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Energy Audit and Energy Efficient Recommendations with Payback Period for Industrial Boiler

Jadhav Kunal Kailash
Mechanical Engineering
Bharati Vidyapeeth (Deemed to be University)
College of Engineering, Pune, India

Shekhar T Shinde
Assistant Professor, Mechanical Engineering
Bharati Vidyapeeth (Deemed to be University)
College of Engineering, Pune, India

Abstract:- Industrialization is increasing every day and there is a great need for industry energy assessment audits. To maintain and save energy from being wasted and help in achieving highest efficiency of industrial equipment, audit plays a very crucial role. This paper carries a carefully prepared industry audit report on boiler operations and performance. Basically this paper deals with the study on Thermal analysis of boilers, thermal skin heat loss of boilers, O2 percentage control in flue gases to standard values, effect of coal additive, etc. This paper also contains a report on waste heat recovery options for thermal boilers. Vane type Anemometer, Glass type Thermometer, Flue efficiency monitor, infrared thermometer, ultrasonic peak detector, IR thermal imager, these equipment are used for energy assessment of boilers. To estimate the radiation and the other losses, a thermography survey of the boiler surface is carried out and it reveals total annual savings after insulation repairing or maintenance is Rs.8.48 lakh and investment is around Rs.6.31 lakh. With the help of suggested measures Economizer performance of both the ISGEC and Thermax boiler can be improved. It will help to save approximately rupees Rs.38.42 Lakh annually and investment on maintenance cost is negligible. Assessment of all boilers, calculate their efficiencies and losses to measure energy saving areas and present them as recommendations with their payback periods is carried out in this paper.

Keywords:- *Assessment, Boiler Energy, Energy Audit.*

I. INTRODUCTION

Boilers are the most energy consumable equipment as compared to any other equipment used in industry and there is a great need for energy assessment of boilers on every early[1,2]. In this paper considering 12TPH Thermax boiler, 18TPH ISGEC boiler, and 18TPH FBC boiler for audit and inspection. New model is proposed for the boiler industry through sincere and careful analysis. Advanced equipment is used In this audit during the boiler assessment and the effect of this reveals accurate analysis of boiler performance. [3] This paper carries an actual industry audit report on boiler performance. For assessment of boiler Thermal analysis of boilers, thermal skin heat loss of boilers, O2 percentage control in flue gases to standard values effect of coal additive, etc. Test are performed on boiler.[4]

II. METHODOLOGY FOR ENERGY ANALYSIS OF BOILERS

1. During the audit we have record output and input parameters of both boilers. Our thermal experts undertook physical inspection of above boilers along with discussions about performance with respective operating staff. [5]
2. We used recorded flue gas parameters and actual proximate analysis results of the coal for efficiency calculations and then to locate losses. [6-7]
3. Detail analysis of all the boilers is shown below which can be compared mutually as as with standards.
4. We have used the following methodology for this analysis.
5. Tests Conducted-

a. A sample trial on both the boilers for sufficient time period including precise measurement of steam quantity and coal supplied.
b. The proximate analysis of the same coal and ash is done to ensure the percentage of various constituents in the same.
c. With the help of proximate analysis results, ultimate analysis parameters were derived and are used to estimate various heat losses.
d. A flue gas analysis is carried out using a high-end flue gas analyzer at the outlet of the convection zone and chimney sampling point to observe the quality of combustion.
e. Infrared Thermography of boiler parts, auxiliaries and steam distribution system is done to inspect the healthiness of insulation and calculate the heat losses due to damage or absence of insulation.

6. With the help of above data, efficiency of both the boilers is calculated by direct method and indirect method.
7. Various losses and operational improvements are identified and categorized into no cost measures, low-cost measures and high-cost measures.

III. AUDIT OBJECTIVE

Assessment of all boilers to evaluate their efficiencies and losses to identify energy saving opportunities and present them in report with their payback periods.

