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DETAILED ENERGY AUDIT IN A CAPTIVE COGENERATION PLANT

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Abstract: The rate of exploitation of the energy resources has been expanding over time and resulted in reduction of fossil fuel reserves. Efficiency of all resources is crucial both in environmental and economic sense. Using energy inefficiently creates waste in all the world's economies. It has environmental impacts with regional, local and global implications.

The key object is to adopt energy management in every field in order to reduce the wastage of energy sources and cost effectiveness without affecting productivity and growth.

The broad scope of the energy audit and conservation study of captive cogeneration plant is as given below

A) To study the entire thermal power plant operations and suggest means to improve energy efficiency wherever possible. This would include
   (i) Performance assessment of the two boilers and turbine to bring out potential areas for energy conservation, leading to fuel and cost savings where ever possible.
   (ii) Performance assessment of pumping system , which includes the boiler feed water pumps, main and auxiliary cooling or circulating water pumps, condensate extraction pumps, to bring out potential areas for energy conservation, leading to energy and cost savings where ever possible.
   (iii) Performance assessment of fan system which includes, forced draft fans, induced draft fans and primary air fans to bring out potential areas for energy conservation, leading to energy and cost savings where ever possible
   (iv) Energy Audit of coal handling system (coal crusher) with a view to bring out energy conservation options where ever possible.
   (v) Energy audit compressed air systems in the ash handling plant, with a view to bring out energy conservation options where ever possible.

B) To study the operational parameters and generate suitable methodology to bring out energy performance indicators that would enable day-to-day assessment of all the key thermal and electrical auxiliaries and monitoring of the plant on a sustained basis. This project brings out in a holistic and simple fashion, the broad frame work and methodology required to be followed to conduct an energy audit and conservation study in a typical cogeneration plant.

Keywords: Audit and Energy performance

PROBLEM STATEMENT

Energy audit and conservation in a cogeneration plant, involves pains taking task with enormous amount of duty parameters that need to be monitored measured and analyzed in a systematic manner to bring to maximum possible energy conservation options.

This project has attempted to address the potential energy conservation options which has a major impact on reduction of energy consumption and energy cost savings in a cogeneration plant and with an objective to provide a frame work for instituting an energy audit in a cogeneration plant along with evaluation methods and analysis to bring out meaningful and substantial energy conservation options, in a easy to implement manner.

This project work would serve as a reference guide to any practicing engineer to conduct with ease an energy audit, in a facility as complex as cogeneration plant, in a professional manner.

1. INTRODUCTION

Cogeneration is defined as the sequential generation of two different forms of useful energy from a single primary energy source, typically mechanical energy and thermal energy. Mechanical energy may be used either, to drive an alternator for producing electricity, or rotating equipment such as motor, compressor, pump or fan for delivering various services. Thermal energy can be used either for direct process applications or for indirectly producing steam, hot water, hot air for dryer or chilled water for process cooling. The overall advantage of cogeneration plant when compared to conventional plant are discussed below and depicted in Figure1.1.

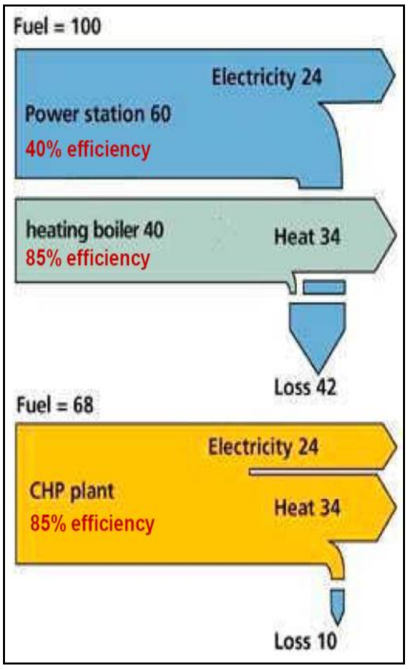

Figure 1.1: The comparison of input and outputs 'Cogeneration VS conventional plant'

ENERGY SCENARIO

Electrical Energy Generation Trend

The Monthly Gross Electrical Energy Generated from the captive cogeneration Power plant is presented in the Figure 4.1 below:

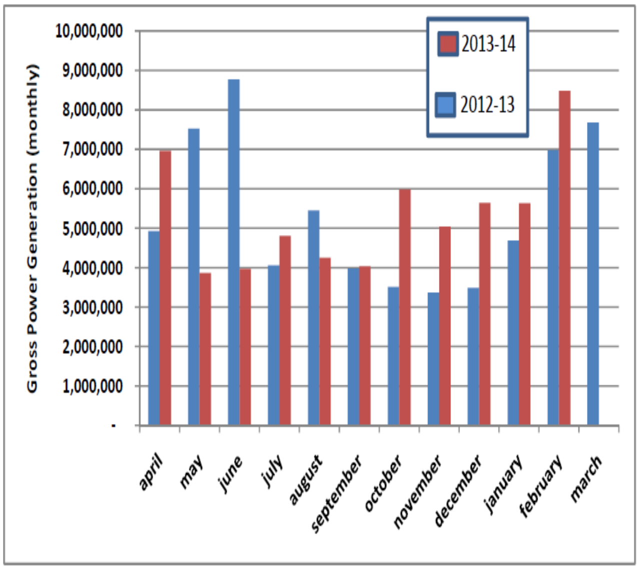

Figure 4.1: Power Generation Trend

ENERGY USAGE BREAKUP:

The following table presents, the trend of usage pattern of total electrical energy generated in the plant. The Main consumers are Power plant auxiliaries, textile unit connected to the plant and the power exported to grid. The Table 4.1 given below gives the break-up of power consumption of various consumers.

