Power Plant Performance Study & Heat Rate Improvement through Energy Audit

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By

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Declaration

This is to certify that

1. The thesis comprises my original work towards the degree of Master of Technology in Mechanical Engineering (Thermal Engineering) at Institute of Technology, Nirma University and has not been submitted elsewhere for a degree.

2. Due acknowledgment has been made in the text to all other material used.

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Undertaking for Originality of the Work

I, Steny R Ghadiyali, Roll. No. 12MMET36, give undertaking that the Major Project entitled "**POWER PLANT PERFORMANCE STUDY & HEAT RATE IMPROVEMENT THROUGH ENERGY AUDIT**" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in Mechanical Engineering (Thermal) of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Abstract

Fossil fuel stack is decreasing day by day and global energy concerns are increasing. Lot of research is going on in development of alternate fuel but till date effective solution is not achieved. In present scenario to last available resources of fuel for longer duration its efficient use is required. One of the approaches in this direction is to measure performance of various equipments using energy and to optimize its performance for conservation of energy. This can be achieved by carrying out energy audit of various equipments. Energy Audit should cover evaluation of the present performance level of all major equipments, identify the controllable losses and suggest remedial measures for improvements with cost benefit analysis and payback period. Performance tests can be carried out using installing high accuracy offline test instruments or using the online plant instrumentation. The primary objective of energy conservation practise is to extract maximum energy from fuel used and to utilize it most effective way in thermal power plant. In power plant energy conservation analysis should be carried out for air compressor, air pre-heater, cooling tower, boiler, turbine, induced draft fan, forced draft fan, condenser and other equipments. In present work energy audit of air compressor and air pre-heater and cooling tower was carried out. For 32 air compressors system analysis was carried out by determining volumetric efficiency, actual isothermal efficiency and specific energy consumption. Based on specific energy consumption these compressors are categorized in poor, satisfactory and good compressors. By controlling leakage losses in three compressors actual isotherm efficiency was improved by 1.23% and specific energy consumption is decreased by 0.03kWh/m^3hr. Effectiveness of air pre-heather is used to measure its performance. In energy audit of air pre-heater by calculating O_2 the leakage can be found and by taking appropriate remedial actions its effectiveness can be improved. In cooling tower, seven cooling tower energy audit carried out and base on that find the effectivness of cooling tower and find out which cooling tower had more water consumption.Also determine exergy anlysis find the secound law efficiency of Auxilary like air compessor, air pre-heater, and cooling tower. Comapred the heat rate of power plant with design heat rate.

Keyword: Energy Audit, Air pre-heater, Air compressor, Cooling tower, Effect of leakage, Heat rate, Exergy Analysis.

Contents

List of Figures

List of Tables

Nomenclature

Q	FAD ($\frac{m^3}{min}$)
Q_f	Corrected FAD ($\frac{m3}{s}$)
r	Pressure ratio
P_1	Absolute intakte pressure ($\frac{kg}{cm^2}$)
P_2	Absolure delivered pressure ($\frac{kg}{cm^2}$)
P_0	Atmospheric pressure ($\frac{kg}{cm^2}$)
t	Load time (min)
T	Unload time (min)
t_1	Ambient air temprature (^{0}C)
t_2	Actual temprature at discharge(^{0}C)
T_{gnl}	Corrected Gas outlet temp for no leakage(^{0}C)
C_{pa}	Specific heat of air ($\frac{kcal}{kg^0C}$)
C_{pg}	Specific heat of gas ($\frac{kcal}{kg^0C}$)
T_{ai}	Temp of air entering to APH (^{0}C)
T_{ao}	Temp of air leaving from APH (^{0}C)
T_{gi}	Temp of gas entring to APH (^{0}C)
T_{go}	Temp of gas leaving from APH (^{0}C)
I	Electrical current (Ampere)
V	Voltage (Volts)
S	Entropy ($\frac{\mathrm{kJ}}{\mathrm{kgK}}$)
m_a	Mass flow rate of air ($\frac{\mathrm{kg}}{s}$)
m_w	Mass flow rate of water ($\frac{\mathrm{kg}}{\mathrm{s}}$)