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IV. DETAILS OF EQUIPMENTS USED

Name of the equipment	Make	Use
Flue Efficiency Monitor	Technovation	Online monitoring of flue efficiency.
Sling type Psychrometer	Dimple	Humidity Measurement
Glass type Thermometer	Vertex	Temperature Measurement
Infrared Thermometer	HTC	Temperature Measurement
Vane type Anemometer	Lutron	Air flow Measurement
Ultrasonic Leak Detector	CS Instruments	Inspection of steam traps
IR Thermal Imager	Testo	Identification of hot surfaces and its temperature measurement

a. Equipements Details Table

V. BOILERS RATINGS

Sr. No.	Description	Boiler 1	Boiler 2	Boiler 3
1	Make	Thermax	ISGEC	Thermax
2	Rated Capacity TPH	18	18	12
3	Rated Steam Pressure, Kg/cm2	28.5	28.59	17.5
4	Model	Travelling Grate Type Boiler	Travelling Grate Type Boiler	FBC type Boiler
5	Fuel	Indian Coal	Indian Coal	Indian Coal
10	Auxiliaries Electrical Supply	415V, 3 Phase	415V, 3 Phase	415V, 3 Phase
12	Heating surface area sq.m.	NA	879	446
13	Design Rated Steam Temp, °C	420	420	208

b. Rating of Boilers Used

- Steam generated by travelling grate type boilers is mainly supplied to two back pressure turbines of 1.5MW and 0.8MW capacities through a common steam header.
- These boilers generate superheated steam of 27 – 29kg/cm^2 pressure.
- Low pressure steam from cogeneration plants at 5-6 kg/cm^2 is utilized for the plant process steam requirement and finally condensate is recovered at 2.5 kg/cm2 for the boiler feed.
- The daily coal consumption for the boilers is 110 -115 MT i.e., Rs 5 Lacs / day.
- A 12TPH FBC type boiler is used to serve the additional process steam requirement which is not continuously used. It can produce steam of 17.5 kg/cm^2 Pressure. The boiler is operated during the maintenance period of above boilers or in case of excess steam demand.
- Condensate recovery of the plant being 80%-85%, very less amount of makeup water is added in the system. This helps to minimize blow down below 1%.
- For ISGEC boiler and FBC boiler, coal feeding is controlled with the help of a drive which is operated manually based on steam pressure. Thermax boilers do not have a drive control for coal feed.
- Annual coal consumption of the plant for these boilers is around 60k-65k tonnes which costs around Rs. 32-35Crores.
- For waste heat recovery, economizer and air pre-heater are provided in the flue gas path of ISGEC boiler whereas for Thermax Boiler only economizer is installed.
- For the 12TPH FBC boiler, water optimizer as well as air pre-heater are installed which extract maximum possible heat from flue gases.

VI. THERMAL ANALYSIS OF BOILERS

Sr. No	Parameters	18 TPH Thermax Boiler	18 TPH ISGEC Boiler	12 TPH Thermax Boiler
1	Efficiency Evaluation Trial Period	180 min	230 min	120min
2	Steam Quantity Generated, T	47.2	72.8	18.66
3	Steam Pressure, ka/cm2	28.71	27	14.47
4	Steam Temperature, ˚C	415	328	191
5	Feedwater Temperature, ˚C	99	75	94.1
6	Enthalpy of steam, Kcal/kg	780.24	733.4	666.97
7	Coal consumed	11.82	15.446	3.4
8	NCV of coal, Kcal/kg	3878.5	4362.67	4145
9	**Steam-Fuel ratio**	**4**	**4.71**	**5.49**
10	**Direct method efficiency**	**70.21**	**71.12**	**75.83**

c. Boilers Thermal analysis Table

Flue Gas Analysis Result

11	O2%	8.30	7	14.20
12	Flue gases temperature after APH	191	150	145
13	CO%	0.17	0.09	0.12
14	CO2 %	11.38	12.74	6.16
15	Excess Air %	65.35	50	208.82

