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A Case Study referring to the Energy Audit in a Captive Thermal Power Plant

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Abstract- *In India, the rate of energy consumption is more than energy generation and resulted in reduction of fossil fuel resources. In this paper, a case study of energy audit in a thermal power plant is carried out to bring energy conservation options wherever possible. The main aim of this paper is to reduce the energy consumption by energy audits and management for enhancing power generation. This can be done by continuous process where target must be set, monitored and re-assessed on a regular basis. This paper presents the results from energy audit of 100 MW captive thermal power plant of TATA Chemicals Limited, situates at Mithapur, Gujarat. A detailed study of performance assessment of the boiler considering fuel and cost savings is presented. The efficiency of boiler and related losses are also calculated.*

Keywords- *Energy Audit, Energy Management, Thermal Power Plant, Boiler, Boiler Efficiency, Losses*

1. INTRODUCTION

The main sources of power generation are fossil fuels.In India about 70% of energy generation is contributed by non-renewable energy sources. Among which coal consumption is about 40% of India's total energy consumption. Energy demand of country is increased in last decade and fossil fuels reserves are diminishing. Energy Audit is important for identifying conservation opportunities in the industrial sector. Energy audit study helps us to identify cost saving opportunities [1]. It study includes an inspection, survey and analysis of energy for energy conservation. To meet the growing demand for energy in industries, one of the aims is to identify the technical support in improving their energy performance through comprehensive energy audits, implementation assistance, technology audits, and capacity building. Energy audits help in identifying energy conservation opportunities in all the energy consuming sectors. While these do not provide the final answer to the problem, but do help to identify the existing potential for energy conservation, and induces the organizations/ individuals to concentrate their efforts in this area in a focused manner. In the present scenario of rapidly growing demand of energy in transportation, agriculture, domestic and industrial sectors, the auditing of energy has become essential for overcoming the mounting problems of the world wide crisis and environmental degradation. There are two factors contributing to the increase in the energy consumption, one is more than 20% increase in world's population and another one is worldwide improvement in standard of living of human being. The industrial sector consumes about 50% of total generated energy. Therefore improving energy efficiency is the main focus of Energy Auditing [9]. Present study focuses on the energy audit of 100 MW captive thermal power plant of TATA Chemicals Limited, Mithapur, Gujarat. The live steam condition at inlet is 280.2 T/hr, 510ºC temperature and 84.4-kg/cm^2 pressures. The turbine is impulse, reaction, and condensing type and is provided with regenerative feed water heating system. After suggestions they will be able to save approximately Rs. 91 lakes per year and total investments will be approximately Rs. 142 lakes and the overall payback period will be 19 months. After implementing the suggestions total annual energy saving potential will be 4.57 MUs. The energy audit evaluates the efficiency of all process equipment/systems that use energy. The energy auditor starts at the utility meters, locating all energy sources coming into a facility. The auditor then identifies energy streams for each fuel, quantifies those energy streams into discrete functions, evaluates the efficiency of each of those functions, and identifies energy and cost savings opportunities.

2. AUDIT OF THERMAL POWER PLANT

Energy audit is considered as a technical inspection of a plant in which the department wise, section wise, machine wise pattern of energy is balance the total energy input with respect to production mode[9]. It includes activities that seek to observe conservation opportunities preliminary to the development of an energy savings program. Energy audit methodology is a standardized technique to reduce energy consumption. It changes different forms of energy and cost of energy of the system. Objective of the energy audit is to decrease the energy cost per unit of production [10]. The current paper audit of thermal Power plant TATA Chemicals Limited, Mithapur, Gujarat, with total installed capacity of 100 MW is located about 20 km North of Dwarka and 9 km South of the port of Okha on State Highway 25-A.The total existing plant area is 231.16 ha. No additional land is to be seized for the proposed expansion as it will be done within the existing plant premises. The existing greenbelt area is 95 ha whereas proposedGreenbelt area is 36 ha. The total greenbelt area after proposed expansion will be 131 ha.