Table 2.1: Energy Break up of captive cogeneration power plant

Month	Auxiliary Power Consumption		Power Supplied to Textile unit		Power exported to Grid	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
April	8,81,057	10,46,656	27,92,248	29,48,680	12,55,680	29,64,360
May	11,43,158	7,13,412	27,57,600	30,46,040	36,23,450	1,03,320
June	11,99,362	6,80,994	29,28,810	31,50,190	46,45,020	1,40,700
July	7,06,410	7,87,234	30,88,960	33,78,634	2,28,240	6,67,380
August	9,51,006	7,22,346	32,64,754	36,33,910	12,30,150	7,560
September	11,78,240	6,79,854	27,84,444	34,32,600	10,500	10,500
October	6,79,038	9,29,922	27,91,270	35,38,554	36,120	15,46,860
November	6,32,335	8,02,060	27,32,406	33,15,044		9,51,300
December	6,32,017	8,81,475	28,54,190	35,02,776		12,66,444
January	8,27,110	8,83,710	25,39,026	35,48,645	13,16,700	12,08,340
February	10,58,405	11,72,245	25,14,632	34,14,959	33,98,640	38,95,920
March	11,19,280		27,13,226		38,42,580	

The above table can be presented as shares in power generation in following Pie Chart.

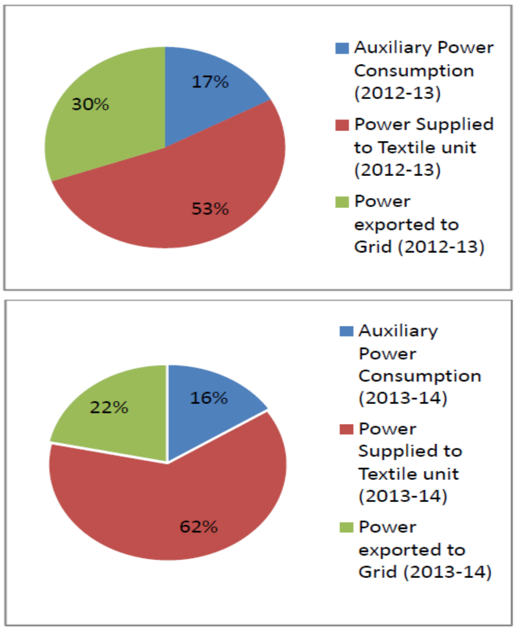

Figure 4.2: Share of Power distribution

The Steam consumed by turbine for power generation and for processing by textile units from the above steam generated quantity is presented in Figure 4.3 below.

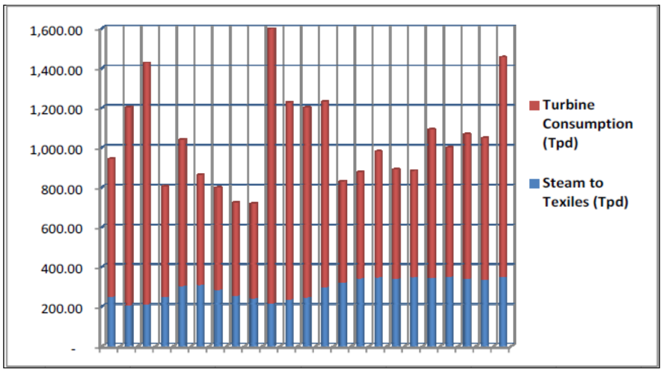

Figure 4.3: Steam Distribution to Turbine and Textile Unit

As seen from the above trends, the turbine accounts for around 72% (748.15 TPD) of total generated steam while, the textile units accounts for the balance 28% (290.35TPD).