16	Ambient temp., ˚C	35	30	35
17	Theoretical air required, kg/kg of fuel	5.53	5.89	6.45
18	Actual mass of air supplied kg/kg of fuel	9.14	8.83	19.92
19	Cp of flue gas, Kcal/kg ˚C	0.24	0.24	0.24
20	Cp of superheated steam, Kcal/kg ˚C	0.45	0.45	0.45
21	Humidity factor, kg/kg of dry air	0.03	0.03	0.03

d. Flue Gas Analysis Result Table

Coal Analysis Report

22	% Carbon	42.44	43.35	49.32
23	% Hydrogen	2.92	3.64	3.28
24	% Nitrogen	1.46	1.33	1.42

e. Coal Analysis Report Table

1. 0% in flue gases and subsequently excess air for combustion is well within operation standards for Thermax and ISGEC boilers which were found abnormal during walk-through audit. In the case of the 12TPH FBC Boiler, it is still at a much higher level indicating maximum dry flue gas loss. Amount of heat input and various losses are indicated in the following Sankey Diagram:

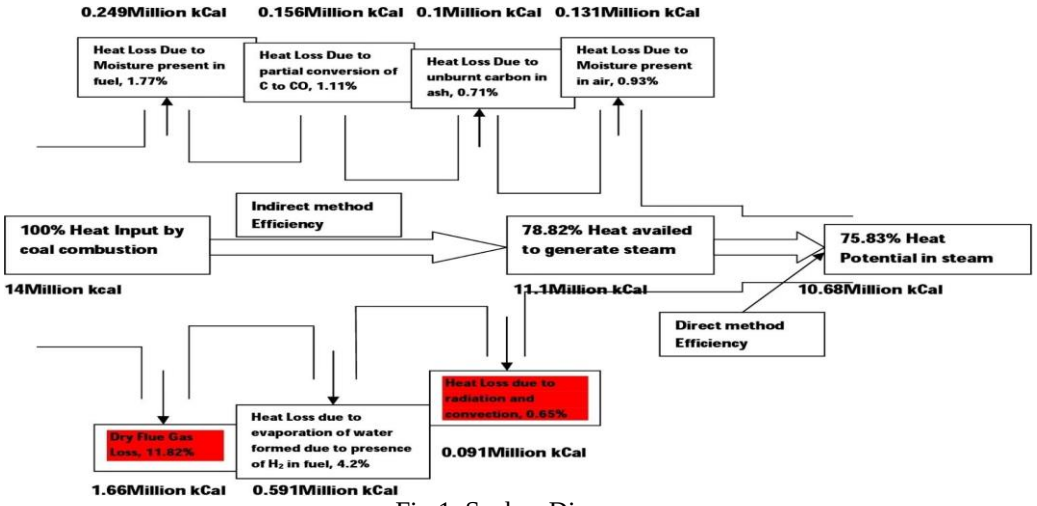

Fig 1. Sankey Diagram

- In the Above diagram, heat flow of the boiler is indicated in terms of kCal (during trial period, i.e., for 2Hrs) and percentage.
- Heat losses right from combustion of coal to exit from air preheater outlets are also mapped.
- The losses that can be controlled by standard operation practice and some modifications are indicated by red colour.
- The dry flue gas loss can be controlled upto 6.4% with the help of excess air control. It will help to avail extra 5% heat for steam generation.

2. For 18TPH travelling grate type Thermax boilers, at present there is no provision of heat recovery after economizer. So, though O2% and other related parameters are within standard, the number of losses seems to be high. Considering site conditions for waste heat recovery, detailed suggestions are discussed in the report. It will also help to improve steam fuel ratio and direct method efficiency of the boiler.
3. During the ISGEC Boiler trial it was found that dampers of FD, ID and Secondary Air Fans are optimally set manually. All the measures for waste heat recovery are taken care of already so the maximum level of indirect method efficiency of the boiler is already achieved.