Greek Symbols

ε_{gas}	Effectivness of gas
ε_{air}	Effectivness of air
φ_{air}	Exergy of air
ψ_{water}	Exergy of water
η_{II}	Secound law efficiency

Abbriviations

FAD	Free Air Delivery
IAC	Instrumental Air Compressor
SAC	Service Air Compressor
PAT	Perform, Achieve & Trade
APH	Air Pre-heater
TPS	Thermal Power Station
SEC	Specific energy Consumption
CT	Cooling Tower
CW	Cooling water
COC	Cycle of Concentration
RH	Relative Humidity
DBT	Dry bulb temprature
WBT	Wet bulb temprature
GCV	Gross Calorific Value

Chapter 1

Introduction

Energy Audit is a technical survey of a plant in which the machine/section wise/ department wise pattern of energy consumption studied and attempts to balance the total energy input correlating with production. As a result of the study the areas where the energy is wastefully used and the improvements are felt, are identified and corrective measures are recommended so that the overall plant efficiency could be improved. Fundamental understanding of the process is essential if we are to improve the overall efficiency of the system.

Performance Improvement in power plants is a high priority within the electric utilities in the new competitive environment. On the other hand, many utilities have downsized and lack experienced staff in the area of performance technology say Energy Audit. In this project is to study Energy Audit Techniques and through which reduction of heat rate and auxiliary power consumptions. This Project includes methodology for heat rate accounting, instrumentation requirements for heat rate monitoring, and key heat rate parameters

1.1 Motivation for project

The PAT Scheme aims to provide incentives to industries to achieve better energy efficiency beyond the specific energy consumption stipulated for each Design Consumer.According to PAT schema Bureau of Energy Efficiency provide target to gsecl Wankbori to reduce 67 kcal/kWh heat rate within four year of span. Present heat rate & targeted heat rate to achieve mention reduction in table 1.1.

For achieving mention heat rate reduction energy audit of various power plant equipment is necessary. “Achievement of the PAT Targets is essential to avoid buying of e-scerts for compliance to the Act in case of non achievement. However all TPS should try to achieve net

Table 1.1: Targets for GSECL WTPS for Heat Rate

BASELINE HR	TARGET NET HR	REDUCTION
2887 kcal/kWh	2820 kcal/ kWh	-67kcal/ kWh

heat rate beyond the targets so that the e-scerts can be earned out of the energy efficiency savings."

1.2 Objective of project

The objective of the work is described below

- Energy audit of Air Compressor, Air preheater, Cooling tower..
- Exergy Analysis
- Heat rate analysis.

1.3 Organization of Report

This report is organized as follows:

Introduction given in chapter-1 which includes energy audit, Objective,motivation for project and organization of Report.Chapter-2 named Literature review contain introduction of energy audit and literature Review. Chapter-3. Result and discussion which include performanse test of energy audit of air compressor and exergy Analysis. Chapter-4 Result and discussion which include performanse test of Energy audit Audit of Air pre-heater and also exergy analysis. Chapter-5 Result and discussion which include perfomanse test of Cooling Tower and exergy analysis.Chapter 6 Its include heat rate Analysis.Chapter 7 Colnclusion and prposed work.

Chapter 2

Literature Review

2.1 Basics of Energy Audit

As per the Energy Conservation Act, 2001, Energy Audit is defined as "The verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption"[1] .

The energy audit is one of the first tasks to be performed in accomplishing an effective energy management program designed to improve the energy efficiency and reduce the energy operating costs of a facility. An energy audit consists of a detailed examination of how a facility uses energy, what the facility pays for that energy, and finally, a recommended program for changes in operating practices or energy consuming equipment that will cost effectively save dollars on energy bills[1].