In this paper efficiency of boiler, turbine & generator, condenser & heater are calculated &compared with standard data. On comparing the efficiencies of different sub-units of plant, we obtain the losses & also get the overall efficiency of plant. In this case study the reading of various sub units are obtained from the control panel, installed in control room. Problem Formulation in TCL, Mithapur, Gujarat100 MW units is consideration for energy audit and efficiencies of main sub-units as like boiler; turbine and generator, condenser & heater are calculated.

Table 1:Details of expansion

	NAME OF ACTIVITY	**UNIT**	**EXISTING CAPACITY**	**PROPOSED (ADDITIONAL CAPACITY)**	**PROPOSED TOTAL CAPACITY**
1	Soda Ash	Tons/year	1,091,000	225,000	1,316,000
2	Cement	Tons/year	787,000	113,000	900,000
3	**S.NO**				
a.	Power Generation	MW	85	40	125
b.	Steam Generation	TPH	757	300	1057

(a) *Power Plant:* The power plant operates on the "Total Energy Concept" – raising steam at high pressure (110 kg/cm2), generating power out of this at Topping Turbines and supplying the exhaust steam at (30 kg/cm2) to the various process units (Steam tube dryers and compressors in Soda ash plant) as well as to Low Pressure Turbines. These turbines generate additional power and low pressure steam, which are used at ammonia stills in the Soda ash plant (at 1.5 kg/cm^2) and the Vacuum Evaporated Salt plant (at 3.5 kg/cm2& 1.5 kg/cm^2).

(b) *SO2 Absorption System*: To reduce the sulphur dioxide emissions to atmosphere, Limestone dust is added to the fuel (Petcoke). Limestone absorbs the SO2 generated forming CaSO4, which comes in bottom ash.

(c) *Electrostatic Precipitator*: The electrostatic precipitators are provided to control particulate matter from boiler flue gas emissions. ESPs are designed to meet prescribed norms for particulate matter.

(d) *Bag Filter*: The other air pollution control equipment provided is bag filters to control the dust emission due to the material handling at fuel and dry fly ash handling.

(e) *Bed Ash System*: Bed ash extraction takes place via discharge pipes from the fluidized bed bottom to bed ash coolers which cool the bed ash to about ~150 °C. This is finally conveyed to the silo.

(f) *Cyclone Ash Recirculation System*: Major part of the fuel ash introduced is carried up as fly ash from the fluidized bed by the flue gases. More than 95% of this fly ash is separated in the cyclones eco/ah pass. The Cyclone ash recirculation is carried out for cooling the fluidized bed, and for increasing the carbon burn-up rate. The Cyclone ash is returned to the fluidized bed via down comers and ash siphons. The ash siphons are used as a pressure seal between cyclone and combustion chamber.

