

A Case Study on Assessment Performance and Energy Efficient Recommendations for Industrial Boiler

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ABSTRACT

As India is a developing country, industrialization is increasing day by day and there is a great need for industry energy audit. Audit helps to maintain and save energy from being wasted and helps in achieving highest efficiency of industrial equipment. This paper contains an actual industry audit report on boiler performance. This paper contains a report 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 boiler, flue efficiency monitor, infrared thermometer, ultrasonic peak detector IR thermal imager. These equipment are used for energy assessment of boilers. Thermography survey of boiler surface is carried out to estimate the radiation and the other losses and the result of this total annual saving after insulation repairing or maintenance is Rs.8.48 lakh and investment is around Rs.6.31 lakh. Economizer performance of both the ISGEC and Thermax boiler can be improved with the help of suggested measures. It will help to save approximately rupees Rs.38.42 Lakh annually and investment on maintenance cost is negligible. In short, this paper deals with assessment of all boilers, evaluates their efficiencies and losses to identify energy saving opportunities and presents them in a report with their payback periods.

Keywords: Energy, Energy audit, assessment, boiler.

INTRODUCTION

Boiler is most energy consumable equipment as compared to any other equipment's used in industry and there is great need of energy assessment of boiler on every early. In this paper taking 18TPH Thermax boiler, 18TPH ISGEC boiler, and 12TPH FBC boiler for assessment. Through sincere and carefully analysis new model is proposed for boiler industry. In this audit during the boiler assessment advanced equipment's are used and result of this concludes accurate analysis of boiler performance. This paper contains 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. tests are performed on boiler.

Methodology for Energy Analysis of Boilers

1. During 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. [1-2]
2. We used recorded flue gas parameters and actual proximate analysis results of the coal for efficiency calculations and then to locate losses. [3]

3. Detail analysis of all the boilers is shown below which can be compared mutually as as with standards.
4. We have used following methodology for this analysis.

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 outlet of 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.

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

Objective and the details of the equipment

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

Details of Equipment 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

BOILER 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/cm ²	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
6	Auxiliaries Electrical Supply	415V, 3 Phase	415V, 3 Phase	415V, 3 Phase
7	Heating surface area sq.m.	NA	879	446
8	Design Rated Steam Temp, °C	420	420	208

- Steam generated by travelling grate type boilers is mainly supplied to two backpressure turbines of 1.5MW and 0.8MW capacities through a common steam header.
- These boilers generate superheated steam of 27 – 29kg/cm² pressure.
- Low pressure steam from cogeneration plants at 5-6 kg/cm² 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.
- 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/cm² Pressure. The boiler is operated during

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 drive which is operated manually based on steam pressure. Thermax boiler does 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 12TPH FBC boiler, water optimizer as well as air pre-heater are installed which extract maximum possible heat from flue gases.

THERMAL ANALYSIS OF BOILERS –

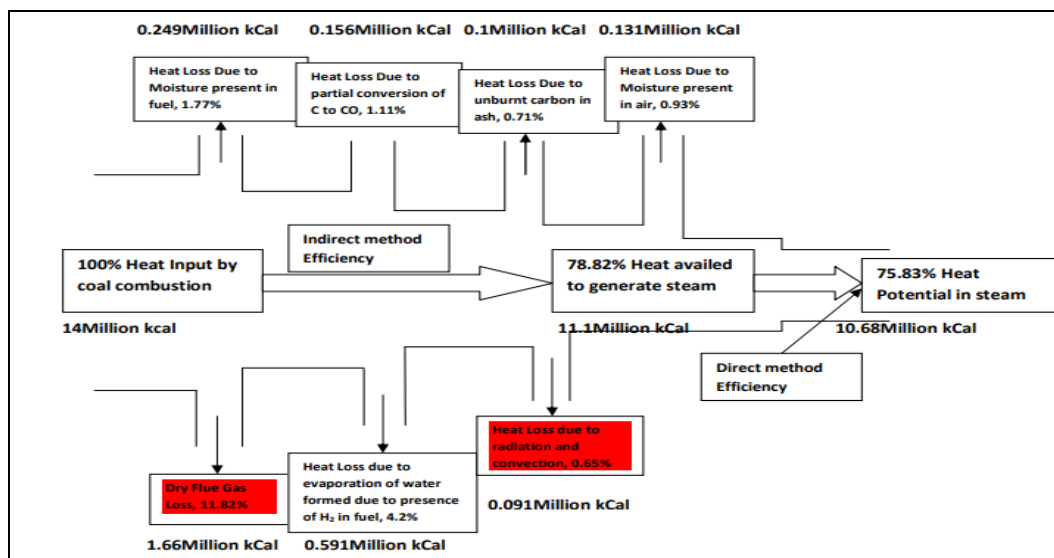
Sr. No	Parameters	18 TPH Thermax Boiler	18 TPH ISGEC Boiler	12 TPH Thermax Boiler
1	Efficiency Evaluation Trial Period	180 min	230 min	120min
2	Steam Quantity Generated, T	47.2	72.8	18.66
3	Steam Pressure, ka/cm2	28.71	27	14.47
4	Steam Temperature, °C	415	328	191
5	Feedwater Temperature, °C	99	75	94.1
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
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
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
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

