Energy Performance Assessment of Boiler at P.S.S.K. Ltd, Basmathnagar, Maharashtra State

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Abstract—Energy Performance Assessment of Boiler is a vital concept in any sugar mill. Because, the heart of sugar mill is Boiler and to maximize efficiency and profit of sugar mill, there is need to increase efficiency of Boiler. The Boiler efficiency can be evaluated by direct and Indirect method. In direct method the energy gain by working fluid is compared with energy content of fuel, while in case Indirect method various losses compared to the energy input. Present Research paper deals with Energy Performance Assessment of co-operative sugar mill’s Existing boiler, with maximum continuous rating (MCR)-100 TPH and outlet steam parameter -110kg/cm2 and540oC and Bagasse used as a fuel at Purna Sahakari Sakhar Karkhana (P.S.S.K.) Ltd, Basmath Nagar, District- Hingoli ,Maharashtra -431512. This research work was conducted as per yearly procedure followed by the Supplier of Boiler, Walchandnagar Industries Ltd, Pune for Energy Performance Assessment of Boiler through the Indirect Method i.e. Heat Loss Method ASME PTC 4.1.So, Boiler Efficiency, Evaporation Ratio and different Heat Losses analyzed by data collected from Daily Boiler Log Book within the last previous three year season’s 2011-12, 2012-13 and 2013-14. From considering overall analysis and Research Methodology, Heat losses due to hydrogen in fuel and due to moisture in fuel were found to be the major problems to decrease the Performance of Boiler. Finally to overcome these problems following suggestions was recommended (1) Installation of Dryer (2) Use of Solid Combustion Catalyst (3) Exchange Air Cooled Condenser with Water Cooled Condenser.

Keywords—Sugar Mill, Bagasse, Boiler, Boiler Efficiency, Evaporation Ratio, Comparison Of Different Losses.

I. INTRODUCTION

Energy is an indispensable instrument in the progress of human race. Today’s high standard living has been possible only through the judicious use of various energy resources at command. Realizing the fact that energy is the sinew of economic growth, energy management and energy conservation are of paramount importance. The above along with energy efficiency improvement are the only cost-effective and viable means of ensuring the proper use of finite natural resources, minimizing operating expenses, and increasing the profitability of enterprises. Boiler is one of the important component in energy generation process i.e. steam generation plant.

Boiler is a closed pressure vessel in to which water can be fed and by applying heat continuously, evaporated in to steam. The function of the boiler is to generate steam at the desired conditions efficiently and with low operating costs. Low pressure steam is used in process an application whereas high pressure superheated steam is used for generating power via steam turbines. Boilers consist of a number of tubes for maximum heat transfer. These tubes runs between steam distribution drum at the top of the boiler and water collecting drums at the bottom of the boiler. Steam flows from the steam drum to the super heater before entering the steam distribution system.

II. METHODS TO CALCULATE THE BOILER EFFICIENCY

Sugar industry is known as one of the major non conventional energy source industry in India. Because it uses renewable sugar cane crop as the raw material, which gives output as a bagasse with sufficient caloric value. Sugar industry mills attached with co-generation plant, both are in co-operative and private sector having great importance in Indian economy. It gives revenues to government, is in the form of generation of power around 9 major states with 3600 MW by using bagasse as the renewable energy source.

In any Sugar industry mills, there are lot of components are included. But out of that, Boiler is important than any other. Any sugar industry mill heart component is Boiler and to maximize beneficiary output from sugar mill, there is need to maintain efficiency of Boiler with the design efficiency. So, boiler efficiency test is necessary for find out variation of boiler efficiency related to its MCR values. Hence it is necessary to find out the current level of efficiency for performance evaluation, which is mandatory for energy conservation action in industry.

A. Boiler Efficiency

Boiler efficiency is a relationship between energy supplied to the boiler and energy output received from the boiler. It is expressed in percentage.

\[ \text{Heat exported by the fluid (water, steam)} \times 100 \]

\[ \text{Heat provided by the fuel} \]
Boiler efficiency classified into three major types

1. Combustion efficiency: It gives an idea about the fuel burning capability of a burner. It is the relationship between Quantity of fuel unburnt in the boiler with surplus exhaust air

2. Thermal efficiency: It is related with to assess the performance of heat exchangers units used in boilers. Thermal efficiency is not considered valuable for economics analysis since it does not take into account the radiation and convection losses occurring in the boiler sections.

3. Fuel-to-steam efficiency: is helpful to determine the overall efficiency of a boiler. Since, it takes into consideration the heat exchanger effectiveness, radiation and convections losses.

Most standards for calculation of boiler efficiency, including IS 8753, ASME Standard: PTC-4.1 Power Test Code and BS 845 are designed for measurement of boiler efficiency. Unfortunately, all these standards do not include blow down as a loss in the efficiency calculation.

The two major Methods employed to find out the fuel-to-steam efficiency of a boiler are explained below

a. Input–output method or direct method: this method of efficiency is also known as direct method. For calculation of efficiency, it needs only the useful output (steam) and the heat input (i.e. fuel).

