Performance Investigation of Fire Tube Boiler

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Abstract— This paper basically deals with the analysis carried out on fire tube boiler which is generally used in small scale industry and is a low pressure or low capacity boiler. In this the horizontal three pass fire tube boiler is used boiler. The performance comparison of the efficiencies and heat losses by the fire tube boiler is done by preparing the heat balance sheet. The performance is tested by making use of two different fuels. The fuels used are Indian lignite coal and rice husk. From the calculation it is seen that the efficiency obtain from the Indian lignite coal is less as compared to the rice husk, which has higher efficiency than lignite coal used. It is observed that higher the ash and moisture content the efficiency obtain is lower. It is also seen that the calorific value also plays an important role in increasing the efficiency of the boiler, higher the calorific value higher the efficiency. It seen that the various heat losses also affect the efficiencies of the fire tube boiler. This heat losses must not be neglected.

Keywords: Boiler Efficiency, Heat Balance Sheet, Fire Tube Boiler, Performance, Rice Husk

I. Introduction

In present situations of the world, it is seen that as energy requirement is rising every day. Due to this plentiful utilization of natural resources their level is diminishing every day and will be minimal in next 50 years. So, altered alternatives must be used in order to lower the use of these resources. Biomass can be used as fuel in boilers which will avoid the use of fossil fuels like coal, natural gas and oil. Also it will lower the emission of harmful gases and prevent the atmosphere. The fuels used for investigation are Indian lignite coal and Rice husk. Their testing is done in laboratory report is done to find out the proximate and ultimate analysis of fuel lab. Fire tube boiler is used here in order to carry out the test all the parameters which are necessary to compute the performance of the boiler. In this project I have done the analysis on fire tube boiler by using two fuels one is coal and other is rice husk and efficiency is their efficiencies compared by direct and indirect method. An heat balance sheet is made in order to know the various heat losses in the boiler. It is seen that the major loss is the loss due to the dry flue gases also the un burnt losses also contribute to the heat losses.

All industries and research organizations in present state are busy with new implementations and thoughts, in order to do survey new sources of energy. One must not be dependent on fossil fuel for providing energy. As, all these are completely on the verge of extinction.

In order to perform analysis of the different fuels in order to evaluate the performance of the boiler. We can go for fire tube boiler as design is quiet simple and are generally available in small scale industries. There are some of the researchers who have worked on different types of boiler by making use of different grades of fuels and also some of the renewable fuels. Some of them are listed below.

Brundaban patro has analyzed the percentage by using rice husk and lignite coal on combination tube boiler (1) chetan patel et al he has used the low grade fuels i e sub bituminous coal and lignite coal to evaluate the performance of boiler (2) j dias et al he has used domestic pellets in this analysis to evaluate the performance (3) afshin ghorbhani et al has tested the performance by using biodiesel blends and diesel in order tu study the combustion analysis (4) verma et al has used the operational masses too evaluate the performance of domestics fired boiler (5) j ganan et al has used the analysis on three stage piro tublar boiler (6) j bujak has analysed by using mathematical modelling to evaluated the performance (7) k reddy et al has done various operation on the power plant by changing the econimizer coil (8) madhav et al has taken measure to recover the heat energy wastage (9) muhaisen et al performance of boiler is studied by him by using the visual basic programme (10) sae maintain the flow rate of cooling water.(11) poulik kathiriaa et al various losses of the boiler is analysed by him and efficiency in calculate and compared (12) s p nangare has used the bagasse as a fuel in boiler and compared its result with the fossil fuels (13) l v et al done fuzzy comprehensive evauluation method to determine the efficiency of coal fired boiler (14) lv et al has done recycling of waste heat of improve the result of the boiler (15) wu et al has used artificial bee colony algorithm to get optimum efficiency (16) mogharia et al has done numerical analysis to study thermal behaviour of boiler (17) dhanre et al has done energy audit of boiler in power station (180 gupta et al has adopted recommendations in order to improve the overall boiler efficiency (19) du et al has tested the efficiency bt direct and indirect method (20) zhou et al has carried out mathematical medeling to determine the performance of D type boiler.[21]

From the research it is fouynd that is more amount of ash available in Indian coal and even the quality of coal found in India is low. As, a result this low grade coal should be used appropriately, to produce the optimum energy. The fuels with lower calorific value has a key problem, when they are used as a fuel in boiler. They have lot of ash content, and also the value is low. They want a huge furnance for the same amount of the power production, for burning such fuels the furnance need to be modified. Some of the fuels such as rice husk, wood scrap, agro wastage and low grade coals require more volume of furnace. The fire tube boiler is having bigger size of reservoir but they have low performance rate. We can go for water tube boiler but is quiet complicated for modelling, also cannot store large amount of steam.

