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Monitoring Boiler Efficiency using DASY Lab and a Case Study on Analysis of Boiler Losses

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Abstract: Boiler efficiency is a great concern in all process industries. To improve thermal efficiency of boiler, heat loss of the boiler needs to be monitored continuously and controlled. Direct method of evaluating the boiler efficiency is simpler but does not provide any information about boiler losses. Calculation of boiler efficiency using indirect method is time consuming process as it involves complex mathematical expressions. In most of the process industries, the boiler efficiency is calculated once in a month, due to which the boiler losses cannot be controlled as and when they vary. This paper presents development of application software for monitoring of boiler efficiency using conventional indirect method. The software eliminates time consuming calculation for boiler engineers and the control action can be initiated immediately, which reduces the fuel consumption. The system is developed in Data Acquisition SYstem Laboratory (DASY Lab) software package and validated using the data collected from one of the leading cement industries. The data is further analysed to identify the causes for various boiler losses and measures to be taken to minimize losses there-by increasing boiler efficiency.

Keywords: Indirect method, Boiler efficiency, DASY Lab, Heat losses.

I. INTRODUCTION

Power is one of the most important raw materials for the cement industry and account for almost 30 % of the total cost of cement manufacturing. Such industries generate the electric power required to run various machines using thermal power plants. Industrial boiler is an essential component of any process industry. It converts water to either hot water or steam at desirable temperature and pressure [1]. There are different types of boilers, based on type of firing, type of fuel used and type of arrangement [2].

Boilers can be classified based on type of firing adopted as:

- Stoker fired boilers
- Pulverized coal fired boilers
- Down shot fired boilers
- Fluidized bed fired boilers
- Cyclone fired boilers

Boilers are classified based on the type of fuel as:

- Coal fired boiler
- Oil fired boiler
- Gas fired boilers
- Multi-fuel fired boilers
- Industrial waste fired boilers
- Biomass fired boilers

Boilers are also classified based on the arrangement as:

- Top supported boilers
- Bottom supported boilers
- Package boilers
- Field erected boilers
- Drum type boilers
- Tower type or single pass boiler
- Closed coupled boilers
- Two pass boilers

Efficiency is the key factor for any boiler and boiler performance is evaluated by finding boiler efficiency [3]. Various types of boiler heat losses account for its overall efficiency. By finding various boiler losses, efficiency can be evaluated. Boiler efficiency can be calculated either using direct method or indirect method [4]. Indirect method is popular as it gives complete details of various boiler losses but it is time consuming [5]. If losses are reduced then automatically boiler efficiency will be improved. The first step in boiler efficiency analysis is finding the percentage of various boiler losses. Algorithm for finding boiler efficiency is implemented in DASY Lab software suite. DASY Lab is icon-based data acquisition, graphics, control and analysis software. This greatly reduces the time and effort.

A. PURPOSE BEHIND THE WORK

The greater interest of any process industry is to increase boiler efficiency and reduce the manual method of evaluating the boiler. In direct method of calculating the boiler efficiency, parameters such as specific enthalpy of feed water, saturated steam and evaporation are to be used. General practice for a boiler engineer is to refer steam table to get the enthalpy values and use them in calculating the boiler efficiency using direct method. The calculation of boiler efficiency using indirect method is tedious and

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time consuming as complex equations for various boiler losses are involved. Data from the fuel analysis such as percentage of carbon, hydrogen, oxygen, and sulphur present in fuel along with flue gas temperature, carbon monoxide, and carbon dioxide content in flue gas are the requirements for finding boiler loss using indirect method. This paper presents a method of calculating boiler efficiency using indirect method in DASY Lab software suite and is validated with the data from industry. This eliminates the manual efforts in calculating boiler efficiency.

B. SCOPE OF THE PRESENTED WORK

In any automated process industry, the boiler efficiency is calculated manually once in 15 days or a month. This process is time consuming as it involves manual calculation. Automation tools such as Programmable Logic Controller (PLC) and Supervisory Control and Data Acquisition (SCADA) are used in any industry for automation of various processes. But till today, the measurement of boiler efficiency is carried out manually in almost all automated process industries. The purpose of this work is to develop system for measuring and monitoring the boiler efficiency. With this software, by knowing the boiler efficiency, the boiler operators can take appropriate measures to control the parameters of boiler, so that the boiler efficiency can be improved. For example, if the concentration of oxygen in dry flue gas is more than the rated value for the boiler, which is one of the main reasons for increase in the dry flue gas loss, the operator can adjust the air-fuel ratio. Further, the interfacing of data acquisition card to the application software to capture the sensor values in real time is initiated.