Boiler Efficiency = \[ \frac{\text{Heat Output} \times 100}{\text{Heat Input}} \]

b. Heat loss method or indirect method: it is also known as heat balance efficiency measurements method. This method of efficiency determination takes into account all kinds of heat losses occurred inside the boiler. In this method the boiler efficiency is calculated by summation of percentage of all losses and deducts this resultant sum of losses from 100 percent.

The major heat losses occurring in the boiler are:

L1- Loss due to dry flue gas.
L2- Loss due to hydrogen in fuel (H₂)
L3- Loss due to moisture in fuel (H₂O)
L4- Loss due to surface radiation and convection.
L5- Loss due to unburnt carbon is ash.
L6- Loss due to moisture in air (H₂O)
L7- Loss due to incomplete combustion

In the above, loss due to moisture in fuel and the loss due to combustion of hydrogen are dependent on the fuel, and cannot be controlled by design.

Boiler Efficiency by Heat loss method or Indirect method =\[100 - (L1+L2+L3+L4+L5+L6+L7)\]

The data required for calculation of boiler efficiency using indirect method are:

- GCV of fuel in kcal/kg.
- Percentage of Oxygen in the flue gas.
- Flue gas temperature in °C (Tf).
- Ambient temperature in °C (Ta) and humidity of air in kg/kg of dry air.
- Water temperature at different levels.
- Ultimate analysis of fuel.
- GCV of ash in kcal/kg.

III. FORMULAE FOR COMPUTING VARIOUS LOSSES

In order to calculate the boiler efficiency by indirect method, all the losses that occur in the boiler must be established. These losses are conveniently related to the amount of fuel burnt. In this way it is easy to compare the performance of various boilers with different ratings.

A. Theoretical air required for combustion

\[ \text{GCV of ash in kcal/kg} \]

\[ \text{Percentage of Oxygen in the flue gas} \]

\[ \text{Flue gas temperature in °C (Tf)} \]

\[ \text{Ambient temperature in °C (Ta) and humidity of air in kg/kg of dry air} \]

\[ \text{Water temperature at different levels} \]

\[ \text{Ultimate analysis of fuel} \]

\[ \text{GCV of ash in kcal/kg} \]

Where C, H₂, O₂ and S are the percentage of carbon, hydrogen, oxygen and sulphur present in the fuel.

B. % Excess air supplied (EA)

\[ \text{From flue gas analysis} \]

C. Actual mass of air supplied /kg of fuel (AAS)

\[ \text{From flue gas analysis} \]

D. Percentage of heat loss due to dry flue gas (L₁)

\[ \text{From flue gas analysis} \]

Where,

- Mass of dry flue gas in kg/kg of fuel
- Combustion products from fuel: CO₂ +SO₂ + Nitrogen in fuel + Nitrogen in the actual mass of air supplied + O₂ in flue gas.
C_p = Specific heat of flue gas (0.23 kCal/kg °C)
T_f = Flue gas temperature in °C
T_a = Ambient temperature in °C

E. Percentage of heat loss due to evaporation of water formed due to H_2 in fuel (L_5)

Oxygen in air combines with hydrogen present in fuel to form water and gets evaporated. Thus heat loss due to evaporation of water.

\[ \text{Heat loss} = 9 \times \text{H}_2 \times \frac{(\text{SV} + \text{C}_p (\text{T}_f - \text{T}_a)) \times 100}{\text{GCV of fuel}} \]

Where,
\[
\begin{align*}
\text{C}_p & = \text{Specific heat of superheated steam (0.47kCal/kg °C)} \\
\text{H}_2 & = \text{kg of hydrogen present in fuel on 1 kg basis} \\
\text{SV} & = \text{Latent heat corresponding to partial pressure of water vapour.}
\end{align*}
\]

F. Percentage of heat loss due to moisture present in fuel (L_5)

Due to moisture entering the boiler with the fuel this heat loss occur.

\[ \text{Heat loss} = M \times \frac{(\text{SV} + \text{C}_p (\text{T}_f - \text{T}_a)) \times 100}{\text{GCV of fuel}} \]

Where,
\[
\begin{align*}
\text{C}_p & = \text{Specific heat of superheated steam (0.47kCal/kg °C)} \\
\text{M} & = \text{kg of moisture in fuel in 1 kg basis}
\end{align*}
\]

G. Percentage of heat loss due to radiation and convection (L_6)

Normally surface loss and other unaccounted losses is assumed based on the type and size of the boiler as given below

For industrial fire tube / packaged boiler = 1.5 to 2.5%
For industrial water tube boiler = 2 to 3%
For power station boiler = 0.4 to 1%

H. Heat loss due to unburnt carbon in ash (L_5)

The calculation of the heat loss due to unburned carbon is based on the carbon content in boiler ash. assuming that the boiler ash consists of the ash in fuel plus the unburned carbon. Generally in solid fuel heat loss due to unburnt fly ash and heat loss due to unburnt in bottom ash are considered.

\[ \text{Heat loss} = \frac{\text{Quantity of ash in fuel} \times \text{GCV of ash}}{\text{GCV of fuel}} \times 100 \]