II. Nomenclature

- T_f flue gas temperature °C
- T_a ambient temperature °C
- T_s surface temperature of boiler, K
- T_{ak} ambient temperature, K
- $M_{,m}$ kg of moisture in fuel on1kg basis

- M_a actual mass of air supplied per kg of fuel
- M_{co} mass of CO formation
- M_f fuel consumption, kg/h
- m mass ofg dry flue gas, kg/kg of fuel
- V_m wind velocity, m/s
- C_p specific heat of flue gas, kcal/kg°C
- C_{ps} specific heat of superheated steam, kcal/kg°C
- C carbon
- A ash
- V volatile matter
- M moisture
- S sulphur
- E excess air supplied air
- H_2 hydrogen
- O_2 oxygen
- CO_2 carbon dioxide
- CO carbon monoxide
- SO_2 sulphur dioxide
- $(CO_2)_t$ theoretical carbon dioxide
- $(CO_2)_a$ actual carbon dioxide

III. Erection Details of Fire Tube Boiler

Fire tube boiler the simplest type of boiler. It is generally used in the commercial areas. In the fire tube boiler the furnace or combustion chamber is placed internally and has fire tubes which are present inside the combustion chamber. It is a portable type of boiler and requires less floor area.

The horizontal return tubular boiler is used here. It consists of a horizontal cylindrical shell, which has fire box at the bottom equipped with it, water space is present in the middle region of the boiler, whereas the steam which is generated is in the upper region. The fire grate is present at the bottom of the fire box and the respective fuels are fire at the fire box. Ash is collected in the ash pit which is placed at the bottom of the grate in order to collect the ash of the burnt coal, which is removed from time to time.

Three pass cross tubes are flanged to the water space which is located in the fire box in order to improve the heating surface area and also to improve the water circulation. A short size chimney is placed at the top of the fire box in order to remove the flue gases or exhaust gases from the boiler to certain height. The man holes and hand holes are there in the boiler for cleaning purpose in order to clean the boiler shell from inside and also to clean the tubes.

The horizontal fire tube boiler is also provide with the pressure gauge, water level indicator, safety valve, steam stop valve, and a Man hole for safety purpose and in order to make working conditions easy.

A. Industrial Details

Design code: IBR 1950{28} as amended.
Maximum evaporation capacity: 2500 kg/hr.
Maximum design and working pressure: 10 bar
Hydraulic test pressure: 1.5 times of working pressure.
Maximum working temperature: 200.5^0 C
Steam temperature outlet: Saturated
Working metal temperature: 228.5 °C
Flange specification: as per IBR 1950{28}

B. Characteristics

1) Simple in design
2) Easy to operate
3) Less expensive
4) Different grades of fuels can be used in this type of boiler i.e, agro waste, biomass, rice husk, and other animal waste.

C. Merits

1) It is suitable to use impure water and sedimentary water in the fire tube boiler. As this impure water produces scales on the tubes which can cause the bursting of tube. In fire tube boiler it can be prevented as the fire is made to flow through the tubes and water is surrounds the tube.
2) Maintenance cost is low as compared to water tube boiler.
3) Design of fire tube boiler is simple and requires less cost.
4) Less skilled labors are required in order to perform the operation.
5) It can be used in small industry.
6) The feed water which is to be used does not require special treatment so cost of pure feed water is reduced.

D. Demerits

1) Maximum working pressure of boiler is limited to 20 bar.
2) Load fluctuations cannot be handled easily.
3) The rate of steam generation and also the quality of steam is not much better as compared to water tube and combination tube boiler.
4) Used only in small power plants.

IV. Applications

It is used in various process industries, small scale industries, heating for small house hold purpose, small rice mills, chemical industries, rail locomotives, in marine, and other industrial sectors.