C. LIMITATIONS OF DIRECT METHOD

In direct method of calculating boiler efficiency, measurement of various boiler losses is not essential. Direct method is very simple as it calculates the boiler efficiency as a ratio of output energy and input energy and does not require any other data. But, fuel consumption, steam output, steam temperature, steam pressure, and fuel quality need to be monitored. Boiler efficiency depends on the boiler design also. One of the major draw backs of direct method of finding boiler efficiency is it does not provide any information of deterioration of boiler efficiency. Because of the limitations of direct method, industries adopt indirect method to measure the boiler efficiency.

D. METHOD OF CALCULATING EFFICIENCY USING INDIRECT METHOD

The following steps are used for the calculation of boiler efficiency using indirect method [6][7].

Step 1: Calculate the theoretical air (Stochiometric) requirement:
Theoretical Air required = TAR

$$TAR = \frac{11.6*C + 34.8(H_2 - \frac{O_2}{8}) + 4.35*S}{100} \text{ kg/kg of fuel}$$

Step 2: Calculate the percentage of Excess Air (EA) requirement:

$$\text{Excess Air supplied} = \frac{O_2*100}{21 - O_2} \%$$

Step 3: Calculate actual air (total air) requirement:
Actual Air requirement = (AAR)

$$AAR = \text{Theoretical Air}*(1 + \frac{EA}{100}) \text{ kg of air / kg of fuel}$$

Step 4: Calculate all the boiler losses using the following formulae:

$$\text{\% Dry Flue gas loss} = L_1 = \frac{m*C_p(T_f - T_a)}{GCV}*100$$

Where
T_f = Temperature of flue gas in ^oC
T_a = Ambient temperature in ^oC
C_p = Specific heat of flue gas in Kcal/kg ^oC
GCV = Gross Calorific Value of fuel (coal) in Kcal/kg

Mass of dry flue gas = m = mass of CO_2 + mass of SO_2 + mass of O_2

$$m = (\frac{C}{100}*\frac{44}{12}) + (\frac{S}{100}*\frac{64}{32}) + (AAR*\frac{77}{100}) + [(AAR - T_a*\frac{22}{100})]$$

Heat loss due to formation of water from H_2 in fuel = L_2

$$L_2 = \frac{9*H_2*[584 + C_p(T_f - T_a)]}{GCV}*100$$

Heat loss due to moisture present in fuel = L_3

$$L_3 = \frac{M*[584 + Cp(T_f - T_a)]}{GCV}*100$$

Heat loss due to moisture in combustion air = L_4

$$L_4 = \frac{AAR*\text{humidity factor}*C_p(T_f - T_a)}{GCV}*100$$

$$\text{Humidity factor} = \frac{\text{kg of water in dry air}}{\text{kg of dry air}}$$

Where
C_p = Specific heat of super heated steam=0.45 kCal/ kg °C

Heat loss due to partial combustion = L_5

$$L_5 = \frac{\%CO*C}{\%CO + \%CO_2}*\frac{5654}{\text{GCV of coal}}*100$$

Heat loss due to radiation and convection = L_6
Heat loss due to radiation and convection is usually not calculated but assumed. It is assumed as a boiler loss of 1 to 2 % for smaller capacity boilers and 0.2 to 1.2 % for large capacity boilers.
L_6 = 1 to 2 % for smaller capacity boiler
= 0.2 to 1.2 % for large capacity boiler
Heat loss due to un-burnt in fly ash = L_7

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$$L_7 = \frac{M_a * GCV \text{ of fly ash}}{GCV \text{ of fuel}} * 100$$

Where,
M_a = Mass of total ash generated

Heat loss due to un-burnt in bottom ash = L_8

$$L_8 = \frac{M_a * GCV \text{ of bottomash}}{GCV \text{ of fuel}} * 100$$

Step 5: Calculate the boiler efficiency:
Boiler efficiency = 100 – (L_1+ L_2 + L_3 + L_4 + L_5 + L_6 + L_7 + L_8)