Note: Generally, there are two different Heat losses by ash considered

1. Heat loss due to unburnt in fly ash

\[ \frac{\text{Total ash collected} \times \text{kg of fuel burnt} \times \text{GCV of fly ash}}{\text{GCV of fuel}} \times 100 \]

2. Heat loss due to unburnt in bottom ash

\[ \frac{\text{Total ash collected} \times \text{kg of fuel burnt} \times \text{GCV of burn ash}}{\text{GCV of fuel}} \times 100 \]

I. Heat loss due to moisture present in air (L_6)

Vapour in the form of humidity in the incoming air, is superheated as it passes through the boiler. Since this heat passes up the stack, it must be included as a boiler loss.

\[ \text{Heat loss} = \frac{\text{AAS} \times \text{humidity} \times \text{C}_p \times (\text{T}_f - \text{T}_a) \times 100}{\text{GCV of fuel}} \]

Where,
\[
\begin{align*}
\text{C}_p & = \text{Specific heat of superheated steam (0.47kCal/kg °C)} \\
\text{AAS} & = \text{Actual mass of air supplied per kg of fuel} \\
\text{Humidity factor} & = \text{kg of water/kg of dry air}
\end{align*}
\]

H. Heat loss due to incomplete combustion (L_7)

Products formed by incomplete combustion could be mixed with oxygen and burned again with a further release of energy.

\[ \text{Heat loss} = \frac{\% \text{CO} \times \% \text{O}_2 \times 5764 \times 100}{\text{GCV of fuel}} \]

Where,
\[
\begin{align*}
\text{L_5} & = \% \text{Heat loss due to partial conversion of C to CO} \\
\text{CO} & = \text{Volume of CO in flue gas leaving economizer (\%)} \\
\text{CO}_2 & = \text{Actual Volume of CO}_2 \text{ in flue gas (\%)} \\
\text{C} & = \text{Carbon content kg / kg of fuel}
\end{align*}
\]

Having established the magnitude of all the losses mentioned above, a simple heat balance would give the efficiency of the boiler. The efficiency is the difference between the energy input to the boiler and the heat losses calculated.

IV. METHODOLOGY OF THE STUDY

A. Study Site

This study was carried out in Purna Sahakari Sakhar Karkhana Ltd, Basmath Nagar, District-Hingoli, Pin Code-431512 (Maharashtra state) as in a part of research.

M/S, Purna S.S.Karkhana Ltd (PSSKL) is one of the pioneering co-operative sugar factory At Basmath Nagar, Dist- Hingoli in marathwada region, (Maharashtra state) registered in year 1970 under the Maharashtra co-operative societies act,1960.
The karkhana has original licenses from Ministry Of Industrial Development dated 22
1. Specification of boiler: The design of boiler is single drum, natural circulation, and radiant furnace with water cooled membrane walls, three stage superheater with inter stage de-superheater and balanced draft. Boilers have all accessories with economiser and air preheater.

- Multi fuel fired boiler with maximum continuous rating (MCR) -100 TPH.
- Outlet steam parameter (working pressure):- 110kg/cm² and 540°C.
- The tolerance on superheater of outlet temperature (+/-) 5 °c.
- The combustion system of boiler with travelling grate with spreader stoker.
- The boiler efficiency for bagasse is 100 % and coal is 70 % on the basis of GCV.
- The dust concentration in the flue gases leaving the boiler -max.150 Mg/Nm³
- Travel grate with continuous ash discharge and an overfeed stoker, with hydraulic drive.
- Fuel is burnt suspended in air above the grate and on the travelling grate ash generated in boiler is continuously discharge.
- Air seal provided in order to control the excess air entry into the furnace.
- Boiler shall be capable of peak generation of 110 % of the MCR generation for a period of one hour in a shift

### TABLE I

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Particulars</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>General Details</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Area</td>
<td>8000</td>
<td>Hectars</td>
</tr>
<tr>
<td>2</td>
<td>Installed Cane Crushing Capacity</td>
<td>2500</td>
<td>TCD</td>
</tr>
<tr>
<td>3</td>
<td>Installed Co-Gen. Capacity</td>
<td>18.9</td>
<td>MW</td>
</tr>
<tr>
<td>B</td>
<td>Fuel (Bagasse) Details</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Fuel Used In Boiler</td>
<td>Wet Mill Bagasse</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Cane Availability</td>
<td>5.6</td>
<td>Lakh Tons</td>
</tr>
<tr>
<td>3</td>
<td>Bagasse To Steam Ratio</td>
<td>2.6</td>
<td>Kg/Kg Of Bagasse</td>
</tr>
<tr>
<td>4</td>
<td>Bagasse Used By Boiler</td>
<td>36</td>
<td>TPH</td>
</tr>
</tbody>
</table>

500 days Boiler’s different performance parameters readings are studied for various observation and different heat losses for research about the boiler performance from last 3 years.
Following areas were covered during the test for measurements for different parameters considered as follows

B. Study Data

This study work was focused on the improvements in boiler efficiency resulting from reduction in various heat losses. By considering data referred by “Walchandnagar Industries Ltd” Pune was conducted for boiler efficiency measurements on 14th to 16th March 2014.