A. Different Types of Fuels for the Fire Tube Boilers

The following fuels are used for the fire tube boilers.
Solid biomass fuels

Due to the abundant use of fossil fuel they are almost on the way of extension, in order to prevent them one must use the alternate fuel such as solid biomass fuels which have low calorific value as compared to fossil fuels. These biomass fuels have more moisture content which is the major reason of heat loss and reduces the performance of boiler. Apart from this drawbacks, this fuels must be used as they are the replacement of the fossil fuel.

Low grade coals

Various low grade coals which can be used as a fuel in fire tube boiler are as follows:
Peat, Lignite, Sub-bituminous coals

Peat: Peat is the lowest grade of coal which is obtained from the carbonized plant debris. To obtain coal from this crude form following steps must be carried out, burial, compaction, and coalification.

Lignite: It is the second's last crude form of coal in the list. It is brown black in colour. It's a form of peat, which has been transformed into a rock. Sometimes, it contains plant structures of the recognizable quantity. It has about 65-70 % coal content.

Sub-bituminous: Sub-bituminous coal is a form of lignite coal. It contains about 72-76% carbon content in it. There are three types of sub-bituminous coal which are sub-bituminous A, sub-bituminous B, and sub-bituminous C, depending on heating value. The heating value of sub bituminous A is 5483 kcal/kg, sub-bituminous B is 5076 kcal/ kg, and sub-bituminous C is 4960 kcal/kg.

Chemical composition of the low grade coals:

The composition of coal varies from place to place. Generally, it has six rings of carbon atoms, joined to each other with significant amounts of hydrogen, oxygen, and nitrogen. It also has some sulfur and atmospheric pollutants in it .The analysis of coal is done for proximate analysis.,i.e., fixed carbon, volatile matter, ash, and moisture content. Other contents are neglected.

B. Heat Balance Sheet

The complete history of the heat interaction in a boiler is known, with the help of a heat balance sheet. The efficiency of a boiler is never 100%. This is due to the reason of the utilization of only a portion of the heat supplied by the fuel, and the remaining is lost. The efficiency can easily be measured, by measuring all the losses occurring in the boiler. A heat balance sheet shows the heat supplied by 1 kg of fuel, and the heat utilized. The heat supplied by the fuel is mainly used for raising the steam, and the remaining heat is lost.

Heat losses in fire tube boilers

The following heat losses are applicable to a fire tube boiler with solid fuels [31]:

HL1: Heat loss due to dry flue gas (%).

HL2: Heat loss due to evaporation of water formed due to hydrogen in the fuel (%).

HL3: Heat loss due to moisture content in the fuel (%).

HL4: Heat loss due to moisture content in the air (%).

HL5: Heat loss due to the formation of carbon monoxide (%).

HL6: Heat loss due to surface radiation, convection, and other unaccounted losses (%).

HL7: Heat loss due to unburnt in fly ash(%).

HL8: Heat loss due to unburnt in fly bottom ash(%).

Calculation for calculating heat balance sheet is as follows:

1) Step – 1 Theoretical air requirement

complete combustion = [(11.6 x C) + {34.8 x (H_2 – O_2/8)} + (4.35 x S)] /100 kg/kg of coal

2) Step – 2 Theoretical CO_2 %

% CO_2 at theoretical condition= (Moles of C)/(Moles of Nitrogen+Moles of C)

Moles of Nitirogen (N_2) = (Wt of nitrogen in theoretical air)/(Molecular weight of Nitrogen)+(Weight of Nitrogen in Fuel)/(Molecular weight of Nitrogen)

3) Step 3 To find excess air supplied

% of excess air supplied = 7900x((%CO_2)t-(%CO_2)$_a$)/ (%CO_2)$_a$x(100-((%CO_2)t)

4) Step 4 Actual mass of air supplied per kg of fuel

=(1+{%E/100}xtheoritical air

5) Step – 5 to find actual mass of dry flue gas

Mass of dry flue gas = Mass of CO2 + Mass of N2 content in the fuel +

Mass of N2 in the combustion air supplied + Mass of oxygen in flue gas

6) Step – 6 to find all losses

1) % Heat loss in dry flue gas

Among the losses of the boiler the chief loss is considered to be as the loss du eto the dry flue gases. The % heat loss due to dry flue gas evaluated by

(L1) = (m x Cp x (Tf – Ta)/ GCV of fuel)x100

Where,m= mass of dry flue gas in kg/kg of fuel

C_p = specific heat of flue gas, kcal/kg°C

T_f = flue gas temperature in °C

T_a = ambient temperature in °C

mass of dry flue gas in kg/kg of fuel is calculated as

= Mass of CO_2 +Mass of N_2 in fuel+Mass of N_2 in combustion air supplied +Mass of O_2 in dry flue gas in kg/kg of fuel

2) % Heat loss due to formation of water from H2 in fuel

In the boiler as combustion is taking place. During combustion various gases are eliminated one of them is hydrogen. So, some amount of heat loss takes place due to the combustion of hydrogen. The product of this combustion is water and which further goes out in the form of steam.