II. LITERATURE SURVEY

Coal is contributing about 45% in generation of electricity in the world. In thermal power plants, boilers are used for converting chemical energy of fuel to heat energy of steam thereby generating electricity using thermal turbines. Steam is also used in other process industries such as food processing industry (57 %), pulp and paper manufacturing industry (81 %), chemical industry (42 %), petroleum refining industry (23 %) and primary metal industry (10 %). Since boiler is used in every process industry for the generation of steam, maximizing its performance is of great interest always. Its performance degrades because of aging, fouling, and improper handling/ maintenance. Boiler's efficiency can be improved by reducing various losses such as loss due to dry flue gas, loss due to moisture in fuel, radiation loss, and blow down loss [8].
The operation of boiler, various types of boiler efficiency and significance of boiler efficiency and the method of finding boiler efficiency using direct method is recommended by Sunit Shah and D.M. Adhyaru [9]. Technical/ design data of boiler used in Ukai thermal power station is taken as a case study and the steps for calculation of boiler efficiency using direct method is listed. Chaunjiang Li et al. [10] suggested a novel method of coal inlet control design for a thermal power plant to improve the efficiency. Four industrial boilers are considered for the design. Inaccuracy and high cost of human labor in estimating the consumption of coal is reduced by the design utilizing PLC and associated hardware circuit.

Yong Li, Han Gao [11] realized the importance of real time/on-line boiler data in determining its operating condition, heat generation, and heat loss. A new method is developed to overcome the difficulty of conventional method. Back Propagation (BP) neural network concept is used.

Exhaust air coefficient is obtained by considering the air leakage coefficient. Fly ash carbon content value is calculated by dynamic fitting method with BP neural network [11]. Analysis of energy and exergy efficiency is highlighted and is applied to the boiler system. General mathematical tools and analytical approaches can be used for estimation of energy and exergy use and efficiency for a boiler. Energy and exergy efficiencies of a boiler are compared [8].
Methods to calculate boiler efficiency is discussed and analysis of boiler efficiency for different Gross Calorific Value (GCV) is carried out and also different improvement possibilities for boiler efficiency are illustrated. From the analysis it is found that the coal with higher GCV yields better boiler efficiency. For the same boiler, the efficiency with semi bituminous coal is higher when compared with Indian lignite coal, because of its high heating value, less ash and moisture content [12]. Predictive tool is implemented for controlling the excess air in gas-fired systems. For developing the tool it is assumed that the combustion of natural gas is complete and at atmospheric pressure and the un-burnt combustible is negligible [13]. Regression and neural network are utilized for finding the relationship between proximate and ultimate analysis of coal with different gross calorific values. U.S. Geological survey coal quality data base is used for the proposed method [14]. On-going discussions reveal that the boiler has to be treated carefully and there is a need to improve its efficiency. Boiler efficiency can be improved by controlling at-least one of its parameters. Science and research community is continuously involved in controlling various parameter of boiler so that the losses can be minimized. Today, energy conservation is one of the major areas in any industry. Energy conservation is possible only when energy consumed is properly estimated.

III. CASE STUDY DISCUSSION

One of the leading cement industries situated near Lokapur of Bagalkot district, where an atmospheric Fluidized Bed Combustion (AFBC), water tube, Babcock and Wilcox boilers are maintained in a boiler house is considered for a case study. A bed material of height 500 mm is maintained inside the boiler to store heat up to 800 °C, which is greater than the self ignition temperature of coal (410 °C). Two identical turbines each of 25 MW are used for generation of 50 MWh of electric power. Boiler generates 110 TPH super heated steam with temperature of 520±5 °C, and steam pressure of 85 kg/cm^2. Either Indian coal or Indonesian coal is used as a fuel depending on availability. Water from either the reservoir or river and from condensed waste steam is provided to the boiler. The water from reservoir consists of dissolved salts, and hence cannot be directly fed to the boiler. The incoming hard water is treated, so that the percentage of Total Dissolved Salts (TDS) of feed water is less than 1 PPM, even though the incoming water TDS is 3000 PPM. The following were the specification of the boiler:

- Two pass, vertical boiler
- Size: 5.9 m width and 6.8 m length
- Capacity : 110 TPH
- Working pressure : 88 kg/cm^2
- Designed pressure : 104 kg/cm^2
- Heating surface : 5324 m^2

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- Chimney height : 104 m
- Force Draft Fan : 550 kW
- Feed pump : 610 kW
- Mass of fuel consumed : 450 MT
- Mass of steam generated : 110 MT

The quantity of carbon, hydrogen, nitrogen, oxygen, sulphur, and moisture present in coal in percentage are obtained from fuel analysis. Constituents of flue gas such as oxygen, carbon monoxide and temperature of flue gas, ambient temperature are obtained from flue gas analyzer. Constituents of fuel and flue gas are recorded for a period of one year (Jan 2013 to Dec 2013). Data analysis is carried out on the recorded observations. The efficiency of boiler is calculated by indirect method for the above mentioned boiler.

Indian coal or Indonesian coal is used as a fuel. The constituent of coal is one of the factors in deciding various boiler losses. The values of the various constituents of fuel such as carbon, hydrogen, nitrogen, and oxygen content for every month are given in Table I. There is variation in the constituents of coal. The carbon content in coal in the month of October is maximum (37 %). The percentage of hydrogen is maximum (5.1 %) during June to September, the percentage of nitrogen is maximum (1.69 %) during February and from June to September, and the percentage of oxygen is maximum (10.26 %) during February, and from June to December. Table II shows the results of flue gas analysis for a period of one year. The flue gas temperature is maintained between 140 °C to 142 °C. The ambient temperature range varies from 30 °C to 35 °C. Oxygen content in the flue gas for an entire year varies from 4 % to 5 %.

The values of various boiler losses for every month are listed in Table III. Carbon, hydrogen, and nitrogen content in coal is maximum as listed in Table I during June to September; the boiler losses are maximum during the same period, as listed in Table III. The percentage of nitrogen (1.69 %) and the percentage of oxygen (10.26 %) are maximum in the month of February, as listed in Table I, but the gross calorific value is more (3648) compared to the period between June and September, the boiler losses are not maximum in February. It means that not only the fuel constituents contribute to the various boiler losses but also the gross calorific value of the fuel. It is recommended to use coal with higher gross calorific value and constituents with low percentage, to obtain less boiler losses and high boiler efficiency.

Table I: Month wise constituents of fuel

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Carbon (%)	33.8	33.1	33.4	33.4	33.4	33.1	33.1	33.1	33.1	37.0	32.0	35.1
Hydrogen (%)	2.23	4.95	5.00	4.80	4.90	5.10	5.10	5.10	5.10	4.20	4.20	3.90
Nitrogen (%)	0.85	1.69	0.85	0.85	0.85	1.69	1.69	1.69	1.69	1.56	1.15	1.20
Oxygen (%)	9.54	10.26	9.54	9.54	9.54	10.26	10.26	10.26	10.26	10.26	10.26	10.26
Sulphur (%)	1.08	0.79	1.08	1.08	1.08	0.79	0.79	0.79	0.80	0.80	0.80	0.80
Moisture (%)	7.21	12.4	20.0	19.0	18.0	18.0	18.0	18.0	12.2	11.7	10.5	10.5
GCV (kCal/kg)	3536	3648	3355	3145	3832	3074	3510	3356	3097	3528	3857	3964

Table II: Month wise constituents of flue gas analysis

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flue gas temp (°C)	140	140	140	140	140	142	142	142	142	142	142	142
Ambient temp (°C)	35	33	35	34	35	35	34	34	33	30	31	30
O_2 (%)	5.0	4.9	5.4	4.3	5.0	4.8	4.4	4.0	4.5	4.80	4.78	4.9