“Walchandnagar Industries Ltd” Pune was used Indirect method ASME PTC 4.1(2005) for the calculation So by taking a reference of this Indirect method ASME PTC 4.1(2005) method and analysis of various parameter of boiler, related to different heat losses this research has been conducted.

1. Water / Steam parameters:
   - Temperature and Pressure measurements of water at Economizer inlet and that of steam at boiler outlet.
   - Steam flow rates(steam pressure, steam generation per hour)
   - DM water quality
   - Feed water analysis
   - Fuel consumption rate per hour, humidity factor etc.

2. Fuel:
   - Collection of Fuel samples.
   - Ultimate analysis of the Fuel (H₂, O₂, S, C, moisture content, ash content)
3. **Flue gas/Ash analysis:**
- Collection of Ash samples for unburnt analysis.
- Online readings for Flue gas analysis.
- Percentage of Oxygen or CO₂ in the flue gas.
- Flue gas temperature in °C (Tₕ)

4. **Surface Conditions:**
- Measurements of Surface Temperatures.

5. **Other data:**
- GCV of fuel in kcal/kg.
- Percentage combustible in ash (in case of solid fuels).
- GCV of ash in kcal/kg (in case of solid fuels).
- Ambient temperature in °C (Tₐ) and humidity of air in kg/kg of dry air.
- Weather any heat recovery devices are attach or not, if attach, than its data.

6. **Format’s used for data collection:**
- Daily 3 shift wise “BOILER LOG SHEET” formats of previous three years i.e., from boiler have been installed.
- Daily “BOILER WATER ANALYSIS REPORT” of previous three years i.e., from boiler has been installed.
- “ENERGY AUDIT REPORT” of co-gen plant submitted by “Enrich Consultant’s”, Pune as per directives of Maharashtra Electricity Regulations Commission (MERC).
- “EFFICIENCY CALCULATION REPORT” given by supplier of Boiler “Walchandnagar Industries Ltd, Pune. Where boiler efficiency was calculated by Indirect method ASME PTC 4.1(2005) was used for the calculation and losses were identified.
### TABLE II

<table>
<thead>
<tr>
<th>SR. NO.</th>
<th>PARAMETER</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Turbine Load</td>
<td>mw</td>
</tr>
<tr>
<td>2</td>
<td>Steam Drum Level</td>
<td>%</td>
</tr>
<tr>
<td>3</td>
<td>Steam Drum Pressure</td>
<td>Kg/Cm²</td>
</tr>
<tr>
<td>4</td>
<td>Deaerator Level</td>
<td>%</td>
</tr>
<tr>
<td>5</td>
<td>Deaerator Pressure</td>
<td>Kg/Cm²</td>
</tr>
<tr>
<td>6</td>
<td>Deaerator Temperature</td>
<td>°C</td>
</tr>
<tr>
<td>7</td>
<td>Furnace Draft</td>
<td>mmWc</td>
</tr>
<tr>
<td>8</td>
<td>Feed Water Pressure</td>
<td>Kg/Cm²</td>
</tr>
<tr>
<td>9</td>
<td>Feed Water Flow</td>
<td>TPH</td>
</tr>
<tr>
<td>10</td>
<td>Attemporator Flow</td>
<td>TPH</td>
</tr>
<tr>
<td>11</td>
<td>Main Steam Temperature</td>
<td>°C</td>
</tr>
<tr>
<td>12</td>
<td>Main Steam Flow</td>
<td>TPH</td>
</tr>
<tr>
<td>13</td>
<td>Main Steam Pressure</td>
<td>Kg/Cm²</td>
</tr>
<tr>
<td>14</td>
<td>Furnace Temperature</td>
<td>°C</td>
</tr>
<tr>
<td>15</td>
<td>Eco I/L Temp</td>
<td>°C</td>
</tr>
<tr>
<td>16</td>
<td>Aph I/L Temp</td>
<td>°C</td>
</tr>
<tr>
<td>17</td>
<td>Esp I/L Temp</td>
<td>°C</td>
</tr>
<tr>
<td>18</td>
<td>Eco O/L Water Temp</td>
<td>°C</td>
</tr>
<tr>
<td>19</td>
<td>Csh-1 O/L Steam Temp</td>
<td>°C</td>
</tr>
<tr>
<td>20</td>
<td>Csh-2 O/L Steam Temp</td>
<td>°C</td>
</tr>
<tr>
<td>21</td>
<td>Id-1 Damping Opening</td>
<td>%</td>
</tr>
<tr>
<td>22</td>
<td>Id-1 Speed</td>
<td>RPM</td>
</tr>
<tr>
<td>23</td>
<td>Id-1 Current</td>
<td>Amp</td>
</tr>
<tr>
<td>24</td>
<td>Id-2 Damping Opening</td>
<td>%</td>
</tr>
<tr>
<td>25</td>
<td>Id-2 Speed</td>
<td>RPM</td>
</tr>
<tr>
<td>26</td>
<td>Id-2 Current</td>
<td>Amp</td>
</tr>
<tr>
<td>27</td>
<td>Fd-1 Damping Opening</td>
<td>%</td>
</tr>
<tr>
<td>28</td>
<td>Fd-1 Speed</td>
<td>RPM</td>
</tr>
<tr>
<td>29</td>
<td>Fd-1 Current</td>
<td>Amp</td>
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<tr>
<td>30</td>
<td>Fd-2 Damping Opening</td>
<td>%</td>
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<tr>
<td>31</td>
<td>Fd-2 Speed</td>
<td>RPM</td>
</tr>
<tr>
<td>32</td>
<td>Fd-2 Current</td>
<td>Amp</td>
</tr>
<tr>
<td>33</td>
<td>Sa Damping Opening</td>
<td>%</td>
</tr>
<tr>
<td>34</td>
<td>Sa Speed</td>
<td>RPM</td>
</tr>
<tr>
<td>35</td>
<td>Sa Current</td>
<td>Amp</td>
</tr>
</tbody>
</table>