It is given by

(L2) = (9 x H2 x {584 + Cp (Tf – Ta)}/ GCV of fuel)x100

Where H_2 =Amt of hydrogen present in fuel on 1 kg basis

C_{ps}= specific heat of superheated steamin kcal/kg °C

584= latent heat due to partial pressure of water vapour

3) % Heat loss due to moisture in fuel

Moisture present in the fuel, entering the boiler with the fuel, leaves as a superheated vapor. This moisture loss is made up of the sensible heat loss, to bring the moisture to the boiling point. The latent heat of evaporation of the moisture and the degree of superheat required, bringing this steam to the temperature of the exhaust gas, cause the heat loss. This loss can be calculated with the following formula:

(L3) = (M x {584 + Cp (Tf – Ta)}/GCV of fuel)x100

where Mm= kg of moisture in the fuel on 1 kg basis.

4) % Heat loss due to moisture in air

Humidity in the entering air is superheated, as it passes through the steam boiler. This is considered as a boiler loss, because this heat passes up the stack. We must know the moisture present in the combustion air and the amount of the air supplied per unit mass of coal burned, to relate this loss to the mass of the coal burned. It is given by

(L4) = (AAS x humidity x Cp x (Tf – Ta)/ GCV of fuel)x 100

Humidity factor per kg of water=kg of dry air.

5) Heat loss due to partial conversion of C to CO

This is due to the incomplete combustion i.e., partial conversion of C to CO. It is given by

(L5) = (%CO x C/% CO + (% CO2)a)x(5744/GCV of fuel)x100

6) Heat loss due to radiation and convection

The other heat losses from a boiler consist of loss of the heat by radiation and convection. These losses are from the boiler casting into the surrounding boiler house. In general, surface heat losses and other unaccounted losses are assumed, based on the capacity and type of the boiler. However, these losses can be calculated, if the surface area of the boiler and its surface temperature are known. Radiation heat loss, W/m2, is given by

(L6)=0.548 x [TS/55.55)4 – (Ta/55.55)4] + 1.957 x (Ts – Ta)1.25 x sq.rtof [(196.85 x 3.5 + 68.9) / 68.9]

where Vm =wind velocity, m/s,

Ts =surface temperature of the boiler, K,

Tak= ambient temperature, K.
Heat losses due to unburnt carbon

Some amount of carbon is present in the ash, and this constitutes a potential heat loss in the fuel in the operation of a boiler. To calculate these heat losses, samples of ash need to be analyzed, for the measurement of carbon content present in the ash. Again, the quantity of ash produced per unit of fuel burnt must also be given.

%Heat loss due to unburnt is fly ash(L7)
=(total ash collected per kg of fuel burnt xGCV of fly ash /GCV of fuel)x100
%Heat loss due to unburnt is bottom ash(L8)
=(total ash collected per kg of fuel burnt xGCV of bottom ash /GCV of fuel)x100

V. Boiler Performance

1) Direct method
2) Indirect method

A. Direct Method

In this the efficiency is given by the ratio of output to input
Boiler efficiency = (heat output/heat input)x100
Heat output=(steam flow ratex(steam enthalpy-feed water enthalpy))/fuel firing rate xGCV of fuel

B. Indirect Method

Efficiency by this method is given by formulae:
=100-(L1+L2+L3+L4+L5+L6+L7+L8)

VI. Various Instruments Used in the Analysis

1) Flue gas analyzer: It is used for the measurement of percentage of carbon dioxide, carbon monoxide and oxygen which are emitted from the flue gases.
2) TDS meter: It is of conductive type which is used to measure the feed water temperature, boiler water temperature, temperature of make-up water.
3) Flow Meter: It is used for the measurement of flow rates of water, steam, fuel and air.
4) Resistance type temperature sensors.