COAL PURCHASED AND CONSUMPTION TREND

The monthly Coal purchased quantity (as received), coal consumed (as fired) (tons) and also purchase cost of coal (at the plant) by the plant for the period 2012-13 & 2013-14, is presented in Table 4.3 as under:

Table 4.3: Details of coal purchased and consumed

Month	Coal purchased (as received) in tons		Coal consumed (as fired) in tons		Coal Purchase Cost (at plant) Rs/ton	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
April	5927.15	7166.47	4,682	7,979	3,980	3,871
May	2348.9	10163.09	6,287	6,610	3,941	3,915
June	9476.41	7453.75	9,126	5,826	3,928	4,055
July	9269.17	5757.93	5,519	7,056	3,666	4,040
August	10880.18	8211.11	7,223	7,006	3,866	4,024
September	7752.63	7820.97	5,702	6,522	4,313	4,020
October	5068.96	7431.89	4,892	8,654	4,662	3,845
November	4363.41	6525.21	4,602	6,904	3,656	3,845
December	3580.9	1440.98	4,765	7,722	3,558	3,845
January	4874.85	15000	6,598	7,590	3,565	4,329
February	9500.11	20000	8,094	9,994	3,647	4,119
March	9069.8		8,650		3,774	
Average	7786		6870		3933	

5. FIELD OBSERVATIONS AND EVALUATIONS

5.1 Boiler Thermal Efficiency Assessment

The method of performance assessment chosen is the indirect method of heat loss and boiler efficiency as per BIS standard 8753 and the employed relationships can be seen in boiler loss assessment calculations presented.

Note: TM: Total Moisture in coal, IM: Inherent Moisture in coal, VM: Volatile matter in coal, FC: Fixed carbon in coal, GCV: Gross calorific value of coal, ARB: As received basis, ADB: Air dried basis, DB: Dry basis.

5.2 Turbine Thermal Efficiency Assessment

Performance assessment of turbine system, based on *'As-run trials'* was conducted during filed visits with the objective of validation against design /PG test values. The *'As- run trials'*, findings are envisaged to help in assessing the performance, vis-à-vis design/PG values, factors and parameters affecting performance, key result areas for improvement and attention.

Table 5.2.1 Summary of Turbine cylinder efficiency

S.No.	Reference Parameter	Units	Design	As-run operating Values
1.	*Turbine inlet to Controlled (1st) extraction stage- cylinder efficiency*	%	69.1	59.65
2.	*Controlled (1st) extraction to 2nd Extraction stage- cylinder efficiency*	%	66.9	62.71
3.	*2nd Extraction to Turbine Exhaust stage- cylinder efficiency*	%	79.6	69.98
4.	**Overall Turbine Cylinder Efficiency**	%	89.6	86.26

5.2.2 Turbine Cycle Heat Rate

Along with turbine cylinder efficiency assessment the '*Turbine Cycle Heat Rate'* value which is a key performance indicator and defined as the ratio of energy input to the turbine cycle to the net electrical generation arrived at the relevant trial parameters.

Table 5.2.2 Evaluation of overall turbine heat rate

Parameter Reference	Units	PG test value	As-run values
Main steam flow to turbine	kgs/hr	65270	64000
Enthalpy of main steam flow to turbine	kCal/kg	819.1	815.79
Feed water flow to boiler	kg/hr	65270	64000
Enthalpy of Feed water to boiler	kCal/kg	188.6	181
Steam flow to process	kg/hr	18000	16000
Enthalpy of process steam	kCal/kg	668	734.5
Generation	kW	12500	12240
Turbine Heat Rate *{((Main steam flow to turbine*Enthalpy of main steam flow to turbine)-(Feed water flow to boiler*Enthalpy of Feed water to boiler)+(Steam flow to process*Enthalpy of process steam))/(Generation in kW)}*	Kcal/kWh	**2330**	**2359**
Thermal efficiency of Boiler- 100	%	84.84	76.87
Thermal efficiency of Boiler- 101	%	85.07	76.63
Average of Boiler -100 & Boiler 101	%	84.96	76.75
Unit Heat Rate {Turbine Heat Rate/Thermal efficiency of Boiler}	kCal/kwh	**2743**	**3074**
Rankine cycle efficiency	%	**31.3**	**27.97**

Table 5.2.3: Evaluation of heat load calculations

Parameter Reference	Units	PG test Value	As-run Values
Inlet Steam Enthalpy	kCal/kg	819.1	815.79
Feed Water Enthalpy	kCal/kg	188.6	181
Inlet Steam Flow	kg/hr	65270	64000
Process Steam Flow	kg/hr	18000	16000
Process Steam Enthalpy	kCal/kg	668	734.5
Generation	kW	12500	12240
Generator Efficiency	%	99	99
Turbo Generator Coupling losses	kW	40	40
Heat Load ((Inlet Steam Flow * (Inlet Steam Enthalpy-Feed Water Enthalpy)) - {(((Process Steam Flow * (Inlet Steam Enthalpy - Process Steam Enthalpy)) + (((Generation/(Generator Efficiency/100)) + (Turbo Generator Coupling losses)) * 860)}	kCal/hr	27539949	28658793

The Heat load of turbine is at as run condition	=	28.6 million Kcal/hr.
In comparison the design Heat Load	=	27.53 million Kcal/hr

5.3 PERFORMANCE ASSESSMENT OF CONDENSER

The assessment of condenser performance is important to determine equipment performance degradation. The "As run performance tests" can be used as the base line for evaluating the performance improvement activities, as well as maintenance efficiency. Before the actual assessment is done, the list of condenser operating parameters are monitored and corresponding transducer reference in the data acquisition system were identified and the same was monitored every 60 minutes interval.