An energy audit is a technique for identifying energy losses, quantifying them, estimating conservation potential, evolving technological options for conservation and evaluating techno economics for the measures suggested e.g. Assist industries in reducing their energy consumption, To promote energy-efficient technologies among industry sectors, Disseminate information on energy efficiency through training programs and workshops, To promote transfer of energy-efficient and environmental-sound technologies to the industrial sectors in the context of climate change[2].

The energy audits sometimes called an energy surveyor an energy analysis, so that it is not confused with a financial audit. The energy audit is a positive experience with significant benefits to the facility. The term "audit" should be avoided if it clearly produces a negative image in the mind of a particular business, organization, or individual. An energy audit identifies where energy is consumed and how much energy is consumed in an existing facility, building or structure. Information gathered from the energy audit can be used to introduce energy conservation measures or appropriate energy-saving technologies, such as electronic control systems, in the form of retrofits. Energy audits identify economically justified, cost-saving opportunities that result in significantly lowered electrical, natural gas, steam, water and sewer costs. An energy audit, therefore, is a detailed examination of a facility's energy uses and costs that generates recommendations to reduce those uses and costs by implementing equipment and operational changes[2].

2.2 Necessacity of Energy Audit

In any industry, the three top operating expenses are often found to be energy (both electrical and thermal), labour and materials. If one were to relate to the manageability of the cost or potential cost savings in each of the above components, energy would invariably emerge as a top ranker, and thus energy management function constitutes a strategic area for cost reduction. Energy Audit will help to understand more about the ways energy and fuel are used in any industry, and help in identifying the areas where waste can occur and where scope for improvement exists[2].

The Energy Audit would give a positive orientation to the energy cost reduction, preventive maintenance and quality control programmes which are vital for production and utility activities.

Such an audit programme will help to keep focus on variations which occur in the energy costs, availability and reliability of supply of energy, decide on appropriate energy mix, identify energy conservation technologies, retrofit for energy conservation equipment etc. In general, Energy Audit is the translation of conservation ideas into realities, by lending technically feasible solutions with economic and other organizational considerations within a specified time frame. The primary objective of Energy Audit is to determine ways to reduce energy consumption per unit of product output or to lower operating costs. Energy Audit provides a " bench-mark" (Reference point) for managing energy in the organization and also provides the basis for planning a more effective use of energy throughout the organization [3].

2.3 Use of Energy Audit

The purpose of energy audit are listed below[1].

- Clearly identify types and costs of energy use.
- Understand how energy is being used–and possibly wasted.
- Identify and analyze more cost-effective ways of using energy.
- Improved operational techniques.
- New equipment, new processes or new technology.
- Perform an economic analysis on those alternatives and determine which ones are cost-effective for your business or industry.

- Identify the generic design deficiencies.
- Suggest appropriate techniques to conserve energy along with economic.

2.4 Classification of Energy Audit

Type of energy audit has to be performed depends on the following factors. [3]

- Type of energy audit
- Desirability of cost reduction
- Depth of final audit needed

Depending on these factors energy audit can be categorised in two types:

- Preliminary audit
- Detailed audit

Preliminary Audit identifies the immediate need of the plant, such as it[4].

- Establishes the energy consumption of the plant
- Estimate the saving
- Identifies area which require immediate attention
- Identifies areas where detailed study is required
- Preliminary energy audit uses existing, or easily obtained data

Detailed Audit consist of three phases[4].

- Phase i Pre-audit phase
- Phase ii audit phase
- Phase iii Post-audit phase

This type of audit offers the most accurate estimate of energy savings and cost. It considers the interactive effects of all projects, accounts for the energy use of all major equipment, and includes detailed energy cost saving calculations and project cost.

2.5 Use of Energy Audit in TPS

Role of energy audit in TPS is mention below[1].