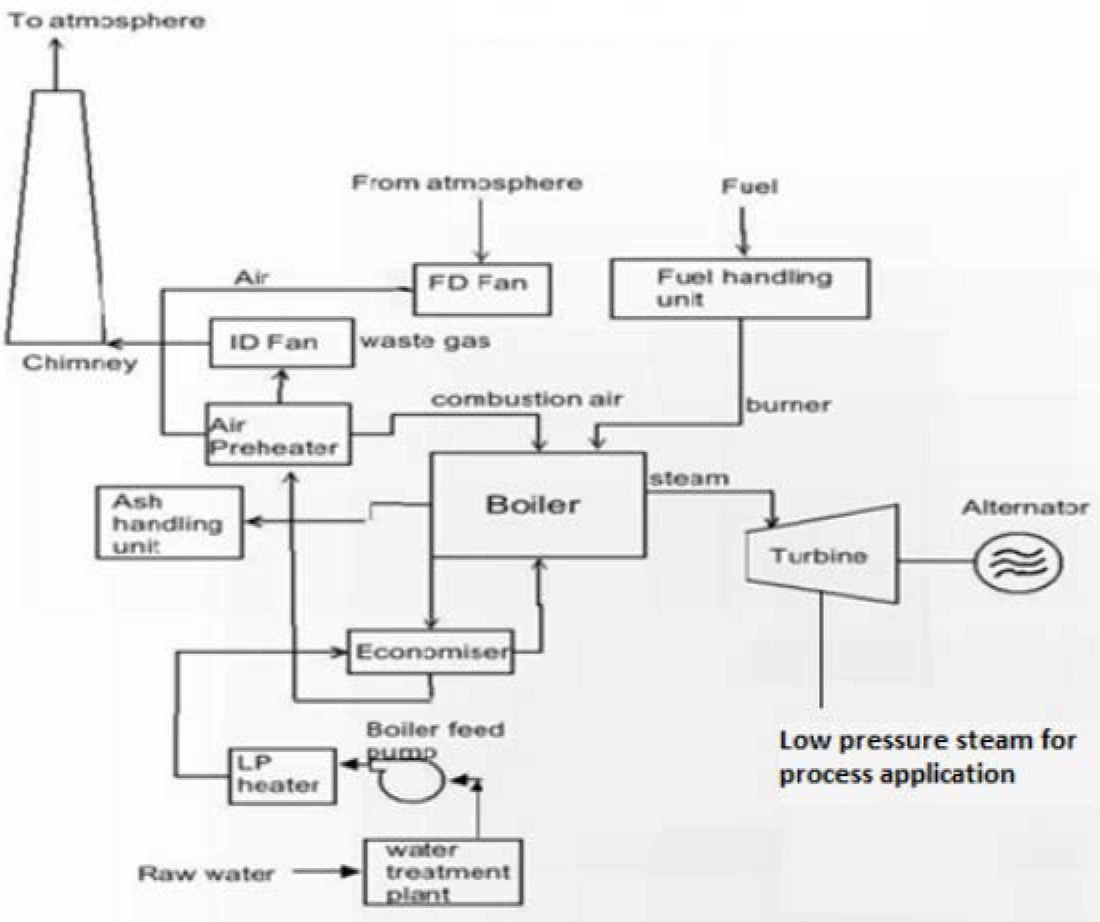

Figure 1: Process Flow Diagram – Captive Co-generation Power Plant

3. ENERGY, POWER REQUIREMENTS AND SOURCE

The steam and power requirement for present case is discussed below:

3.1. *Steam requirement***:** The existing steam generation capacity is 757 TPH. Additional 300 TPH steam generation capacity is proposed in expansion project. Thus the total steam generation capacity after proposed expansion project will be 1,057 TPH.

3.2. *Power requirement and Source:* The existing power generation capacity is 85 MW. Additional 40 MW power generation capacity is proposed in expansion project. Thus, the total power generation capacity after proposed expansion will be 125 MW.

Table2: Energy Requirements (along with sources)

PURPOSE	POWER / STEAM	REQUIREMENT		SOURCE
		EXISTING	PROPOSED	
Soda Ash Plant	Power	174.5 kwh/T of soda ash	174.5 kwh/T of soda ash	Captive
	Steam	3.611 T/T of soda ash	3.611 T/T of soda ash	
Cement Plant	Power	142 kwh/T of Cement	139 kwh/T of soda ash	Captive
	Steam	Not Applicable	Not Applicable	

Captive Power Plant	Power	22.7% of power generation	22.7% of power generation	Captive
	Steam	13.75% of gross steam production	13.75% of gross steam production	
Colony	Power	1.1 MWH	1.1 MWH	Captive / GEB
	Steam	Not Applicable	Not Applicable	
Installed Capacity	Power	85 MW	40 MW	Captive
	Steam	757 TPH	300 TPH	