Table 5.3.3: Calculations showing Predicted condenser vacuum improvement

Back pressure with clean tubes at design 32 °C CW Inlet temp.	=	98	Mbar
Predicted Saturation temperature on account of CW Inlet temperature being lower, at ideal as-run weather conditions	=	24.6	Actual Inlet Temperature
	=	24.6+8+3	°C + Design CW temp. raise + Design approach
	=	35.6	°C
Corresponding predicted back pressure in ideal conditions with lower CW Temperature	=	56.97	Mbar
Predicted Saturation temperature at as-run actual CW Outlet temperature and design approach.	=	32.7	°C + Design approach of 3 °C
	=	35.7	°C
Corresponding predicted back pressure with lower CW Inlet temperature, actual CW ΔT due to lower flow and design approach.	=	57.28	Mbar
Saturation temperature w.r.t. actual CW Outlet conditions and actual approach (As-Run condition)	=	32.7+10.7	°C + Actual approach of 10.7 °C
	=	43.4	°C
As-Run back pressure, at above condition	=	86.47	Mbar
Loss in vacuum on account of lower CW flow, and fouled condenser tubes, at 24.6 °C CW Inlet temp. in as run conditions. {Item (vii) – Item (iii)}	=	(86.46-56.96)	Mbar
	=	***29.5***	Mbar
Loss in vacuum on account of lower CW flow, and fouled condenser tubes above, at 32.7 °C CW outlet temperature. {Item (vii) – Item (v)}	=	(86.46-57.28)	Mbar
	=	***29.18***	Mbar

A profile of desirable vacuum conditions at varying inlet CW temperature from 28°C to 36°C, with 8°C as CW Temperature raise and 3°C as approach, are as follows

Table 5.3.4: Desirable Vacuum conditions at varying inlet temperatures

CW Inlet Temperature (°C)	Predicted Saturation temperature in °C (Ideal)	Predicted Vacuum in mbar (Ideal)
28	39	68.51
30	41	76.21
32	43	84.66
34	45	93.90
36	47	104.00

5.4 ENERGY PERFORMANCE ASSESSMENT OF HP HEATER

The performance of the HP heater (HPH) was assessed based on as-run duty parameters. These measured parameters were chosen based on various aspects of HPH performance that were desired to be monitored and assessed. To ensure consistency and reliability of as-run data for the performance assessment of HPH, the data was grouped and captured at regular one hour intervals by the data acquisition system.

Table 5.6.1: Performance Evaluation of APH

Parameters	Units	Value	BOILER-100	BOILER-101
Unit load	**Mw**	**12.5**	10.0	
Total coal flow	**TPH**	**5.503**	8.32	7.71
Steam flow	**TPH**	**38**	40.35	36.13
FG Temp APH inlet	°C	**240**	267.1	275.0
FG Temp APH outlet	°C	**140**	142.6	149.0
Air Temp APH in	°C	**40**	31.9	30.5
Air Temp APH out	°C	**160**	170.1	154.9
Δ Temperature drop in flue gas	°C	**100**	**124.5**	**126.0**
Δ Temperature raise in air	°C	**120**	**138.1**	**124.3**
LMTD	°C	89.63	103.7	119.3
Diff. Press. Across (gas)	mmwc		51.0	22.2
Diff. Press. Across APH (air)	mmwc		106.9	111.626
Flue gas flow through APH	TPH	53.3	64	58.5
Air flow through APH	TPH	48.2	57.3	51.1
Effectiveness of APH	%	60	58.7	50.9
Heat given up by flue gas	***m.kCal/hr***	***1.439***	***2.152***	***1.990***
Heat gained by Air	***m.kCal/hr***	***1.387***	***1.900***	***1.525***
% heat pickup	%	0.96	0.88	0.77

5.7 ENERGY PERFORMANCE EVALUATION OF COOLING TOWER

The performance of the Cooling Tower (CT) was assessed based on as-run duty parameters which were measured at site location. These measured parameters were chosen based on various aspects of Cooling Tower performance that were desired to be monitored and assessed. To ensure consistency and reliability of as-run data for the performance assessment of Cooling tower, several sets of measurements were taken and averaged. The cooling Tower performance was conducted in afternoon period.

The performance of the I.D fans was assessed based on as-run duty parameters. These parameters were chosen based on various aspects of ID fans performance that was desired to be monitored and assessed. To ensure consistency and reliability of as-run data for the performance assessment of ID Fans, the data was grouped and captured at regular one hour intervals by the data acquisition system. This information was captured over a period of four days.

5.14 ENERGY PERFORMANCE EVALUATION OF PRIMARY AIR FAN

The performance of the PA fans was assessed based on as-run duty parameters. These measured parameters were chosen based on various aspects of PA fans performance that were desired to be monitored and assessed. To ensure consistency and reliability of as-run data for the performance assessment of PA Fans, the data was grouped and captured at regular one hour intervals by the data acquisition system. This information was captured over a period of four days.