- Identifies Wastage areas of Fuel, Power and Water & Air Utilization.
- Reduction in cost of generation by implementing findings of EA.
- Increases power generation by efficient utilization of steam in turbine cycle and reduction in Aux Power Consumption.
- Maintenance planning and availability improvement.
- Provides guidance in Loading Sequences of the Units.
- Identification and Rectification of errors in on-line Instruments.
- Leads to reduction in Green House Gases.
- Utilizes specialized services of experienced Engineers.
- Training of O&M staff for Efficient Control of Unit Operation.
- Improves competitiveness by reducing unit generation.
- Creates bench mark for all equipments and systems.
- Fulfills bureau of energy efficiency mandatory requirement of Energy Audit.

2.6 Exergy

Exergy is a measure of the maximum capacity of a system to perform useful work as it proceeds to a specified final state in equilibrium with its surroundings. Exergy is generally not conserved as energy but destructed in the system. In contrast, exergy analysis will characterize the work potential of a system. Exergy is the maximum work that can be obtained from the system, when its state is brought to the reference or dead state (standard atmospheric conditions). Exergy analysis is based on the second law of thermodynamics.[5]

The main objective of the implementation of an exergy-based approach is to find Appropriate trade-offs between fuel use and investment cost or environmental impact, in order to improve a process.

Exergy analysis of the systems, which analyses the processes and functioning of systems, is based on the second law of thermodynamics. In this analysis, the effectiveness of the second law which states the exact functionality of a system and depicts the irreversible factors which result in exergy loss and efficiency decrease is mentioned. Therefore, solutions to reduce exergy loss will be identified for optimization of engineering installations.[6]

The great advantage of exergy calculations over energy calculations is that exergy Calculations pin point exactly where the real losses in processes appear. Furthermore the exergy content stream is a real evaluation of energy it indicates the fraction of energy that really can be used.

2.7 Comparison of Energy and Exergy

Table 2.1: Comapre of Energy and Exergy

Sr no	Energy	Exergy
1	It is subjected to the law of conservation l .	It is destroyed in every real process
2	It is function of the states of the systems under consideration	It is the function of state of the system and of surroundings.
3	It may be calculated on the basis of any assumed reference state.	In this case reference state is imposed by the environment.
4	It is increase with increase in Temperature.	In this case reference state is imposed by the environment.
5	It does not depends on pres- sure for ideal gases.	It depends on pressure.

Chapter 3

Energy Audit of Air Compressors

3.1 Introduction

Air Compressors account for significant use of electrical energy in Indian Industries. They are used in variety of industries to supply process requirements, to operate pneumatic tools and instruments and to meet instrumentation needs. Compressors in thermal power plant normally comprise of Instrument Air Compressor and Plant (Service) Air Compressor. The instrument air is used for control systems, solenoid valves operations, etc. While service air is used for atomization, cleaning, maintenance, general service application, etc. The compressed air system is not only an energy intensive utility but also one of the least energy efficient. Over a period of time, both performance of compressors and compressed air system reduces drastically. The causes are many such as poor maintenance, wear and tear etc. All these lead to additional compressors installations leading to more inefficiency. A periodic performance assessment is essential to minimize the cost of compressed air.

3.2 Literature review

3.2.1 Literature

The present chapter reviews of the work carried out by various investigators on energy Audit and Exergy analysis. The work reviews details of methodology, their relative merits and applications to Thermal power plant. More emphasis is given on the power generation industries to increase the efficiency and Augmentation of power, as it is the main aim of the present study.

Energy Audit of Air compressor is carried according to guideline of BEE. Two method are proposed in BEE Guide line 1. Nozzle method 2.Pump up method. Using pump up method it is possible to find out leakage test factor which affects the performance efficiency[1].

For exergy analysis of reciprocating air compressor a better approach was proposed by Mahmood faezaneh-gord. In this work they show effect of angular speed, discharge pressure on efficiency of compressor. They also carried out exergy analysis of air compressor[7].