A. Drafting of Design

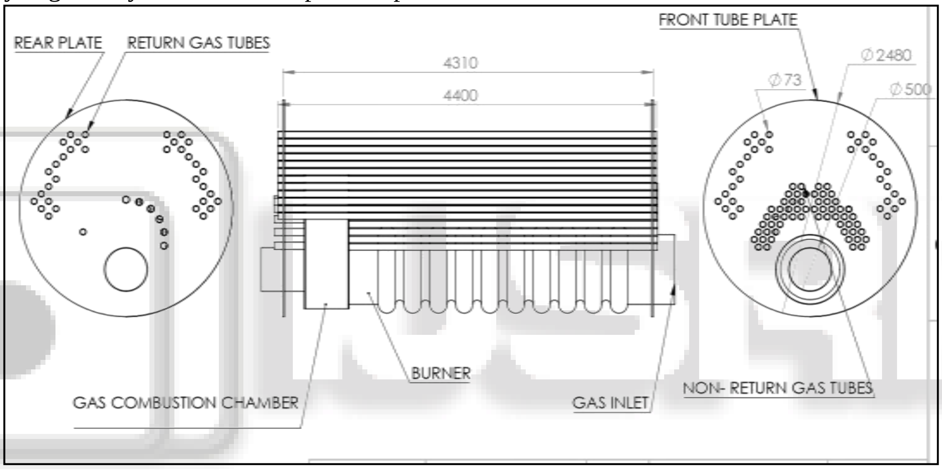

Fig. 1:

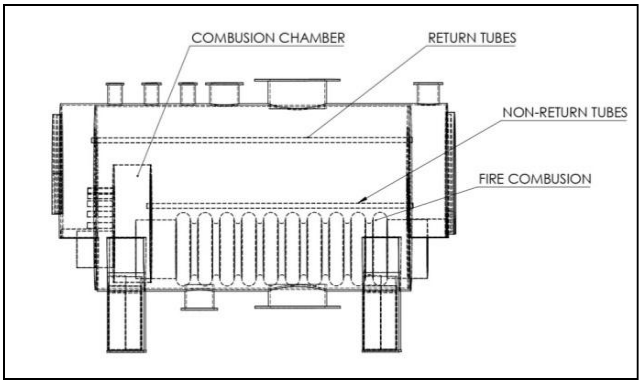

Fig. 2:

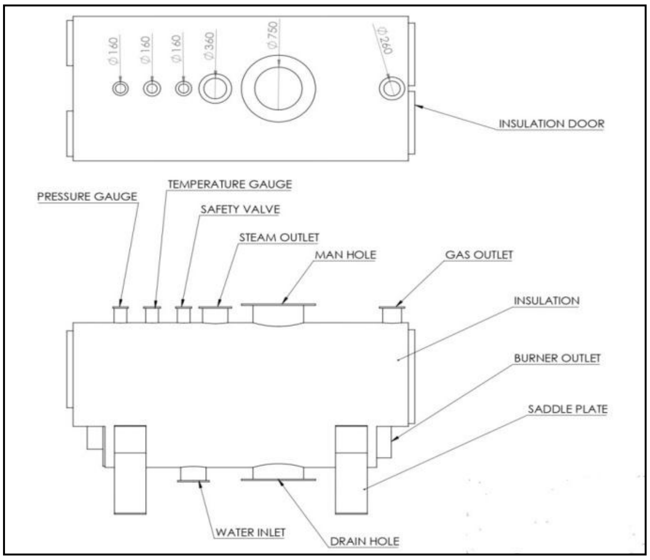

Fig. 3:

1) How the Tests Were Carried Out

In order to perform any analysis one must have testing preparations to carry out the test, for getting better results. The testing on boiler is carried out under steady load condition. Testing is not carried out the boiler is in working condition. First of all the fuel is fired at the required rate. In order to calculate the efficiency of the performance of the boiler, the is operated for an hour under full load or steady load conditions, and then the readings were taken in the next 1 hour, in order to perform testing. So, it is seen that in order to perform a single test it takes 2 hours. The testing was done two times and data was recorded and cross checked. The various parameters were calculated by the instruments and it data was noted down. Two Fuels were taken and its analysis was done in the laboratory in order to obtain the proximate and ultimate analysis of the fuels, also the gross calorific value of the fuels were obtained from the testing carried out in the laboratory. All the instruments were checked whether they are performing well or not. At, the end the leakages and cracks were checked of the combustion chamber to see whether is there any outside air coming inside the combustion chamber.