Table:5.14.1 Energy Performance of PA Fan –II Boiler-1

S.No	Parameter reference	Units	Rated Value of each fan	As run trial values of PA-II	Comments
1	Megawatt load	MW	10.0	10.0	
2	Frequency	Hz	50	49.7	
3	Voltage (Generator)	kV	11	11.1	
4	Flow	m3/hr	14580	7253.0	From Boiler trails
5	Flow	TPH	11.48	5.7	*Note
6	Suction Pressure	mmWC$_G$	-	531.8	
7	Discharge pressure	mmWC$_G$	-	977.5	Measured
8	Head developed	mmWC$_G$	700	445.6	
9	PA air temperature	^oC	171	171	
10	PA air density	kg/m^3	0.787	0.787	
11	Motor Efficiency	%	94.2	94.2	
12	Fan motor rated power	kW	45	45	
13	Motor input Power	kW	38.0	37.9	Measured
14	VFD efficiency	%	97	97	
15	Air KW *(Fan hydraulic power)*	kW	27.76	8.79	
16	Power absorbed by Fan	kW	35	35	
17	Combined efficiency		73	23	
18	Fan Efficiency (Effi. 80% is assumed for designed effi., as fan curves are not available)	%	80.00	25.4	
19	Sp. Energy Consumption	kWh/1000m^3	2.38	4.77	
		kWh/ton	3.31	6.64	
20	% margin on flow	%	reference	75.1	
21	% margin on Head	%	reference	36.3	
22	% margin on Power	%	reference	20.7	
23	Throttle Valve condition	% open	VFD	VFD	VFD
24	Speed for Fan -1	Rpm	1480	1380	
25	Speed for Fan -2	Rpm	1480	1380	

5.14.2 Observations for BH-100

➢ s seen, the as-run air flow rate of PA fan II of BH100 is measured to be 7253 m3/hr (@171^{o}C) as against a rated flow rate of 14580m3/hr. The as-run air flow rate is nearly 75% lower than the rated value.

➢ t is also seen that the operating head developed by the fan is 445 mmWC against a rated value of 770 mmWC which again is 36% lower than rated.

➢ n spite of huge margins on flow as well as head, the margin on power in merely 20%, which is indicative of inefficient operation of PA fan-motor system.

➢ he above performance parameters show that the PA fan II of boiler BH100 is performing below par on the efficiency front with an as-run efficiency of around 25.4%. This is very low compared to expected efficiencies of at least 75%.

➢ he fans are operating at 95% of full rated speed through VFD action.

The following table 5.14.2 encapsulates the key rated and operating duty parameters of Boiler-BH-101 PA fan II.

Table 5.14.2: Energy Performance of PA Fan -II Boiler-BH101

S. No	Parameter reference	Units	Rated Value of each fan	As run trial values of PA-II	Comments
1	Megawatt load	MW	10.0	10.0	
2	Frequency	Hz	50	47.4	
3	Voltage (Generator)	kV	11	11.1	
4	Flow	m3/hr	14580	6516.3	From Boiler trails
5	Flow	TPH	11.48	5.1	*Note
6	Suction Pressure	mmWC$_G$	-	559.5	
7	Discharge pressure	mmWC$_G$	-	990.0	Measured
8	Head developed	mmWC$_G$	700	430.5	
9	PA air temperature	^oC	171	171	
10	PA air density	kg/m^3	0.787	0.787	
11	Motor Efficiency	%	94.2	94.2	
12	Fan motor rated power	kW	45	45	
13	Motor input Power	kW	38.0	36.6	Measured
14	VFD efficiency	%	97	97	
15	Air KW *(Fan hydraulic power)*	kW	27.76	7.63	
16	Power absorbed by Fan	kW	35	33	
17	Combined efficiency		73	21	
18	Fan Efficiency *(Effi. 80% is assumed for designed effi., as fan curves are not available)*	%	80.00	22.8	
19	Sp. Energy Consumption	kWh/1000m^3	2.38	5.13	
		kWh/ton	3.31	7.13	
20	% margin on flow	%	reference	77.7	
21	% margin on Head	%	reference	38.5	
22	% margin on Power	%	reference	23.4	
23	Throttle Valve condition	% open	VFD	VFD	VFD
24	Speed for Fan -1	rpm	1480	1380	
25	Speed for Fan -2	rpm	1480	1380	

*Note: *10% of the FD air total flow is considered for PA fan flow (As per CVL the design PA flow is factored at 8.33% of FD flow.*