Above analysis mainly focuses on performance parameters like steam-fuel ratio, direct method efficiency (enthalpy division), indirect method efficiency (sources of losses and their quantification).

1. O2% in flue gases and subsequently excess air for combustion is well within operation standards for Thermax and ISGEC boilers which found abnormal during walk-through audit. In case of 12TPH FBC Boiler, it is still at much higher level indicating maximum dry

flue gas loss. Amount of heat input and various losses are indicated in the

following 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 pre-heater outlet 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 boiler, at present there is no

provision of heat recovery after economizer. So though O₂% and other related parameters are within standard, amount of losses seems to be high. Considering site conditions for waste heat recovery, detail suggestions are discussed in the report. It will also help to improve steam-fuel ratio and direct method efficiency of the boiler.

3. During 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 already so maximum level of indirect method efficiency of the boiler is already achieved.

Observations and energy saving potential –

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

2. O₂% CONTROL IN FLUE GASES TO STANDARD VALUES –

Boiler	Present O ₂ %	Standard O ₂ %	PresentS/F Ratio	Improved S/F Ratio	Annual Saving, Rs.
Thermax Boiler	8.3	7.5	3.9972	4.0200	11.21Lac
ISGEC Boiler	7		Already at Optimum level		
FBC Boiler	14.2	7.5	5.4867	5.6437	13.36Lac

- For every 1% reduction in O₂% in flue gases, there is approximately 0.6% rise in efficiency.
- Currently ISGEC Boiler O₂% level is at optimum level so maximum possible indirect method efficiency is achieved. With close monitoring of O₂% 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 O₂% 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 boiler, 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 portable flue gas analyzer. According to 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.

Boiler	Fan	Capacity	Cost of VFD
Thermax Boiler	FD	30 HP	1,35,000
Online O ₂ monitoring equipment			1,25,000
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

3. EFFECT OF COAL ADDITIVE

Working Principle of coal additive

1. It reduces ignition temperature from 454°C to 316°C due to which faster heat generation is achieved in lesser time.
2. It regulates the release of carbon due to which uniform & synchronized heat generation takes place and heat intensity increases.
3. 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 efficiency trial on Thermax travelling grate type boiler. We observed avg. 7% increase in s/f ratio of Thermax Boiler.

With application of coal additive to both Thermax and ISGEC boiler, 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

- The coal additive mixing proportion recommended by manufacturer 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 additive 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 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 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	

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

- Efficiency of 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 water side.
- In case of ISGEC Boiler economizer, efficiency is very poor. Still the low temperature of flue gases at economizer outlet 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 boiler also.

5. WASTE HEAT RECOVERY OPTIONS FOR THERMAX BOILER:

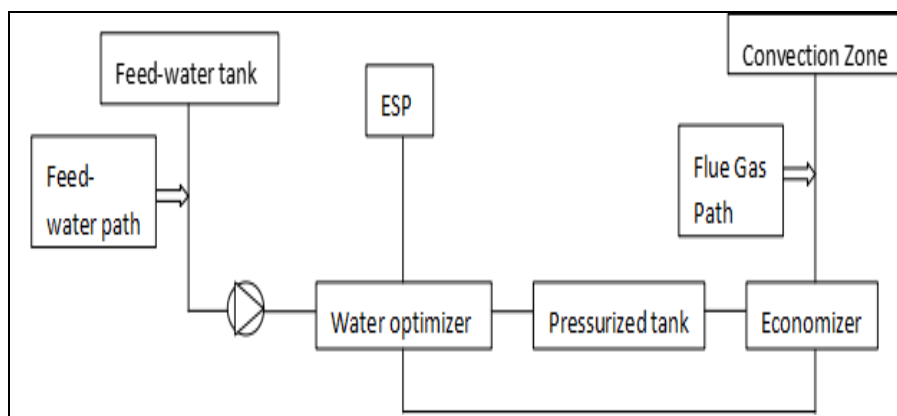
For Thermax boiler, flue gas outlet temperature out of economizer is 191Deg C. In flue gas path, after economizer there is no provision of heat recovery due to which losses quantified in the indirect method

efficiency calculations are much higher compared to ISGEC boiler where air pre-heater is installed for waste heat recovery.