Indirect Method Efficiency Evaluation

25	Heat loss due to dry flue gas loss %	8.30	5.88	11.82
26	Heat loss due to evaporation of water formed due to H2 in fuel, %	3.75	4.35	4.20
27	Heat loss due to evaporation of moisture present in fuel, %	2.33	1.23	1.77
28	Heat loss due to moisture present in air, %	0.38	0.27	0.93
29	Heat loss due to partial conversion of C to CO	0.79	0.36	1.11
30	Heat loss due to radiation losses & other losses	1.26	1.01	0.65
31	Heat loss due to unburnt in fly ash, %	0.11	0.63	0.12
32	Heat loss due to unburnt in bottom ash, %	2.59	1.88	0.59
33	**Efficiency by indirect method**	**80.48**	**84.31**	**78.82**

f. Efficiency by Indirect Method

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VII. OBSERVATION AND ENERGY SAVING POTENTIAL

Total cost associated			**6,85,000**
Boiler	**Fan**	**Capacity**	**Cost of VFD**
FBC Boiler	FD 1	30 HP	1,35,000
Online O_2 monitoring equipment			1,25,000
Total cost associated			**6,80,000**

h. Total Cost Associated Table

O_2% Control in Flue Gases to Standard Values

Sr. No.	**Description**	**Thermax Boiler**	**ISGEC Boiler**	**FBC Boiler**
1	Total Heat loss in kCal	192703.03	178195.94	91110.19
2	With proper Thermal Insulation savings in heat loss (Kcal @ 20% of total heat loss)	38540.61	35639.19	18222.04
3	Calorific value of Coal, kcal/kg	4200	4200	4300
4	Reduction in Coal consumption per day, kg	200	200	95

g. Observation Table

3. Effect of Coal Additive –

Working Principle of coal additive

- It reduces ignition temperature from 454°C to 316°C due to which faster heat generation is achieved in a shorter time.
- It regulates the release of carbon due to which uniform & synchronized heat generation takes place and heat intensity increases.
- For every 1% reduction in O_2% in flue gases, there is approximately 0.6% rise in efficiency.
- Currently ISGEC Boiler O_2% level is at optimum level so maximum possible indirect method efficiency is achieved. With close monitoring of O_2% level in flue gases with the help of portable flue gas analyzer, present performance should be retained.
- In case of Thermax Boiler, there is a slight opportunity to lower the O_2% level in flue gases which will enhance the efficiency from 70.21% to 70.61% and consequently s/f ratio from 3.9972 to 4.0200. For FBC boilers, efficiency can be raised upto 78% which reflects in the improvement of s/f ratio upto 5.6437.
- Annual saving associated with O2% Control in flue gases is tabulated above for all the boilers.

O2% Control in flue gases can be implemented with two methods

1. *Manual damper control of FD, ID fans of boilers* – Periodic checking of O2% in flue gases should be carried out with the help of a portable flue gas analyzer. According to the measured value, the dampers can be adjusted to maintain the standard value.

2. *Provision of VFDs to FD and ID fans of the boilers* – With the installation of VFD for FD and ID fans of both the boilers, automatic control of O2% in flue gases can be achieved. It should be in closed loop for which O2%, furnace draft pressure can be given as feedback parameters

Metallic based compounds in carbonizer ionize the air between gas particles which improves heat transfer rate.

To evaluate the effect of coal additive, we conducted an efficiency trial on Thermax travelling grate type boilers. We observed an avg. 7% increase in s/f ratio of Thermax Boiler.

With the application of coal additives to both Thermax and ISGEC boilers, following savings can be achieved.

Sr. No.	**Boiler**	**Present Monthly Coal Consumption, T**	**Revised Monthly Coal Consumption, T**	**Associated Annual Savings, Rs.**
1	Thermax Boiler	2810	2615	1189500
2	ISGEC Boiler	2560	2380	1093120
Total Monthly Savings due to Coal Additive				**2282620**

i. Monthly Saving Calculations Table

- The coal additive mixing proportion recommended by manufacturers is 1.1 kg of coal additive/T of coal.
- Revised monthly coal consumption for both the boilers due to coal additive will be 4995T. So, the required monthly coal additive quantity will be 5495kg which costs around Rs.12.1Lacs (considering Rs 220/kg of coal additive).
- The net saving due to coal additives is Rs. 10.73Lacs.

4. Assessment of Economizer Performance –

Economizer efficiency is assessed based on heat quantity available in the flue gases and heat absorbed by feedwater while passing through economizer.

For a FBC Boiler, there is no provision for temperature measurement of feedwater as well as flue gases before and after water optimizer. It should be made so that the performance evaluation of the water optimizer and air pre-heater can be carried out.