Table 3: Details of Fuel requirements

NAME OF THE UNIT	**FUEL**	**EXITING (TPA)**	**PROPOSED (TPA)**	**TOTAL AFTER PROPOSED EXPANSION**	**SOURCE**
Soda Ash Plant	Coke and Coal	1,26,011	25,988	1,51,999	Coke: Domestic (Gujarat) Coal: Import(Indonesia, South Africa)
Cement Plant	Coal	1,44,211	20,706	1,64,917	Import(Indonesia, South Africa)
Captive Co-generation Power Pant	Coal	4,83,946	92,391	5,76,337	Import(Indonesia, South Africa)
	Petcoke	2,81,984	2,54,075	5,36,059	Domestic (Gujarat), Import(Refineries, Global Market)
	HSD	251 KL/Annum	99 KL/Annum	350 KL/Annum	IOCL, Jamnagar
	Furnace Oil	476 KL/Annum	189 KL/Annum	665 KL/Annum	IOCL, Kandla

4. Main Steam System

(a) Estimating Boiler Efficiency

The boiler has maximum steam output of 325 T/hr at 515ºC temperature and 107 kg/cm^2 pressure. The boiler efficiency of the Unit is evaluated by loss calculation method. During the time of site measurement parameters like O_2, CO_2, CO and excess air in the flue gas were measured and tabulated below.

The value of combustible in fly ash and bottom ash is also tabulated in Table. During the test period blow down, soot blowing & oil firing was terminated. The losses mentioned for computation of boiler efficiency are listed below:

1. Dry flue gas loss
2. Wet flue gas loss
3. Sensible heat loss
4. Moisture in combustion air loss
5. Un-burnt gas loss
6. Combustible in ash
7. Radiation & un-accounted loss

The losses are added and finally subtracted from 100% to get the efficiency of the boiler. Detailed calculation on the basis of site measurement is given below:

5. Boiler Design Efficiency:

Table 4: Measured Parameter

S.No.	**Parameters**	**Design**
1	Total carbon (C)	29.29%
2	Hydrogen (H)	1.97%
3	Sulphur (S)	2.65%
4	Oxygen (O)	11.30%
5	Nitrogen (N)	1.77%
6	Ash	17.35%
7	Moisture (M)	35.66%
8	GCV(Gross Calorific Value)	11425.8210 kJ/kg
9	CO2 at ECO outlet	14.02%
10	SO2 at ECO outlet	0.00%
11	CO at ECO outlet	0.01%
12	O2 at ECO outlet	4.30%
13	N2 at ECO outlet	81.68%
14	Excess air %	25.75%
15	Flue gas outlet Temp. at APH o/l (T)	170.0000°C
16	Ambient air temp (t)	40.0000°C
17	Ambient air Humidity (H)	0.0150 kg/kg dry air
18	Bottom ash percentage	3.47%
19	Fly ash percentage	13.88%
20	Un-burnt carbon in fly ash	0.0007% of coal
21	Un-burnt in bottom ash	0.0069% of coal
22	Un-burnt carbon	0.0076

Table 5: Loss calculation

Calculated Design efficiency				
Sl.No.	**Losses**	**Unit**	**Design**	**Design %**
1	Dry flue gas loss	kJ/kg	697.78	6.11
2	Wet flue gas loss	kJ/kg	1416.75	12.4
3	Moisture in combustion air	kJ/kg	19.12	0.17
4	Un-burnt gas loss	kJ/kg	2.5	0.02
5	Combustible in ash loss	kJ/kg	257.24	2.25
6	Radiation loss	kJ/kg	25.14	0.22
7	Unaccounted and manufacturing margin loss	kJ/kg	171.39	1.5
8	Total Loss	kJ/kg	2589.91	22.67
9	Boiler Efficiency	%	77.33	77.33

6. Formula used in calculation of boiler efficiency:

1 Dry flue gas

$= \frac{M+9\times H}{100}[1.88 \times (T-25) + 2442 + 4.2 (25-t)]$ kJ/kg of coal

4 Moisture in combustion air

$= \frac{3.034 \times N_2}{(CO_2+CO)} \left(\frac{C}{100} + \frac{S}{267} - C \text{ in Ash}\right) \times h \times 1.88 \times (T-t)$ kJ/kg of coal