2) Tests Carried Out on Fire Tube Boiler

The two tests were carried out on the fire tube boiler by using two different fuels in order to obtain the efficiency of the boiler and see various losses using heat balance sheet. The two fuels used are a low grade coal i.e, Indian lignite coal and the other is the solid biomass fuel i.e, rice husk. Indian lignite coal has a gross calorific value of 3187 kcal/kg and the rice husk has the gross calorific value of 3984 kcal/kg. Indian lignite coal is used as a fuel in Test 1 and the second 2 test was carried out using rice husk as fuel.

These are the measurements and observations which were recorded during the tests:

1) Temperature and pressure of water at the inlet of economizer and quality of water.
2) Temperature and pressure of the steam at boiler outlets, and flow rate of steam.
3) Fuel analysis by ultimate and proximate analysis.
4) Readings of the flue gas were taken by the flue gas analyzer.
5) Ash analysis was done after collection of ash samples for both the fuels.
6) Surface temperature of the boiler was recorded by the resistance temperature sensors.

As the fuels are burnt in the combustion chamber the residue or the waste from fuels burnt as well as the ash from the fuel is collected at the bottom of the combustion chamber. In order to remove this waste and ash from the combustion chamber it is removed from the ash doors provided at the bottom where the boiler rests. The surface temperature of the boiler is measured by mounting the resistance type temperature sensor on the surface of the boiler at different locations on the boiler. 10 temperature sensors were used for the recording of surface temperature. The final surface temperature of boiler is the arithmetic mean of the measured individual surface temperature. The feed water which is supplied to the boiler is first passed to the economizer to heat feed water before it passes to the boiler, it is heated by making use of the flue gases. External economizer is in this boiler arrangement. The economizer is placed in between the air pre heater and the flue gas outlet. Chimney is there from where the flue gases are exhausted to the atmosphere. After calculation of the surface temperature, the flue gas is fired in the combustion chamber and after that readings of the steam temperature and pressure, feed water temperature and pressure, flue gas analysis, average temperature of flue gas was recorded.

Fuel analysis

CONTENTS	TEST 1 LIGNITE COAL	TEST 2 RICE HUSK
GCV of fuel(ADB) kcal/kg	3187	3984
Total Moisture (ARB) %	32.54	10.62
Inherent Moisture (ADB) %	9.86	11.64
V.M (ADB) %	41.27	50.59
Fixed carbon (ADB) %	22.44	31.62
Ash (ADB) %	24.65	7.93
Oxygen %	10.31	22.24

Table 1: Data of Fire Tube Boiler

PARAMETERS	TEST 1 LIGNITE COAL	TEST 2 RICE HUSK
GCV of the coal, kcal/kg	3187	3984
Rate of steam generation, kg/h	1900	2000
Steam pressure, kg/cm^2 (gauge)	6.2	8
Steam temperature, C	145	161
Feed water temperature, C	60	65
% of CO_2 in the Flue gas	11	10
% of CO in the flue gas	0.45	0.6
Average flue gas temperature, C	142	152
Ambient temperature, C	30	34
Humidity in the ambient air, kg/kg of dry air	0.020	0.017
Surface temperature of the boiler, C	50	62
Wind velocity around the boiler, m/s	3.4	3.1

Table 2: Ash Analysis

PARAMETERS	LIGINITE COAL	RICE HUSK
GCV of the bottom ash, kcal/kg	133.3	200
GCV of the fly ash, kcal/kg	510	620
Ratio of the bottom ash to the fly ash	164	182

Table 3

VII. RESULTS AND DISCUSSIONS

From the above table it is seen that

1) Higher the gross calorific value higher is the efficiency of the boiler.
2) The dry flue gas loss is maximum when we have used a fuel of higher Gcv.
3) Loss due to moisture content is less for rice husk as compared to lignite coal as it has lower amount of moisture content. Moisture present in fuels lower the performance rate of boiler.
4) The losses due to unburnt carbon is lower as compared to the lignite coal.
5) From the table it can be seen that the overall performance of the boiler is improved by using the rice husk as the fuel in boiler as compared to the lignite as fuel.

The key heat loss seen in the fire tube boiler is the loss due to dry flue gas. The loss of heat due to un burnt carbon is also the loss which must be into consideration which also affect the performance of boiler.