3.2.2 Compressed Air System Components

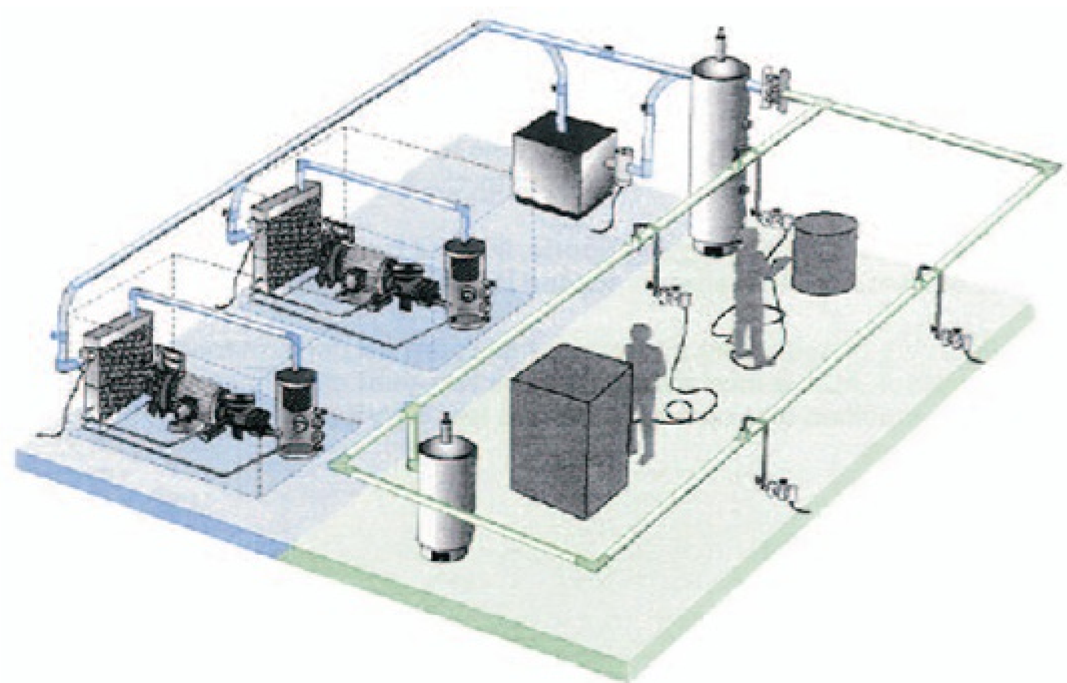


Figure 3.1: Compressed air system[1]

Compressed air systems consist of following major components: Intake air filters, inter-stage coolers, after coolers, air dryers, moisture drain traps, receivers, piping network, filters, regulators and lubricators.

- **Intake Air Filters**: Prevent dust from entering compressor; Dust causes sticking valves, scoured cylinders, excessive wear etc.

- **Inter-stage Coolers**: Reduce the temperature of the air before it enters the next stage to reduce the work of compression and increase efficiency. They are normally watercooled.

- **After Coolers**: The objective is to remove the moisture in the air by reducing the temperature in a water-cooled heat exchanger.

- **Air-dryers**: The remaining traces of moisture after after-cooler are removed using air dryers, as air for instrument and pneumatic equipment has to be relatively free of any moisture. The moisture is removed by using adsorbents like silica gel /activated carbon, or refrigerant dryers, or heat of compression dryers.

- **Moisture Drain Traps**: Moisture drain traps are used for removal of moisture in the compressed air. These traps resemble steam traps. Various types of traps used are manual drain cocks, timer based / automatic drain valves etc.

- **Receivers**: Air receivers are provided as storage and smoothening pulsating air output -Reducing pressure variations from the compressor.

3.2.3 Purpose of the Performance Test

The purpose of performance test is to determine mentioned compressor performance parameter :

- Actual Free Air Delivery (FAD) of the compressor
- Isothermal power required
- Volumetric efficiency
- Specific power consumption

After knowing this parameters actual performance of the plant is to be compared with design/standard value for assessing the plant energy efficiency and necessary remedial action for improvement.