Table III: Month wise various losses and boiler efficiency

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average value
L_1 (%)	4.20	4.80	5.30	5.30	4.50	5.70	4.90	5.00	5.60	5.40	4.30	4.50	4.95
L_2 (%)	3.58	7.72	8.64	8.68	7.26	9.44	8.27	8.65	9.38	6.80	6.21	5.62	7.52
L_3 (%)	1.29	2.15	3.74	3.82	2.97	3.70	3.24	3.39	2.49	2.11	1.74	1.69	2.69
L_4 (%)	0.15	0.18	0.19	0.20	0.17	0.21	0.18	0.18	0.21	0.20	0.16	0.16	0.18
L_5 (%)	0.37	0.36	0.40	0.42	0.34	0.42	0.37	0.39	0.42	0.41	0.32	0.35	0.38
L_6 (%)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00	2.00	2.00	1.25
L_7 (%)	0.09	0.06	0.22	0.19	0.16	0.15	0.15	0.11	0.14	0.10	0.15	0.13	0.08
L_8 (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BE (%)	89.32	83.75	80.51	80.38	83.56	79.39	81.88	81.26	80.72	82.98	85.08	85.50	82.86

The values of boiler heat loss due to dry flue gas (L_1 = 5.7 %), the heat loss due to formation of water because of presence of H_2 in fuel (L_2 = 9.44 %), heat loss due to moisture present in fuel is nearer to the maximum value (Max L_3 = 3.82 % and L_3 for June = 3.7 %), heat loss due to moisture present in air (L_4 = 0.21 %), heat loss due to incomplete combustion (L_5 = 0.42 %) is maximum and the boiler efficiency calculated from indirect method is minimum (79.399 %) during the month of June. The major coal constituents are of high value during the period between June to September; the boiler efficiency is less and is within the range of 79.39 % to 81.88 %. The boiler efficiency is also less during March and April, because the moisture content in coal is more. To reduce moisture in coal and to reduce the boiler losses during this period, the coal must be treated with blowing pressurized steam.

A. **FINDINGS**

The average value of heat loss due to formation of water due to the presence of H_2 in fuel is maximum (L_2 = 7.52 %) followed by the average value of heat loss due to dry flue gas (L_1 = 4.95 %), average value of heat loss due to moisture present in fuel (L_3 = 2.69 %). All the other heat losses are less than 1 %.

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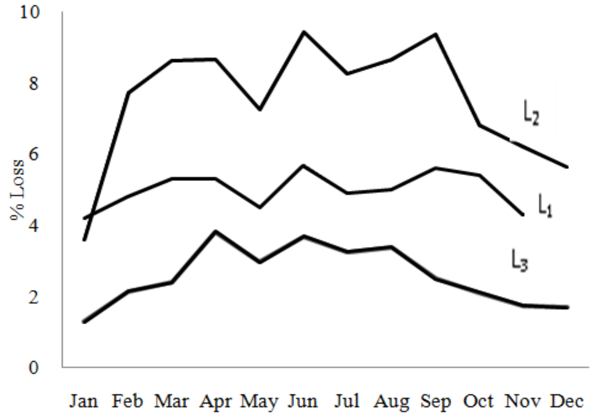

Fig. 1: Month wise percentage boiler losses (L_1, L_2 and L_3)

The value of radiation loss is assumed and the average value is 1.25 %. As mentioned above all most all the heat losses are maximum in the month of June and hence the boiler efficiency is minimum (79.39 %) during that month when compared with the average value of boiler efficiency is 82.86 %.

Figure 1 shows that the boiler losses are maximum during the period of June to September. Figure 2 shows the percentage of boiler efficiency for an entire year, considering the humidity as 0.0198 kg/kg of dry air. The loss due to dry flue gas and the loss due to un-burnt carbon are related to each other.

These losses can be controlled by controlling the temperature of flue gas and air-fuel ratio. The boiler loss due to formation of water from H_2 of coal can be controlled only by changing the quality of coal. Loss due to moisture present in fuel can be controlled by controlling the moisture of fuel.

If moisture of fuel is reduced, then the boiler loss due to moisture in fuel can also be reduced, thereby increasing the boiler efficiency. Moisture of fuel can be reduced by providing proper treatment to the fuel. The fuel is to be passed through the hot environment, which reduces the moisture content of the finely powdered fuel (coal).