For Thermax and ISGEC boiler, the calculations are shown below:

Sr. No.	Description	Thermax Boiler	ISGEC Boiler
1	Steam Generated during efficiency trial period, T	47.2	72.8
2	Coal Consumption for steam generation, T	11.82	15.446
3	Actual mass of air supplied for combustion, kg/kg of fuel	9.14	8.83
4	Economizer flue gas inlet temperature, ˚C	312	316
5	Economizer flue gas outlet temperature, ˚C	191	176
6	Economizer feed-water inlet temperature, ˚C	95	75
7	Economizer feed-water outlet temperature, ˚C	146	100
8	Cp of flue gases, kcal/kg˚C	0.26	0.26
9	Grate Ash Quantity measured during efficiency trial period, kg	2788	3464.7
10	Heat available in flue gases, kCal	3682921.53	4985215
11	Heat absorbed by steam in the economizer, kCal	2537472	1820000
12	Efficiency of economizer, %	68.9%	36.5%
13	Additional heat available if efficiency reaches to 75%	220975.3	1919307
14	Daily Coal Saving, kg	420	1680
15	Annual Savings, Rs	38.42	

j. Thermax and ISGEC Boilers calculations

The standard efficiency of any heat exchanger is around 80% and above

- Efficiency of the Thermax Boiler economizer is quietly satisfactory but can be improved with the help of proper cleaning by effective use of soot blowers, avoiding scale and sludge formation on the water side.
- In the case of ISGEC Boiler economizer, efficiency is very poor. Still the low temperature of flue gases at economizer outlets is observed which might be due to air ingress in the economizer path or some other openings.
- This should be immediately prohibited to avail maximum waste heat recovery and the above mentioned precautions for Thermax Boiler should be followed for ISGEC boilers also.

VIII. WASTE HEAT RECOVERY OPTIONS FOR THERMAX BOILER

For Thermax boiler, flue gas outlet temperature out of economizer is 191Deg C. In flue gas path, after economizer there is no provision of heat recovery due to which losses quantified in the indirect method efficiency calculations are much higher compared to ISGEC boiler where air preheater is installed for waste heat recovery

1. Water optimizer after economizer in flue gas path –

Considering the space constraint for Thermax boiler, we suggest installation of a water optimizer. Compared to duct size for air handling, water pipe size is much smaller and is feasible to install in the available space. For Thermax Boilers, feedwater used is condensate recovered from the system and its temperature is around 93-99˚C.

After installation of the water optimizer, the feed-water temperature at the outlet of it will reach in the range of 110 to 120˚C depending on the temperature of the recovered condensate. To retain its water phase, the system needs to pressurize up to 2 to 2.5kg/cm2 in place of the existing atmospheric system. We propose a pressurized tank in between water optimizer and economizer. The schematic of the system will be as follows:

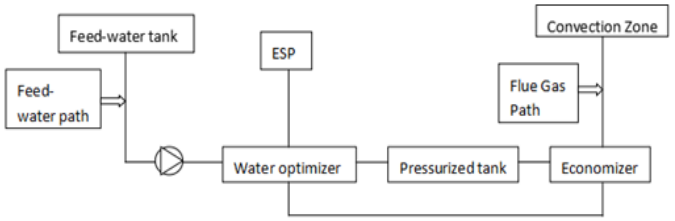

Fig 2. System Schematic

Savings associated with above proposed system:

- Coal Consumption / Hr. – 3.94T
- Heat Available for waste heat recovery when O2% is controlled up to 7.5% (kCal/Hr) – 342400.
- Waste heat recovery possible (kCal/Hr) – 256800
- Coal Saving (kg/hr.) – 60
- Annual Saving Cost Rs. – 26.35Lacs
- Investment required Rs. – 20Lacs (Including provision of the pressurized tank) Payback period – 9 to 10 months

2. Secondary Economizer –

Another option for waste heat recovery is provision of secondary economizer in between existing economizer and ESP. But due to the arrangement of pressure piping, the structure needs an IBR approval.