3.2.4 Field Testing

Field Testing of energy audit can be possible by two methods.[1]

- Measurement of Free Air Delivery by Pump Up Method.
- Measurement of Free Air Delivery by Nozzle method.

In this performance test measurement carried out by pump up method also known as receiver filling method. It is not possible to find out free air delivery using nozzle method because nozzle is to be installed in pipe caring compressed air which is not possible in present situation.

WTPS consist of 32 compressor. Energy Audit of these compressor were carried out using pump up method. This WTPS consist of 7 unit name as 1 to 7. Table3.1 gives information about no of air compressor available in each unit. It also provides information about no of compressor are in use and are in stand by.

Table 3.1: Information about compressor in WTPS

Unit No	No of compressor	Compressor in use	Compressor in stand by
1	3	2	1
2	3	2	1
3	3	2	1
4	3	2	1
5	4	2	2
6	4	3	1
7	4	3	1

- Stage 1 of WTPS contains 05 Service Air Compressors.
- Stage 2 of WTPS contains 05 Service Air Compressors.

3.2.5 Measuring instruments for Energy Audit.

The following instruments were used during Energy Audit.

(A) 3 Phase Power Analyzer

This instrument shown in fig 3.2 is used for measuring the electrical parameters like V, I, PF, kW, Hz, etc. and power quality. It is also having data logging and storage facility. It can measure both single phase and 3- phase power. It is possible to measure voltage up to 600 volts and ampere up to 1000 A. Accuracy of this instrument is 0.6%. It has facility to measure energy in kWh to compute the specific energy consumption.

Figure 3.2: 3 Phase Power Analyzer

(B) Pressure Gauge

This instrument shown in figure 3.3 is used for measuring pressuere of air. It is having capacity to measure pressure upto 10 kg/cm^2. Accuracy of this instrument is 0.5%.

Figure 3.3: Pressure Gauge

(C) Digital Temperature Indicator

This instrument is showing figure3.3 is use for measuring the temperature. It is contact type digital temperature indicator. It range is 0 to 1200 ^{0}C. Its accuracy is 0.5% .

Figure 3.4: Digital Temperature Indicator

(C) Digitial Stop watch

Digital stop watch is used for measuring the time during loading and unloading reciver tank.

3.2.6 Test procedure of energy audit

- The measurements were made for the performance test by using pump-up method (free air delivery Test) while plants were shut down.
- The compressor was isolated with its individual receivers for the test from compressed air delivery system by tightly closing the isolation valves.
- Pressure can be measure using pressure gauge installed on the receiver.

- Receiver was made completely empty before starting the test.
- Initial pressure was set in receiver to 0.4 kg/cm^2 by filling the receiver.
- Compressor was then started with stopwatch activated and was allowed to run until the final pressure was achieved 7 kg/cm^2. Simultaneously energy consumption for that time period was also measured using 3-phase power analyzere.

3.3 Data Collection

Table 3.2 to 3.6 provides information of design data of air compressor intercooler, air receivers, air driers, motor respectively.

Table 3.2: Air compressors[8]

Location	0.0 M
Total Numbers	03 Per Unit (02+01)
Manufacturer	M/s K. G. Khosla Compressor Ltd.
Type	2 HA. 2 QT, Horizontal balanced opposed, Double Acting, Non Lubricated
Rated Speed	658 rpm
Rated Discharge Pressure	8.1 kg/cm^2
Compressor Design Flow	16.07m^3/min
Capacity	944.6 Nm^3/hr
Volumetric Efficiency	83.3%

Table 3.3: Inter Coolers[8]