**V. OBSERVATION AND SIMULATION**

- By considering data referred by “Walchandnagar Industries Ltd” Pune was conducted boiler efficiency measurements on 14th to 16th March 2014. Walchandnagar Industries Ltd was used Indirect method ASME PTC 4.1(2005) for the calculation and losses were identified.

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**A. Fuel Analysis Of Bagasse**

In the following table, we present the details ultimate analysis of bagasse shown, which were used as the fuel.
**B. Boiler data Analysis**

In the following table, we present the Boiler data Analysis of boiler where bagasse, is used as the fuel.

**TABLE IV**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Quantity Of Steam Generated</td>
<td>104500</td>
<td>Kg/Hr</td>
</tr>
<tr>
<td>2</td>
<td>Quantity Of Bagasse Consumed</td>
<td>38500</td>
<td>Kg/Hr</td>
</tr>
<tr>
<td>3</td>
<td>Steam Temperature</td>
<td>540</td>
<td>0°C</td>
</tr>
<tr>
<td>4</td>
<td>Steam Pressure</td>
<td>104</td>
<td>Kg/CM²</td>
</tr>
<tr>
<td>5</td>
<td>Temperature Of Flue Gas At Outlet Of Air Preheater</td>
<td>140</td>
<td>0°C</td>
</tr>
<tr>
<td>6</td>
<td>O₂ In Flue Gas</td>
<td>4.9</td>
<td>%</td>
</tr>
<tr>
<td>7</td>
<td>Ambient Temperature</td>
<td>40</td>
<td>0°C</td>
</tr>
<tr>
<td>8</td>
<td>Feed Water Temperature At Economiser Inlet</td>
<td>175</td>
<td>0°C</td>
</tr>
</tbody>
</table>

**C. Boiler Efficiency**

1. **Direct Method:**

*a. Heat output data*

Quantity of steam generated (output): 104.5 TPH  
Steam Pressure: 110 kg/cm² (g)  
Steam Temperature: 540 °C  
Enthalpy of steam at 110 kg/cm² (g) pressure:  
829.88 kCal/kg (Calculated by Molier Chart)  
Feed water Temperature: 175°C  
Enthalpy of Feed Water: 178.62 kCal/kg (calculated by Molier chart)  

*b. Heat input data*

Quantity of Bagasse consumed (Input): 38.5 TPH  
GCV of Bagasse (GCV)  
\[ GCV = 4600 \times (1 - w) - (1200 \times s) \]  
Where,  
\[ w = \text{moisture in bagasse} \]  
\[ s = \text{bagasse pol in %} \]  
\[ GCV = 4600 \times (1 - w) - (1200 \times s) = 2276 \text{ kcal/kg} \]  
Therefore, Boiler efficiency (η)  
\[ \eta = \frac{Q \times (h_g - h_f)}{q \times GCV} \times 100 \]  
Where,  
\[ Q = \text{Quantity of steam generated per hour (kg/hr)} \]  
\[ q = \text{Quantity of fuel used per hour (kg/hr)} \]  
\[ GCV = \text{Gross calorific value of the fuel (kCal/kg)} \]  
\[ h_g = \text{Enthalpy of steam (kCal/kg)} \]  
\[ h_f = \text{Enthalpy of feed water (kCal/kg)} \]  
**Boiler efficiency**  
\[ = \frac{104.5 \times (829.88 \text{ kCal/kg} - 178.62 \text{ kCal/kg})}{38.5 \times 2276 \text{ kcal/kg}} \times 100 \]  
\[ = 77.66 \% \]  
**Evaporation Ratio**  
\[ = \frac{104.5 \text{ Tonne of steam}}{38.5 \text{ Tonne of bagasse}} = 2.71 \]