Input/Output Parameters	Test For Liginite Kcal/kg of fuel	%	Test for Rice Husk Kcal/kg of fuel	%
Total heat input in fuel	3187	100	3984	100
Losses in Boiler				
1.Dry flue gas loss	254.25	7.97	414.69	10.40
2.Loss Due to hydrogen in fuel	232.095	7.28	310.20	7.781
3.Loss Due to moisture in fuel	206.43	6.477	67.66	1.698
4.Loss Due to moisture in air	11.18	0.350	18.16	0.455
5.Partial Combustion of C to CO	98.06	3.077	199.59	5.010
6.Surface heat loss	90.23	0.1786	102.3	0.217
7.Loss due to unburt in fly ash	4.041	0.1268	1.443	0.0362
8.Loss due to unburt in fly ash	112.71	3.53	44.24	1.10
Total losses		28.68		26.69
Boiler efficiency		71.0106		73.30

VIII. CONCLUSION

1) Heat balance sheet is prepared in order to identify the performance of the boiler. Direct method and indirect method is employed in order to calculate the efficiency of the boiler.
2) There are losses in the boiler which are must in order for comparisons of the performance.
3) Abundant use of fossil fuel has made us to think toward the replacement of fossil fuel.
4) It is found that biomass such as rice husk, wood pellets, apple pellets, sugarcane bagasse, and low grade fuels can be used as fuel.
5) Its tests were compared and found that higher the calorific value higher the efficiency. Also, the ash content, humidity level, moisture content also effects the performance of the boiler.
6) Higher the ash content and higher the moisture content the performance of boiler is reduced.
7) In this I have compared the performance of the comparison by using the rice husk and lignite on fire tube boiler and founded the losses and the performance obtained from biomass fuel is optimum as compared to low grade fuels.
8) GCV of the fuel is the important parameter which is to be discussed for better performance.

Low grade biomass fuel must be selected and its comparisons on the boiler should be done and justified.

9) We can also compare the efficiencies of the boiler by using different fuels on fire tube boiler, and justify the results which we will obtain after comparison.
10) Other methods can also be employed in order to improve the performance of the small capacity boilers.

IX. FUTURE SCOPE

– Comparison of the results of this work can be compared by using different conventional fuels and its performance and losses can be evaluated.
– Depending on this data calculated simulation can be carried out by adding different value of data and some improvements can be done in the boiler system design which improve the boiler and steam efficiency.
– Surface losses can be prevented by using appropriate insulation method.

REFERENCES

[1] Brundaban Patro, Efficiency studies of combination tube boiler, 2015.
[2] Chetan T.Patel, Dr. Bhavesh K. Patel, Vijay K. Patel, Efficiency with different gcv of coal and efficiency improvement oppourtinity in boiler, 2013
[3] J. Dias, M. Costa, J.L.T. Azevedo, Test of a small domestic boiler using different pellets, Biomass Bio energy 27 (2004) 531– 539.
[4] Ghorbani, B. Bazooyar, A. Shariati, S.M. Jokar, H. Ajami, A. Naderi, A comparative study of combustion performance and emission of biodiesel blends and diesel in an experimental boiler, Appl. Energy 88 (2011) 4725–4732.
[5] V.K. Verma, S. Bram, G. Gauthier, J.D. Ruyck, Evaluation of the performance of a multi-fuel domestic boiler with respect to the existing European standard and quality labels: Part-1, Biomass Bioenergy 35 (2011) 80–86
[6] J. Ganan, A. Al-Kassir, J.F. Gonzalez, J. Turegano, A.B. Miranda, Experimental study of fire tube boilers performance for public heating, Appl. Therm. Eng. 25 (2005) 1650–1656.
[7] J. Bujak, Mathematical modelling of a steam boiler room to research thermal efficiency, Energy 33 (2008)
[8] Madhav, D., Ramesh, L. & Naveen, M. 2013. Heat Recovery through Boiler Blow Down Tank. International Journal of Engineering Trends and Technology (Ijett), 4.
[9] Muhaisen, N. & Hokoma, R. 2012. Calculating The Efficiency Of Steam Boilers Based On Its Most Effecting
[10] Factors: A Case Study. International Journal of Engineering and Applied Sciences, 6.
[11] S.B. Kang, J.J. Kim, K.S. Choi, B.S. Sim, H.Y. Oh, Development of a test facility to evaluate performance of a domestic wood pellet boiler, Renewable Energy 54 (2013) 2–7.