Total Nos.	01 per compressor
Type	Shell and Tube Type
Capacity	944.6 m^3/hr
Cooling Water Quantity	3.3m^3/hr
Working Pressure on each shell and tube side	2 kg/cm^2
Design Pressure on each shell and tube side	5 kg/cm^2 and 8 kg/cm^2 respectively

Table 3.4: Air Receivers[8]

Total Nos	Two Per Unit (Inter Connected)
Type	Vertical,Cylinder with welded dished ends
Capacity	4.5 m^3
Design Pressure	10.125 kg/cm^2
Diameter and Height	1200 mm x 3670 mm

Table 3.5: Air driers [8]

Location	Near Air Compressor
Total Nos.	02 per Unit (1+1)
Make	CHEMECH Engineers
Type	Fully Automatic Blower reactivated
Rated Capacity at Specified Pressure	750 Nm^3/hr
Maximum Capacity at given inlet condition	800 Nm^3/hr
Inlet Pressure	8.1 kg/cm^2
Inlet Temperature	45^0C
Relative Humidity	100%
Design Pressure	10.124 kg/cm^2
Absorption Cycle	06 hours

Table 3.6: Motor[8]

Make	M/s Kirlosker Elect. Co.
Rating	98 kW
Full Load Current	172 A
Voltage	415 V
Speed	1490rpm

3.4 Performance test measured data & Result

Data of performance test were taken for 32 comoressor detail of it is mentioned in appendix A.

- Unit 01 of WTPS has 03 Instrument Air Compressors, out of which 02 are in operation and 01 is standby.
- The Test was conducted by keeping two receivers in line.

Table 3.7: Measured parameters

Sr. No	Parameters	Unit	IAC-1
1	Initial air receiver pressure (P_1)	kg/cm^2	0.4
2	Final air receiver pressure(P_2)	kg/cm^2	7
3	Final air temperature at receiver (t_2)	^{0}C	37
4	Barometric pressure (P_0)	kg/cm^2	1.026
5	Ambient temperature (t_1)	^{0}C	32
6	Load time (T)	Min	4
7	Unload time(t)	Min	40
8	Time taken to reach final air receiver pressure	Min	5.81
9	Volume of the pipe and fittings	M^3	0.37
10	Total volume Receiver plus Pipe fittings (V)	M^3	9.57

Table 3.8: Instantaneous Power

Sr no	Parameters	Unit	IAC-1A
1	Voltage	V	421
2	Current	A	139
3	Power factor	-	0.87
4	Energy consumed during run	kWh	8.529
5	Power	kW	88.08

3.4.1 Calculation Procedure to find out performance parameter

(A) Percentage of leakage

$$\frac{T}{T+t} * 100 \tag{3.1}$$

here,

T = Loading time (min)

t = Unload time (min)

(B) Leakage correction factor

$$\frac{Percentage\, of\, leakage + 100}{100} \tag{3.2}$$

(C) Free air delivery

$$Q = \frac{P_2 - P_1}{P_0} * \frac{V}{T} \tag{3.3}$$

here,

P_2 is final pressure after filling (kg/cm^2)

P_1 is initial pressure after bleeding (kg/cm^2)

P_0 is atmospheric pressure (kg/cm^2)

V is volume of receiver and connected pipe (m^3)

T is time taken to build pressure from$P_1$to P_2 (min)

Capacity of a compressor is the full rated volume of flow of gas compressed and delivered at conditions of total temperature, total pressure, and composition prevailing at the compressor inlet. It sometimes means actual flow rate, rather than rated volume of flow. This also termed as **Free Air Delivery (FAD)** i.e. air at atmospheric conditions at any specific location. Because the altitude, barometer, and temperature may vary at different localities and at different times, it follows that this term does not mean air under identical or standard conditions.[2]

(D) Temperature Correction Factor

$$\frac{t_1 + 273}{t_2 + 273} \tag{3.4}$$

here,

$t_1$is the ambient air temperature (^{0}C)

t_2 is the actual temprature at discharge (^{0}C)