1. Water optimizer after economizer in flue gas path-

Considering space constraint for Thermax boiler, we suggest installation of 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 Boiler, feedwater used is condensate recovered from the system and its temperature is around 93-99°C.

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



Savings associated with above proposed system:

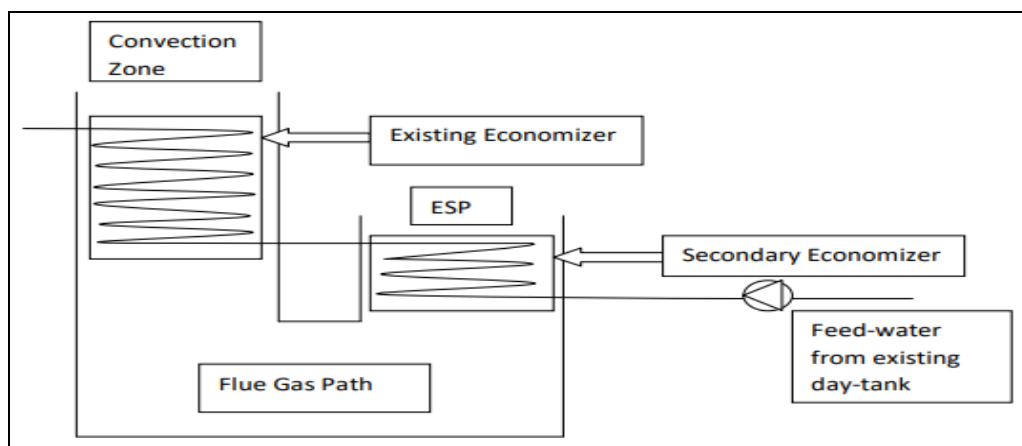
Coal Consumption / Hr.-3.94T
 Heat Available for waste heat recovery when O₂% is controlled up to 7.5% (kCal/Hr) – 342400.
 Waste heat recovery possible (kCal/Hr)-256800
 Coal Saving (kg/hr.)-60
 Annual Saving Cost Rs. -26.35Lacs
 Investment required Rs. - 20Lacs (Including provision of pressurized tank)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

OR

2. Secondary Economizer –

Another option for waste heat recovery is provision of secondary economizer in between existing economizer and ESP. But due to 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:



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 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.

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 detail analysis of ISGEC and Thermax Boiler, a level of O₂% was better than observed during walk-through audit. For FBC boiler it 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 of 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 boiler 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 pre-heating 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 boiler assessment period, a significant control on daily boiler operation is observed. Considering age of the boiler, the extent of control can be rarely seen elsewhere.

Sr. No.	Energy saving opportunity	Possible Saving in Rs. Lacs/Annum	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 Benefits Excess Air Control Optimization of dry flue gas loss Boiler Efficiency Improvement	Thermax – 11.21	Manual Damper Control – No Investment	7 months	No Cost
		ISGEC - Nil			
		FBC – 13.36	Installation of VFD –13.65		Medium Cost
		Total – 24.57			
2.	Prevention of convection and radiation heat losses by application of insulation on boiler body	Thermax –3.66	1.93	9 months	Low cost
		ISGEC – 3.66	2.34		
		FBC – 1.16	2.04		
		Total – 8.48	6.31		
3.	Waste Heat Recovery Options for Thermax Boiler: a) Water optimizer after economizer in flue gas path	26.35	20	9-10 Months	High Cost
	b) Secondary Economizer		Will depend on material steam pressure and selected material		
4.	Economizer Performance Improvement	38.42	2-3	Negligible	Low cost
Total		97.82	42.96		
Verified Saving from plant operation practice:					
Annual cost saving possible due to use of coal additive is Rs. 2.74Crore. The coal additive cost associated to above savings is Rs. 1.45Crore so the net annual saving due to use of coal additive will be Rs. 1.28Crore.					

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