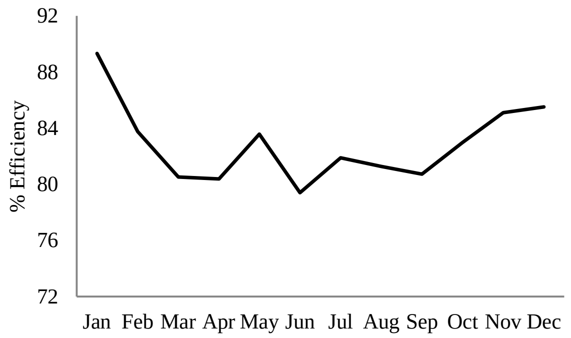

Fig. 2: Month wise percentage boiler efficiency

Above discussion indicates that there is a requirement of real time monitoring of these losses. With real time boiler loss monitoring system, reasons for boiler loss can be identified and controlled.

IV. SOFTWARE SYSTEM IMPLEMENTATION

A system is developed using Data Acquisition System Laboratory (DASY Lab) software package to measure the boiler losses and to monitor the boiler efficiency.
The percentage of various components of coal such as carbon, hydrogen, oxygen content, and moisture content, are recorded in operators log book, and are used to calculate various losses. Various boiler losses from L_1 to L_8 are calculated in the application program.

Then all the losses are added up to get the total boiler losses. Finally total boiler loss is subtracted from 100 to obtain boiler efficiency. The application program for calculation of loss due to dry flue gas (L_1) using DASY Lab software package is as in Fig. 3. Loss due to formation of water because of hydrogen present in fuel (L_2) is calculated and is as in Fig. 4. Boiler efficiency calculation from boiler losses is as in Fig. 5.

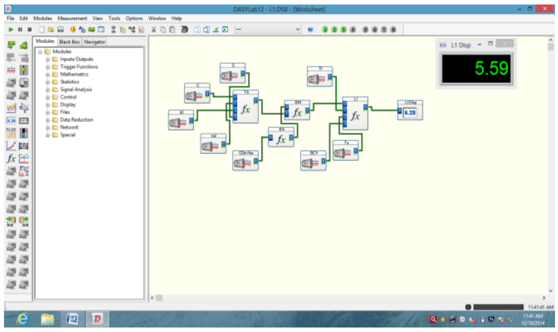

Fig. 3: Application program to monitor L_1

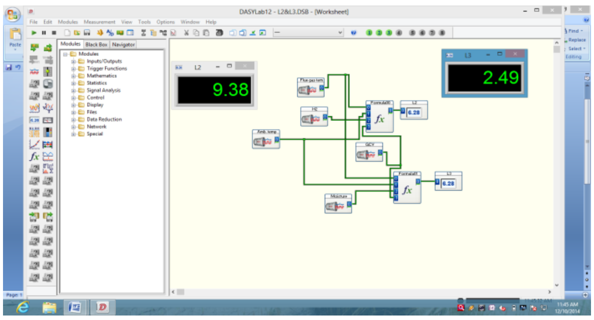

Fig. 4: Application program to monitor L_2 and L_3

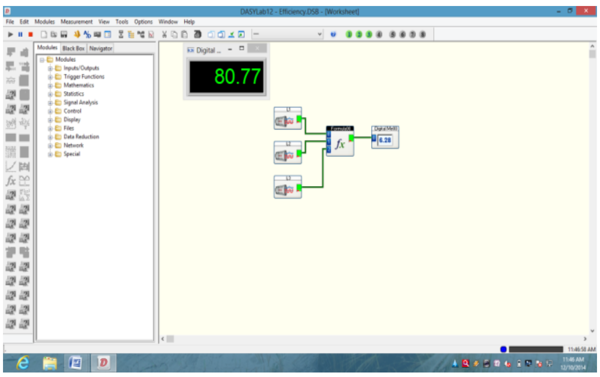

Fig. 5: Application program to monitor boiler efficiency

Table IV: Month wise boiler losses using application program

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
% L_1	4.15	4.74	5.31	5.28	4.51	5.64	4.87	4.97	5.59	5.28	4.26	4.44
% L_2	3.58	7.72	8.47	8.68	7.26	9.44	8.27	8.65	9.38	6.8	6.21	5.62
% L_3	1.29	2.15	3.76	3.82	2.97	3.91	3.42	3.39	2.49	2.1	1.74	1.69
% L_4	0.16	0.17	0.19	0.20	0.16	0.21	0.19	0.19	0.21	0.19	0.16	0.16
% L_5	0.37	0.38	0.40	0.42	0.35	0.42	0.36	0.39	0.43	0.41	0.33	0.35
% L_6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00	2.00	2.00
% L_7	0.08	0.06	0.22	0.19	0.16	0.15	0.15	0.12	0.13	0.11	0.14	0.13
% L_8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% BE	89.3	83.7	80.6	80.4	83.5	79.2	81.7	81.2	80.7	83.1	85.1	85.6