2. **Indirect Method:**

*Step -1. Find Theoretical Air Requirement*

*a. Theoretical air required for combustion*

\[ = \left[ (11.6 \times C) + \{34.8 \times (H_2 - O_2 / 8) \} + (4.35 \times S) \right] /100 \text{ kg/kg of fuel.} \]  
\[ = \left[ (11.6 \times 23.17) + \{34.8 \times (4.10 - 21.33 /8) \} + (4.35 \times 0) \right] /100 \]  
\[ = 3.185 \text{ kg/kg of bagasse.} \]

*Step -2. To Find Excess Air Supplied On The Basis Of % O₂*

*b. % Excess air supplied (EA)*

\[ = \frac{O_2 \% \times 100}{(21 - O_2 \%)} \cdot \text{[From flue gas analysis]} \]  
\[ = 4.90 \times 100 / (21 - 4.90) \]  
\[ = 30.43 \% \]
Step 3. To Find Actual air Supplied (AAS)

c. Actual mass of air supplied /kg of fuel (AAS)

\[
\text{AAS} = \left(1 + \frac{\text{EA}}{100}\right) \times \text{theoretical air}
\]

\[
\text{AAS} = \left(1 + \frac{30.43}{100}\right) \times 3.23
\]

\[
\text{AAS} = 4.213 \text{ kg/kg of bagasse}
\]

Step 4. To find out the actual mass of dry flue gas (m)

d. To find out the actual mass of dry flue gas (m)

\[
\text{mass of CO}_2 + \text{mass of N}_2 + \text{mass of N}_2 + \text{mass of oxygen in flue gas}
\]

\[
\text{mass of CO}_2 + \left(\frac{0.1}{100}\right) + (4.213 \times \frac{77}{100}) + (4.213 - 3.187) \times \frac{23}{100}
\]

\[
\text{mass of CO}_2 + 0.041 \times \left(584 + 0.45(140 - 40)\right) / 2276 = 4.285 \text{ kg/kg of bagasse}
\]

Step 5. To Find All Losses

1. Percentage Heat loss due to dry flue gas (L1)

\[
\text{L1} = \left[\frac{\text{mass of CO}_2 \times C_p \times (T_f - T_a)}{\text{GCV of fuel}}\right] \times 100
\]

\[
\text{L1} = \left[4.285 \times 0.24 \times (140 - 40)\right] / 2276 \times 100 = 4.42\%
\]

2. Percentage Heat loss due to evaporation of water formed due to H2 in fuel (L2)

\[
\text{L2} = \left[9 \times \text{H}_2 \times \left[584 + C_p (T_f - T_a)\right] / \text{GCV of fuel}\right] \times 100
\]

\[
\text{L2} = \left[9 \times 0.041 \times [584+0.45(140-40)] / 2276\right] \times 100 = 10.198\%
\]

3. Heat loss due to moisture present in fuel (L3)

\[
\text{L3} = \left[0.50 \times \left[584 + 0.45(140 - 40)\right] / 2276\right] \times 100
\]

\[
\text{L3} = 13.818\%
\]

4. Heat loss due to radiation (L4)

\[
\text{L4} = 1.00\% \text{ (Here Radiation loss is always taken as a constant value)}
\]

5. Heat loss due to unburned carbon in ash (L5)

\[
\text{L5} = \left[\frac{\text{quantity of ash in fuel} \times \text{GCV of ash}}{\text{GCV of fuel}}\right] \times 100
\]

\[
\text{L5} = \left[0.013 \times 800\right] / 2276 \times 100 = 0.46\%
\]

NOTE: Here L6 and L7 Heat losses are neglected. So, values of that were not considered in boiler efficiency.

Boiler efficiency by indirect method

\[
\text{Efficiency} = 100 - (L1 + L2 + L3 + L4 + L5)
\]

\[
\text{Efficiency} = 100 - (4.42 + 10.198 + 13.818 + 1.00 + 0.46)
\]

\[
\text{Efficiency} = 70.104\%
\]

Computation of steam to fuel ratio (evaporation ratio)

\[
\text{evaporation ratio} = \frac{\text{GCV of bagasse} \times \text{Efficiency}}{\text{H_{steam} - H_{feed water}}}
\]

\[
\text{evaporation ratio} = \frac{2276 \times 0.701}{(829.88 - 178.62)} = 2.45 \text{ kg of steam} / \text{kg of bagasse}
\]

From above simulation, heat balance sheet formed. Data analysis can be done as per given below:

- Analysis of three season’s (2011-12, 2012-13, 2013-14) considered.
- Analyse 500 days different parameters readings are studied for the research about the boiler performance, from last 3 years performance of boiler
- Analyse season wise (three years season’s) weekly parameter readings, on the basis of random sampling.

Here research instrument used-Microsoft excel sheet.