So, the option is slightly costlier than water optimizer. The schematic for secondary economizer will be as follows:

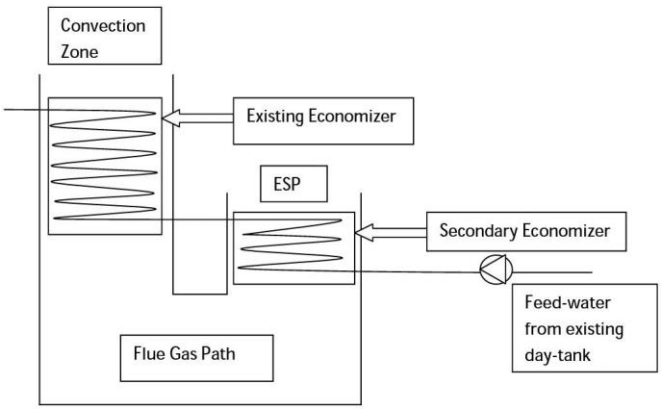

Fig 3. Secondary Economizer

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IX. ENERGY CONSERVATION OPPORTUNITIES

1. Condensate recovery of the plant is around 80-85% which is at its best level.
2. Ultrasonic inspection of steam traps is carried out during which no leakages were observed. All the steam traps in the steam distribution system are working properly.
3. If O2% control is achieved with the help of VFDs, electrical energy consumption for boiler auxiliaries will be reduced.

X. CONCLUSION

With the help of various tests conducted and site measurements we have reached to following points:

O2% in flue gases is observed several times to optimize the dry flue gas loss for all the boilers. While detailed analysis of ISGEC and Thermax Boiler, a level of O2% was better than observed during walk-through audit. The FBC boiler was far away from the required value. It can be fine-tuned manually as well as with the help of automation.

Savings and Investments associated with this remedy are tabulated in the following table.

- Thermography survey of boiler surfaces is carried out to estimate the radiation and other losses. The regions where insulation is damaged or absent are noted and investment required for repairing the insulation is enlisted. Total annual savings after insulation repairing is 8.48Lac and investment is around Rs. 6.31Lac.
- Economizer performance of both ISGEC and Thermax boilers can be improved with the help of suggested measures. It will help to save Rs. 38.42Lac annually and investment or maintenance cost is negligible.
- As there is no provision of air pre-heater for Thermax Boiler, there is an opportunity for waste heat recovery. Considering space constraint, we have suggested feed-water preheating by absorbing heat from flue gases. The two options are discussed in detail in the respective section.
- Annual savings associated with this opportunity is Rs. 26.35Lacs. During the boiler assessment period, a significant control on daily boiler operation is observed

XI. HIGHLIGHTS OF AUDIT FINDINGS AND RECOMMENDATIONS

Sr. No.	Energy saving opportunity	Possible Saving in Rs. Lacs/An num	Estimated investment in Rs. Lacs	Payback in Months	Category
Identified saving opportunities during energy assessment					
1.	O_2% control in flue gases to standard values	Thermax – 11.21	Manual Damper Control – No Investment		
		ISGEC - Nil			No Cost
		FBC – 13.36	Installation of VFD – **13.65**	7 months	
		Total – 24.57			Medium Cost
2.	Prevention of convection and radiation heat losses by application of insulation on boiler body	Thermax – 3.66	1.93		
		ISGEC – 3.66	2.34		
		FBC – 1.16	2.04		
		Total – 8.48	**6.31**	9 months	Low cost
3.	Waste Heat Recovery Options for Thermax Boiler: a) Water optimizer after economizer in flue gas path	**26.35**	20	9-10 Months	
	b) Secondary Economizer		Will depend on material steam pressure and selected material		High Cost
4.	Economizer Performance Improvement	**38.42**	**2-3**	Negligi ble	Low cost
Total		**97.82**	**42.96**		
Verified Saving from plant operation practice:					
Annual cost saving possible due to use of coal additives is Rs. 2.74Crore. The coal additive cost associated with the above savings is Rs. 1.45Crore so the net annual saving due to use of coal additives will be Rs. 1.28Crore.					

k. Highlights and Recommendations Table

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