Table 5.16.1: Performance of air compressors

Parameter Reference	Units	Instrument Air Compressors	Ash Handling Compressors
		Value	Value
Type		Reciprocating	Screw
Make		Chicago Pneumatic	Atlas Cop co
Application		Instrument Air and For operating Hydraulics for opening and closing of Dampers	Ash Handling /removal and conveying of ash from ECO, APH and ESP hopper to Ash Silo
VFD Installed		VFD	no VFD
Compressor motor rating	kW	75	45
Rated Capacity @ 35^{o}C	m^3/hr	581.06	464.4
	Nm^3/hr	515	412
Rated discharge pressures	kg/cm^2(g)	7.7	7.7
Temperature	^{o}C	35	35
Running Hours per day	hrs/day	24	24
Number of compressors		2	2
Number of operating compressors		1	1
Number of standby compressors		1	1
Number of stages in compressor		2	
Speed of compressor	Rpm	731	2965
Cut off pressure	kg/cm^2(g)	7	5
Cut in pressure	kg/cm^2(g)	6.1	4.3
Average load time	seconds	9.23	44.04
	%	88	64
Average unload time	seconds	1.2	24.6
	%	12	36
Load Power	kW	36.85	43.20
Unload Power	kW	19.80	30.20
Average operating Power	kW	34.83	38.54
Specific power consumption (kW/(m^3/hr))	**kWh/m^3**	**0.0599**	**0.0830**

6. RESULTS AND DISCUSSIONS (ENCONS)

6.1 ENCON IN BOILERS

(i) The average boiler heat losses are 23.13 % and 23.37% as against design value of 15.16% and 14.93% for BH100 and BH101 respectively which are a combination of controlled and uncontrollable heat losses.

(ii) The controllable losses like combustible loss in ash, unburnts in flue gas, sensible heat loss to dry flue gas in as run boiler trials are higher at 11.99% and 11.84% as against design of 8.58% and 7.71% in BH100 and BH101 respectively. Based on as-run boiler efficiency trails, it is seen that there is a margin of 7-8% between present boiler thermal efficiency and design efficiency. It is possible through simple practical interventions to improve boiler efficiency by around 2 to 3%.

Table 6.1.1: Rationale of Energy Saving By improving Boiler Efficiency

Present as run average boiler efficiency [(76.87+76.63)/2]	%	76.75
Boiler Efficiency improvement by reducing the stack temperatures to 140°C from existing 160°C.	%	0.8
Boiler Efficiency improvement by reducing carbon monoxide loss in fuel gas to 1%.	%	1
Boiler Efficiency improvement by reducing the heat loss by unburnts in ash to 3% from the existing level of 4.4%	%	1.4
Total boiler efficiency improvement possible	%	3 to 3.2
Savings possible by considering a conservation value of 2.5% improvement in Boiler Efficiency by implement various measures.		
Proposed Average boiler efficiency by controlling above losses (2.5% improvement in Boiler efficiency)	%	79.25
Fuel Savings = (1/76.75%) - (1/79.25%) * 100%	%	4.11
Fuel savings per year (considering 1,06,000 TPY coal consumption)	Tons/ year	4353
Monetary savings @ Rs. 3900 per ton of coal	Lakhs Rs./year	169.8

(iii) The ID fans are equipped with VFD at 50hz and is operating very close to full load RPM (almost 96% of rated RPM). There is very little room left for operating flexibility, in-case of need, as the VFD is at 50Hz and has no scope for any further speed increase. The existing input power of ID fan motor for boilers BH100 & BH101 are 32.77kW & 33.01kW and 32.02kW & 33.57kW respectively. It would augur well, from the point of view of operational flexibility to have a single large fan with a margin of 10% on flow and head, and accordingly size the VFD such that it operates at 75% of its maximum speed capability with ID fan at full rated duty conditions. Due to larger duct diameter and elimination of mismatch of flow distribution, around 20mmWC pressure drop reduction can be expected.

Table 6.1.2: Rationale of Energy saving by changing to Single ID fan with VFD per boiler from present system

Present flue gas flow rate (9kg flue gas/kg coal * 8TPH coal per boiler*2 boilers/0.84kg/m³ flue gas density)	M³/hr	1,71,428
Envisaged pressure drop reduction due changing the 2 fans to single large ID fan (pressure drop reduces due to larger duct diameter and elimination of mismatch of flow distribution)	mmWC	20
Fan Efficiency	%	83
VFD	%	97
Motor Efficiency	%	94
Equivalent input power reduction [(Fluid power reduction/(fan effi.*VFD & Transmission Effi.*motor effici.)]	Kw	12.3
Energy savings per year (@ 7200years per year)	kWh	88,722
Monetary savings (@Rs.5/kWh)	Lakhs Rs./year	4.43
Investment for ID fan with VFD (two fans, one for each boiler)	Lakhs Rs./year	5.6
Simple pay back	Months	15

(iv) The differential O_2 analysis was conducted in the flue gas path between Economizer out and ID fan out and it was found that the O_2 at Eco out, which figured on an average at around 2.5% in both the boilers, increased to around 9% at APH outlet and further to 10% at ID fan outlet. This is a sure indication of false air ingress into the ID fan suction path between Eco out and ID fan in, thus adding unwanted burden on to the ID fan by way of false air ingress. The quantity of false air ingress amounts to around 39TPH (considering average 55TPH as actual air supplied), which around 69 to 71% over and above the actual air quantity that is required to be handled by ID fan. Presently the two ID fan together draw around 66kW which is expended towards handling this excess unwanted ingress air besides the actual flue gas quantity. If at-least 50% of this ingress air is eliminated (by sealing of all possible ingress air points along the flue gas path between Eco out and ID fan in) it would be reduce the combined twin fan power consumption from the existing 66kW by around 12.5kW at full load. The reduction of 12.5kW load on ID fan per boiler amount to a monetary savings of Rs.9.1 Lakhs per annum for two boilers. This would also allow the presently saturated VFD to kick-in and be able to operate the ID fans at lower speeds. The maximum investment of Rs. 2lakhs towards sealing false air ingress would be paid back in around 3 months.