The values of L_1 using equation and using application program for one year are almost same as given in Fig. 6. The values of L_2 and L_3 using equation and application program are shown in Fig. 7 and Fig. 8 respectively. The values of various losses and the boiler efficiency calculated from application program are listed as in Table IV. The boiler efficiency for each month using equation and application program are as in Fig. 9.

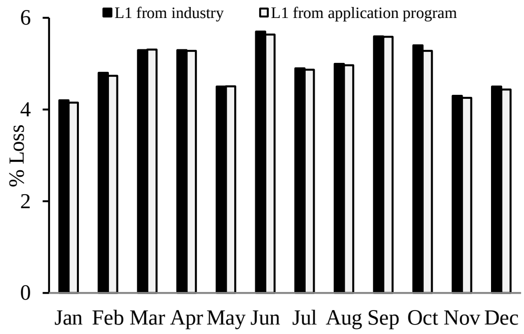

Fig. 6: Month wise comparison of L_1

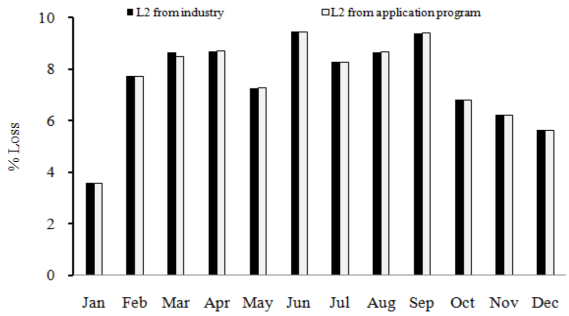

Fig. 7: Month wise comparison of L_2

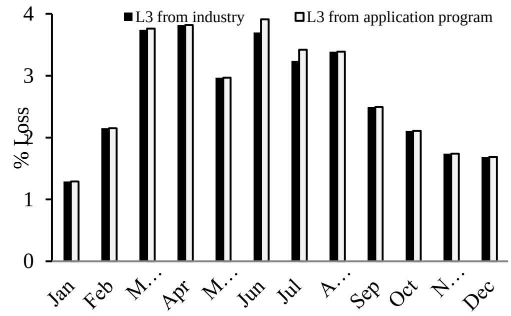

Fig. 8: Month wise comparison of L_3

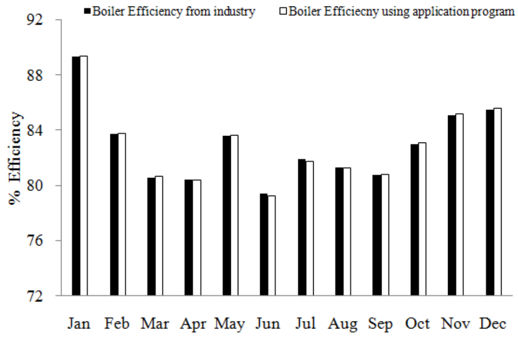

Fig. 9: Month wise comparison of boiler efficiency

V. CONCLUSION

The traditional method for calculation of boiler efficiency using indirect method involves complex mathematical equations, which is a tedious work for operation department people of an industry. Instead of manual calculation, the software system developed in this paper can be easily adopted which provides measurement and monitoring of various losses and boiler efficiency. In indirect method, no need to measure or monitor the parameters which are necessary for finding boiler efficiency and boiler design cannot depict its efficiency. As the performance evaluation of boiler is based on its boiler efficiency, finding boiler efficiency using indirect method is an easy task if the developed application software is used. The error between the boiler efficiency calculated using conventional method and the calculated using application software is very small. Calculation of boiler losses and efficiency is carried out using DASY Lab software package and tested with data obtained from industrial environment.

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