5 Un-burnt gas loss

$= \left[\frac{CO}{(CO_2+CO)}\left(\frac{C}{100} + \frac{S}{267} - C \text{ in Ash}\right)\right] \times 23{,}717$ kJ/kg of coal

(Where 23,717 = CV of burning 1 kg of carbon in CO to CO_2 in kJ/kg)

6 Combustible in ash

Combustible loss

= C in Ash × 33,820

(Where 33,820= Calorific value of carbon burnt to CO_2 in kJ/kg)

7 Radiation loss

Radiation loss **=* 0.22%** (Assumed)

Source: * from BEE guide line book 2&3

8 Unaccounted and manufacturing margin loss

Unaccounted and manufacturing margin loss= ***1.5%** (Assumed)

Source: * from BEE guide line book 2&4

7. Operating Efficiency: (Load- 100 MW)

Table 6: Measured parameters

S.No.	Parameters	Operating
1.	Total carbon	24.61%
2.	Hydrogen	1.45%
3.	Sulphur	2.65%
4.	Oxygen	8.79%
5.	Nitrogen	1.83%
6.	Ash	26.52%
7.	Moisture	34.13%
8.	GCV	9466.69 kJ/kg
9.	CO_2 at ECO outlet	12.20%
10.	SO_2 at ECO outlet	0.00%
11.	CO at ECO outlet	0.0016%
12.	O_2 at ECO outlet	6.90%
13.	N_2 at ECO outlet	80.89%
14.	Excess air %	48.93%
15.	Flue gas outlet Temp. at APH o/l	193.00°C
16.	Ambient air temp	35.00°C
17.	Ambient air Humidity	0.018 kg/kg dry air
18.	Bottom ash percentage	5.304%
19.	Fly ash percentage	21.216%
20.	Un-burnt carbon in fly ash	0.0010% of coal
21.	Un-burnt in bottom ash	0.0089% of coal
22.	Un-burnt carbon	0.0099

Table 7: Calculated parameters

Calculated boiler efficiency				
Sl.No.	**Losses**	**Unit**	**Operating**	**Operating %**
1.	Dry flue gas loss	kJ/kg	812.69	8.58
2.	Wet flue gas loss	kJ/kg	1281.73	13.53
3.	Moisture in combustion air	kJ/kg	26.47	0.28
4.	Un-burnt gas loss	kJ/kg	0.76	0.008
5.	Combustible in ash loss	kJ/kg	335.80	3.54
6.	Radiation loss	kJ/kg	20.82	0.22
7.	Unaccounted and manufacturing margin loss	kJ/kg	142.00	1.5
8.	Total Loss	kJ/kg	2620.28	27.67
9.	Boiler Efficiency	%	72.32	72.32

Table 8: Measured Parameters

Sl.No.	**Losses**	**Operating (%)**	**Design %**
1.	Dry flue gas loss	8.585	6.107
2.	Wet flue gas loss	13.539	12.400
3.	Moisture in combustion air	0.280	0.167
4.	Un-burnt gas loss	0.008	0.022
5.	Combustible in ash loss	3.547	2.251
6.	Radiation loss	0.22	0.220
7.	Unaccounted and manufacturing margin loss	1.50	1.500
8.	Total Loss	27.679	22.667
9.	Boiler Efficiency	72.321	77.333

8. Results and Discussion:

a. Comparisons of different losses and gross efficiency between the design and current values have been given in the above table
b. Current dry flue gas loss is 8.585% (actual) ,compared to the design value of 6.107%. Higher flue gas loss is due to higher flue gas exit temperature. Also excess oxygen percentage in APH outlet is 6.9 against the design value of 4.3% this is also big factor of increased flue gas loss.
c. Wet flue gas loss is closed to design value.
d. Un-burnt gas loss is within permissible limit (Design 0.220). This insures complete combustion of fuel but in expense of excess air.
e. Hence boiler efficiency is lower than the design value due to excess air is provided to the boiler. During energy audit the cause of excess air has been discussed with plant engineers and found that this is required to bring down furnace zone temperature below the fusion point of silica present in the lignite. Proper cooling of furnace zone environment is necessary to avoid the clinker formation in the burning zone.