Table 6.1.3: Rationale of Savings by arresting False air ingress in Flue gas path

Average quantity of air ingress per boiler	TPH	39
Density of Flue gas [at 160°C temperature]	Kg/m³	0.84
Average head developed by ID fans	mmWC	150
Fan Efficiency	%	83
VFD	%	97
Motor Efficiency	%	94
Equivalent input power savings per boiler by arresting 50% of false air ingress [(Fluid power reduction/(fan effi.*VFD & Transmission Effi.*motor effici.)]	kW	12.5
Annual energy savings for two boilers (@ 7200 years per year)	kWh	1,80,219
Monetary savings (@Rs.5/kWh)	Lakhs Rs./year	9.01
Investment for sealing false air ingress	Lakhs Rs./year	2
Simple pay back	Months	3

Table 6.1.4: Rationalization of measured values of Air viv-a-vis calculated

Item Reference	Units	BH100	BH101
Coal Consumption rate during boiler trial	TPH	8.32	7.71
A. Based on measurement of Aerofoil flow instrument			
Avg. measured aerofoil DP of total FD air during 6hr Boiler trail	mmWC	108	117.71
Equivalent flow	**TPH**	**50.99**	**53.23**
Specific total air consumption	$kg_{total\ air}$/ $kg_{coal\ burnt}$	6.13	6.90
B. Based on first principles			
Specific theoretical air consumption	kg/kg coal	6.04	5.97
Theoretical air consumption flow rate	TPH	50.28	46.03
Excess air factor at NPC measured O_2 of 5.94% at ECO I/L	[-]	0.394	0.314
Total air as per NPC O2 reading	**TPH**	**70.11**	**60.50**
Specific total air consumption (Based on NPC O_2 %)	$kg_{total\ air}$/ $kg_{coal\ burnt}$	8.42	7.85
Excess air factor at HLL measured O_2 reading of 2.51 % at ECO O/L	[-]	0.136	0.114
Total air as per HLL O_2 reading	**TPH**	**57.10**	**51.28**
Specific total air consumption (Based on HLL O_2%)	$kg_{total\ air}$/ $kg_{coal\ burnt}$	6.86	6.65

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Table 6.1.5: Rationale of Energy Saving By insulating Furnace area of BH 101

Boiler Efficiency improvement by reducing the radiation loss of Boiler BH 101.	%	0.4
Fuel Savings =(((0.4/100)*8TPH coal feed*7200hrs/year	Tons per year	230
Monetary savings [@ Rs. 3900 per ton of coal]	Lakhs Rs./year	8.98
Investment	Lakhs Rs.	4
Simple payback	Months	5

6.2 ENCONS IN TURBINES

Based on the As-Run turbine performance test, the performance parameters of turbine systems are summarized as below:

Table 6.2.1: Rationale for Heat Rate loss of turbine

S. No	Item Reference	Units	Value
1	Average Annual PLF	%	60
2	Average Load	MW	7.4
3	Design load	MW	12.5
4	Average annual Generation	MU	64.68
5	Design Turbine Heat Rate	kCal/kWh	2330
6	As-run Turbine Heat Rate	kCal/kWh	2359
7	Gap In Turbine Heat Rate between design and as-run	kCal/kWh	29
8	Equivalent loss in generation due to increased Turbine Heat Rate. (29*64.68)/(2359)	MU	0.79
9	Achievable Heat Rate Gap reduction target	%	50
10	Avoidable loss generation potential	MU	0.385
11	Equivalent saving in coal consumption (considering 4560 kCal / kg coal CV)	Tons coal per year	197
11	Envisaged Annual monetary benefit @ Rs. 3930/ton coal	Rs.Lakhs	7.7

6.3 ENCONS IN CONDENSER

(i) It is recommended to install an accurate vacuum gauge for regular monitoring of performance. (with mbar reading).

(ii) The CW flow to condenser needs to be enhanced to 2700 CMH (rated condition) by improving the performance of the MCW pumps.