**TABLE V**

**BOILER HEAT BALANCE SHEET**

<table>
<thead>
<tr>
<th>Input/Output Parameter</th>
<th>k Cal/kg of fuel</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Input in fuel</td>
<td>2276</td>
<td>100</td>
</tr>
<tr>
<td>Various Heat losses in boiler</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Dry flue gas loss (L1)</td>
<td>100.5992</td>
<td>4.42</td>
</tr>
<tr>
<td>2. Loss due to hydrogen in fuel (L2)</td>
<td>232.106</td>
<td>10.198</td>
</tr>
<tr>
<td>3. Loss due to moisture in fuel (L3)</td>
<td>214.497</td>
<td>13.818</td>
</tr>
<tr>
<td>4. Loss due to surface radiation and convection(L4)</td>
<td>22.76</td>
<td>1</td>
</tr>
<tr>
<td>5. Loss due to unburnt carbon in ash(L5)</td>
<td>10.4556</td>
<td>0.46</td>
</tr>
<tr>
<td>Total Losses</td>
<td></td>
<td>29.896</td>
</tr>
</tbody>
</table>

Boiler Efficiency = 100 - (1-2+3+4+5) = 100 - 29.896 = 70.104 %

Steam to fuel ratio = 2.45 kg of steam / kg of bagasse.
For three years season’s 72 weeks parameters readings are considered.
For every season 24 weeks parameters readings are considered.
On each micro soft excel sheet simultaneously season wise 8 weeks data calculated and average values calculated for 8 weeks.
In this way, for 72 weeks, averages of 9 values are calculated.
From that 9 average values, data interpretation graphs has been drawn.

And, from that graphs –
- Reasons for decreasing the efficiency of boiler calculated.
- Values of different heat losses \(L_1, L_2, L_3, L_4, L_5\) and its effect on efficiency of boiler
- Remedies have been calculated.

### TABLE VI
THREE YEAR’S AVERAGE PARAMETERS PERFORMANCE SHEET

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Description</th>
<th>Unit</th>
<th>Season 2011-12</th>
<th>Season 2012-13</th>
<th>Season 2013-14</th>
<th>Average Of Last Three Season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>8 Weeks Average</td>
<td>8 Weeks Average</td>
<td>8 Weeks Average</td>
<td>8 Weeks Average</td>
</tr>
<tr>
<td>1</td>
<td>Main Steam Pressure</td>
<td>Kg/Cm²</td>
<td>99</td>
<td>99.3</td>
<td>105</td>
<td>102.7</td>
</tr>
<tr>
<td>2</td>
<td>Main Steam Temperature</td>
<td>°C</td>
<td>532</td>
<td>532</td>
<td>540</td>
<td>512.62</td>
</tr>
<tr>
<td>3</td>
<td>Quantity Of Steam Generated</td>
<td>Tph</td>
<td>107</td>
<td>107</td>
<td>102.13</td>
<td>107</td>
</tr>
<tr>
<td>4</td>
<td>Temp. Of Flue Gas At Outlet Of Air Preheater (T2)</td>
<td>°C</td>
<td>144.6</td>
<td>153.5</td>
<td>136.1</td>
<td>137.87</td>
</tr>
<tr>
<td>5</td>
<td>O2 In Flue Gas</td>
<td>%</td>
<td>3.25</td>
<td>3.2</td>
<td>2.96</td>
<td>2.96</td>
</tr>
<tr>
<td>6</td>
<td>Ambient Temperature (T1)</td>
<td>°C</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>7</td>
<td>Feed Water Temp. At Economiser Inlet</td>
<td>°C</td>
<td>220</td>
<td>220</td>
<td>220</td>
<td>220</td>
</tr>
<tr>
<td>8</td>
<td>Quantity Of Mass Consumed</td>
<td>Tph</td>
<td>51.875</td>
<td>51.375</td>
<td>49.25</td>
<td>51.25</td>
</tr>
<tr>
<td></td>
<td>Excess Air Supplied (%)</td>
<td></td>
<td>18.31</td>
<td>17.98</td>
<td>16.41</td>
<td>16.41</td>
</tr>
<tr>
<td></td>
<td>Actual Air Supplied (Kg/Kg)</td>
<td></td>
<td>3.77</td>
<td>3.76</td>
<td>3.71</td>
<td>3.71</td>
</tr>
<tr>
<td></td>
<td>Actual Mass Of Dry Flue Gas (Kg/Kg)</td>
<td></td>
<td>3.89</td>
<td>3.88</td>
<td>3.83</td>
<td>3.83</td>
</tr>
<tr>
<td></td>
<td>Heat Loss In Dry Flue Gas In % (L1)</td>
<td></td>
<td>4.29</td>
<td>4.64</td>
<td>3.88</td>
<td>3.93</td>
</tr>
<tr>
<td></td>
<td>Heat Loss Due To Hydrogen In The Fuel In % (L2)</td>
<td></td>
<td>10.23</td>
<td>10.3</td>
<td>10.17</td>
<td>10.18</td>
</tr>
<tr>
<td></td>
<td>Heat Loss Due To Moisture In Fuel In % (L3)</td>
<td></td>
<td>13.86</td>
<td>13.95</td>
<td>13.79</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td>Heat Loss Due To Radiation In % (L4)</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Heat Loss Due To Unburnt Carbon In Ash In % (L5)</td>
<td></td>
<td>0.46</td>
<td>0.46</td>
<td>0.46</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>Total % Heat Loss=L1+L2+L3+L4+L5</td>
<td></td>
<td>29.84</td>
<td>30.35</td>
<td>29.3</td>
<td>29.39</td>
</tr>
<tr>
<td></td>
<td>Efficiency %</td>
<td></td>
<td>70.16</td>
<td>69.65</td>
<td>70.71</td>
<td>70.61</td>
</tr>
<tr>
<td></td>
<td>Evaporation Ratio (Kg/Kg)</td>
<td></td>
<td>2.06</td>
<td>2.08</td>
<td>2.07</td>
<td>2.09</td>
</tr>
</tbody>
</table>
VI. DATA INTERPRETATION AND RESULTS

