergy Analysis of Boiler in Cogeneration Thermal Power Plant,American Journal of Engineering Research (AJER),Vol.2, Issue10, pp.385-392,2013.
6. Ravindra Kumar, B.Sridhar Reddy,Study of Improvement in Boiler Efficiency through Incorporation of Additional Bank of Tubes in the Economiser,International Journal of Applied Science and Engineering Research,Vol.1, Issue 6, pp.747- 754, December,2012.
7. M. Costa, J. L. T. Azevedo, M G Carvalh,Combustion Characteristics of a Front-Wall-Fired Pulverized-Coal 300 MW" Utility Boiler, Overseas Publishers Association, vol. 129, pp. 277- 293, 1997.
8. R K Kapooria,S Kumar,K S Kasana,An Analysis of a Thermal Power Plant Working on a Rankine cycle: A Theoretical Investigation,Journal of Energy in Southern Africa, Vol. 19,No.1,pp.77-83, February, 2008.
9. Chih-juG.jou, Chien-li Lee, Cheng-Hsien Tsai, H.pauln Wang, Mei-Lin Lin, Enhancing the Performance of a High-pressure Cogeneration Boiler with Waste Hydrogen Rich Fuel,International Journal of Hydrogen Energy,Vol.33, pp.5806–5810, 2008.
10. Kumar Chakraborty, Nilotpal Manna, SurodhDey, Importance of Three-Elements Boiler Drum Level Control and its Installation in Power Plant,International Journal of Instrumentation and Control Systems (IJICS), Vol.4, No.2,pp.1-12, April, 2014.