Table 6.3.1 Power savings envisaged by installing air cooled condenser

Avoided power		
Power consumed by MCW pumps (2 no's)	kW	277.00
Annual power consumed by MCW pumps	lakh kWh	19.94
Cost of power	Rs/kWh	5
Annual Monetary savings envisaged through MCW pumps	**Rs in lakhs**	**99.7**
Power consumed by CT fan's (2 no's)	kW	64.23
Annual power consumed by CT fans	lakh kWh	4.62
Cost of power	Rs/kWh	5
Annual Monetary savings envisaged through CT fans	**Rs in lakhs**	**23.1**
Total Monetary savings by Avoiding MCW pumps and CT fans	**Rs in lakhs**	**122.8**
Water savings envisaged by installing air cooled condenser		
Total Make up water added	m^3/day	800
Annual water savings envisaged	lakh m^3	2.4
Purchased Cost of water	Rs/m^3	25
Annual Monetary savings envisaged through water savings	**Rs in Lakhs**	**60**
Total Monetary savings by switching to air cooled condenser	**Rs in Lakhs**	**282.6**
Operating cost involved by switching to air cooled condenser		
Power consumed by air cooled condenser fans	kW	277.89
Annual Power consumed by air cooled condenser fans	Lakh kW	20.01
Cost of power	Rs/kWh	5
Annual power cost for operating air cooled condenser fans	**Rs Lakhs/yr**	**100.04**
Estimated Power consumption by additional booster pump	kW	30.00
Annual power consumed by Additional booster pump	lakh kW	2.16
Cost of power	Rs/kWh	5
Annual Cost towards operating additional booster pump	**Rs in lakhs**	**10.8**
Maintenance cost of fans (estimated)	**Rs Lakhs/yr**	**10.00**
Total Annual operating cost of air cooled condenser	**Rs Lakhs/yr**	**120.85**
Total estimated cost of air cooled condenser	**Rs in Lakhs**	**300**
(Cost of coal based power plant is 4.5 crores/MW, and 5% is the estimated cost of condenser (ref.2009:2010 year).The figures are estimated and has to be checked with detailed engineering study.)		
Estimated annual monetary savings	**Rs in Lakhs**	**161.72**
Pay back period	**years**	1.86

Table 6.3.2: Rationale for energy savings for condenser vacuum

Average plant load	=	7400	kW
Envisaged Annual generation	=	64680000	kWh/yr
Margin available for reduction in unit heat rate on account of condenser vacuum improvement	=	29	kCal/kWh
Conservative estimate of heat rate reduction	=	20	kCal/kWh
Envisaged Annual Energy savings	=	1293600000	kCal/yr
Envisaged equivalent coal input savings @ 4550 kCals/ kg coal, on as fired (to boiler)basis (ADB, 25% M)	=	284308	kgs coal /year
		284	TPY of coal
Envisaged Annual Monetary savings @ Rs.3930/Ton coal	=	11	Rs lakhs/yr
Investment towards additional (20% additional heat transfer area) parallel condenser, MCW pump, piping, condenser cleaning etc	=	20	Rs lakhs
Simple payback period	=	1.79	Years

7.0 RECOMMENDATIONS AND CONCLUSIONS

The energy audit of a cogeneration plant has brought out several options that result in reduction in energy consumption.

Boiler Thermal Efficiency

The method of performance assessment chosen for Boiler evaluation is the indirect method of heat loss and boiler efficiency as per BIS standard 8753. The Thermal efficiencies of the boiler were evaluated at 76.87% against the PG test efficiency of 84.84% for the Boiler BH100 and 76.63% against a PG test efficiency of 85.07% for Boiler BH101. The controllable losses like combustible loss in ash, unburnts in flue gas, sensible heat loss to dry flue gas in as run boiler trials are higher at 11.99% and 11.84% as against design of 8.58% and 7.71% in BH100 and BH101 respectively. Based on as-run boiler efficiency trails, it is seen that there is a margin of 7-8% between present boiler thermal efficiency and design efficiency. It is possible through simple practical interventions to improve boiler efficiency by around 2 to 3%. (Average 2.5%).

Turbine thermal efficiency assessment

The turbine cylinder efficiency was evaluated to be around 86.26% as against the design value of 89.6%. The as-run turbine heat rate has been evaluated at 3074 kCal/kWh, as against the design turbine heat rate of 2743 kCal/kWh and the Rankine cycle efficiency is evaluated at 27.97% as against design efficiency of 31.3%. The as-run heat load on the turbine works out to 28658793 kCal/hr as against the design value of 27539949 kCal/hr.

Economizer Performance

The effectiveness of the economiser is seen to be higher in as-run condition (30% for boiler BH-100 and 29.7% for boiler BH-101, as against design value 28.6%). This is again indicative of the good condition of the economiser and slightly elevated performance, in as-run condition.

This cogeneration plant for textile unit has an overall saving potential of around 34.05 Lakh Units/yr electrical and 5065 Tons of coal per year. Implementing all of the above options is likely to mitigate Green House gas emission equivalent to around 11,334 Tons of CO_2/yr worth 11,334 CER (Certified Emission Reduction) in the International Market as per Kyoto Protocol.

8. FUTURE SCOPE

This thesis report details the methodology for conducting and evaluating energy conservation and audit for a cogeneration plant of 10 MW capacities. In future a comparative study can be done among the captive cogeneration plants of similar capacities with the plants having latest technologies like organic Rankin cycle, ash water reclamation, decentralization of compressed air system, high pressure roller mills, etc.

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