A. Figure 1 Shows
- When evaporation ratio value having range between 2.6-2.10, efficiency is above 69.50%.
- But when evaporation ratio value increases above given range, efficiency (%) decreases.
- So for increase in efficiency evaporation ratio should be maintained i.e. factors – quantity of mass consumed quantity of steam generated.

![](Fig_1.png)

Fig. 1 Evaporation Ratio With Efficiency In %

B. Figure 2 Shows
- It is seen that, efficiency (%) varies according to values of O$_2$ % in dry flue gas.
- Efficiency is directly proportional to O$_2$ % in dry flue gas.

![](Fig_2.png)

Fig. 2 O$_2$ In Flue Gas With Efficiency %

C. Figure 3 Shows
- It is seen that, heat loss due to moisture in fuel (%) having highest values.
- Heat loss due to hydrogen in fuel (%) having average value in between 10-11 %.

![](Fig_3.png)

Fig. 3 Comparisons Of Different Heat Losses In Boiler

D. Figure 4 Shows
- It is seen that, quantity of steam generated (TPH) and mass of fuel consumed (TPH) are both directly proportional to each other.

![](Fig_4.png)

Fig. 4 Quantity Of Steam Generated And Quantity Of Mass Consumed

E. Figure 5 Shows
- It is seen that, Excess Air Supplied (%) and Actual Air Supplied (Kg/kg) are both directly proportional to each other.
F. Figure 6 Shows
- It is seen that, within a specific range of values, Efficiency % and Heat loss in dry flue gas (%) are both inversely proportional to each other.
- Efficiency is tends to decreases when values of Heat loss in dry flue gas (%) increases.

G. Figure 7 Shows
- It is seen that, Efficiency % and Heat loss due to hydrogen in fuel (%) (L2) are both directly proportional to each other.
- But after a specific range Efficiency (%) is decreases when values of Heat loss due to hydrogen in fuel (%) (L2) suddenly increases.

H. Figure 8 Shows
- It is seen that, Efficiency (%) and Heat loss due to moisture in fuel (%) (L3) and are both directly proportional to each other.
- But after a specific range Efficiency (%) is decreases when values of Heat loss due to moisture in fuel (%) (L3) suddenly increases.

VII. CONCLUSIONS
Conclusion derived from the data related to the boiler, heat loss due to hydrogen in fuel and heat loss due to Moisture content in the fuel will affect the efficiency.
Here by using bagasse as a fuel average boiler efficiency for last three years is 69.61%.
1. Heater must be provided:

From the overall analysis and results it is found that, Heat loss due to moisture due to hydrogen in the fuel (L₂) and Heat loss due to moisture in the fuel (L₃). These both losses are more responsible for decreasing the boiler performance.

Part or all of a primary stream of bagasse from the sugar mill is dried from its initial moisture content, e.g. in the order of 50%, to a lower moisture content, e.g. in the order of 35%, using a portion of the hot flue gases from the boilers which are used to supply power for the sugar mill operation.

The resulting drier material is separated to (i) an oversize particle stream (ii) a secondary stream of fine particle size. An oversize particle stream which may be sent directly to the boiler for burning or to storage in the bagasse house. Due to this, boiler loss must be increased (presence of moisture as well as hydrogen in fuel). So, instead of this secondary stream, with optional addition of oversize particles from the primary drying operation, is then dried in contact with another portion of hot flue gases in the separate Heater to reduce moisture content.

So Heater must be provided before bagasse is feed to the boiler. By use of heater, the above losses must be minimized by 70%.

2. Use Of Solid combustion catalyst:

By use of solid combustion catalyst for example THERMACT B increasing boiler efficiency, one can save fuel input to power plant and also earn carbon point and can increase profit to plant.

The THERMACT-B additive is a solid mixture of primarily carbon the helps breaking the bond between the two hydrogen and oxygen molecule. The THERMACT-B then increases the reactivity between the carbon and the moisture in bagasse. THERMACT-B was added directly into bagasse feeders with the help of Vibro-feeder assembly. The feed rate of THERMACT-B was controlled by the Vibro-feeder and regulator as per the bagasse consumption. 1kg of THERMACT-B is dosed for 20 tons of bagasse.

3. Use of water cooled condenser instead of air cooled condenser:

In sugar factory air cooled condenser for a cooling range of 10 °C and an approach of 5 °C, while operating under the atmospheric wet bulb temperature of about 27 °C is used. Instead of air cooled condenser use of water cooled condenser for effectiveness increase in above properties of condensate, so boiler efficiency is increased.

REFERENCES