9. Recommendation:

So, it is advised to optimize excess air supplied to boiler by maintaining the furnace zone temperature well below the fusion point of silica. Due to operational compliances excess air to boiler only can be reduce up to certain limit by seeing the temperature of furnace zone to avoid clinker formation. Oxygen percentage reading in control room is also erratic and need to be calibrated. It is also be advisable to calibrate CO sensor to control the un-burnt gas loss while reducing /optimizing airflow. Real saving potential cannot be judged due to uncertainty in extent of excess oxygen reduction. But some energy can be conserve by adapting good operational practices.

10. Determination of Air Pre-heater Performance:

Performance evaluation of APH was evaluated based on the measurements taken during the energy audit study. Measured values are tabulated in table. The detailed calculations are tabulated below.

Table 9: Measured & Calculated Parameters

Sl. No.	Measured parameters	Design	PAPH#A	PAPH#B
1.	**Load**	**70**		
2.	Air inlet temperature	40.00	48.00	48.00
3.	Air outlet temperature	272.00	254.00	248.00
4.	Gas inlet temperature	325.00	310.00	303.00
5.	Gas outlet temperature	170.00	189.00	188.00
6.	Gas inlet oxygen	4.30	7.15	6.65
7.	Gas outlet oxygen	4.30	N.P	N.P
8.	Gas CO2 at inlet	15.00	11.75	12.25
9.	Gas CO2 at outlet	15.00	N.P	N.P
10.	N2 At inlet	80.70	81.10	81.10
11.	N2 at outlet	80.70	N.P	N.P
12.	Excess air percentage at inlet	25.75	51.62	46.34
13.	Excess air percentage at Outlet	25.75	N.P	N.P
14.	Air side pressure drop	60.00	33.00	38.00
15.	Flue gas side pressure drop	150.00	122.00	115.00
16.	Percentage of air leakage	0	N.P	N.P
17.	Computed effectiveness (air side)	81.40	78.63	78.43

N.P.: Not possible

- ✓ Performance of the RAPH is satisfactory. Effectiveness of both the Air Pre-Heater is closed to design value.
- ✓ Air leakage across the RAPH # A & B cannot be calculated due to unavailability of oxygen percentage at APH outlet. But good heat transfer across heating surface indicates air leakage is within the limit.

Table 10: Determination of Economizer Performance

S. No	Measured parameters	Design	ECO # R	ECO # L	Avg Value
1	Load	70	70		70.0
2	Flue gas temperature at the inlet	499	410	416	413.0
3	Flue gas temperature at the outlet	355	310.00	303.00	306.5
4	Feed water inlet to ECO	230	230		230.0
5	Feed water outlet to ECO	279	271		271.0
6	Flue gas flow	530	515.56		515.6
7	Feed flow (TPH)	325	325		325.0
8	Heating surface (m2)	N.A	N.A		N.A
Calculated parameters					
1	LMTD	168.04	113.2		
2	LMTD Corr. factor for cross flow	0.98	0.98		
3	True LMTD	164.68	110.9		
4	Flue gas side effectiveness	53.53	58.0		

Effectiveness of the economizer is 58%, which is close to the design value. Hence, performance of the economizer is satisfactory.

11. Conclusion:

The thermal audit of power plant has been successfully completed and during the audit we found that there are many problems in the power plant through which huge amount of electrical energy is wasting , so we have suggested to the client that they reduced the supply voltage and install VFD where we suggested and maintain the pumps , compressors , fans etc. regularly due to regular maintenance and by implements the suggestions they will be able to save approximately Rs. 91 lakes per year and total investments will be approximately Rs. 142 lakes and the overall payback period will be 19 months. After implementing the suggestions total annual energy saving potential will be 4.57 MUs.

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