(E) Corrected free air delivery

$$Q_f = (FAD * Temp. corr. factor * leakge\, corr.factor) \tag{3.5}$$

(F) Isothermal power =

$$Isothermal\, Power = \frac{P_0 * Q_f * \ln r}{36.7} \tag{3.6}$$

here

r = Pressure ratio P_2/P_1

Q_f=Corrected Free air delivered m^3/hr

P_1= Absolute intake pressure kg/cm^2

P_2= Absolute deliverd pressure kg/cm^2

P_0= Atmospheric pressure kg/cm^2

Isothermal power is defined by least power required to compress the air assuming isothermal condition.

(G) Volumetric efficiency

$$Volumetric\, efficiency = \frac{Corrected\, FAD}{Compressor\, flow} \tag{3.7}$$

(H) Specific energy consumption

$$Specific energy consumption = \frac{Power}{Corrected FAD} \tag{3.8}$$

(I) Isothermal Efficiency

$$Isothermal efficiency = \frac{Isothermale Power}{Actual measered Input power} \tag{3.9}$$

(J) Actual Isothermal Efficiency

$$Actual Isothermal Efficiency = \frac{Isothermal Efficiency}{Motor Efficiency} \tag{3.10}$$

Motor Efficiency was considered 93% for calculation of isothermal efficiency of compressor.

3.4.2 Result of compressor performamnce

Above calculation results for arecompressor is mentioned in table3.9 and other 32 air compressors result given in appendix A.

Table 3.9: Calculated parameters

Sr no	Calculated parameters	Unit	IAC -1A
1	Percentage of leakage	%	9.09
2	Leakage correction factor	_	1.091
3	Free air delivery (Q)	$\frac{m^3}{min}$	10.59
4	Temperature correction factor	_	0.9383
5	Corrected free air delivery(Q_f)	$\frac{m^3}{min}$	11.37
6	Isothermal power	kW	39.29
7	Volumetric efficiency	%	70.76
8	Specific energy consumption	kWh/m^3/hr	0.129
9	Isothermal efficiency	%	44.60
10	Actual Isothermal efficiency	%	47.93

3.5 Exergy analysis of Air compresor

Exergy analysis of compressor is show here. Assume that kinetic energy and potential energy is neglected in this analysis.

Exergy balance For the compressor:[5]

$$\eta_{II} = \frac{m \star (a_{f2} - a_{f1})}{W} \tag{3.11}$$

Table 3.10: Measured data for exergy analysis

Parameter	Unit	IAC-1
T_o	K	300
T1	K	305
T_2	K	310
P_2	Bar	7
P_2	Bar	1
m	kg/s	0.2367
W	$\frac{\text{kJ}}{\text{S}}$	88
C_{pa}	$\frac{\text{kJ}}{\text{KgK}}$	1.005
R	$\frac{\text{kJ}}{\text{kgK}}$	0.287

$$a_{f2}\text{-}a_{f1}=h_2\text{-}h_1\text{-}T_0\text{-}(s_2\text{-}s_1) \tag{3.12}$$

$$a_{f2}\text{-}a_{f1} = C_{pa}(T_2\text{-}T_1)\text{-}T_0(C_{pa}\ln\ \tfrac{T_2}{T_1}\text{-}\mathrm{R}\ln\tfrac{P_2}{P_1}) \tag{3.13}$$

a_{f2}-a_{f1}=1.005*(310-305)-300(1.005*ln$\frac{310}{305}$- 0.287 ln$\frac{7}{1}$)

=269.025$\frac{\text{KJ}}{\text{kg}}$

η_{II}=$\frac{m*(af2-af1)}{W}$*100

=$\frac{0.2368*269.025}{88}$*100

η_{II}=44.18%

3.6 Suggestions for performance improvement

Performance of volumetric efficiency, isothermal efficiency and specific energy consumption of 32 compressor available in WTPS is graphically represented through figure 3.5 to 3.7.

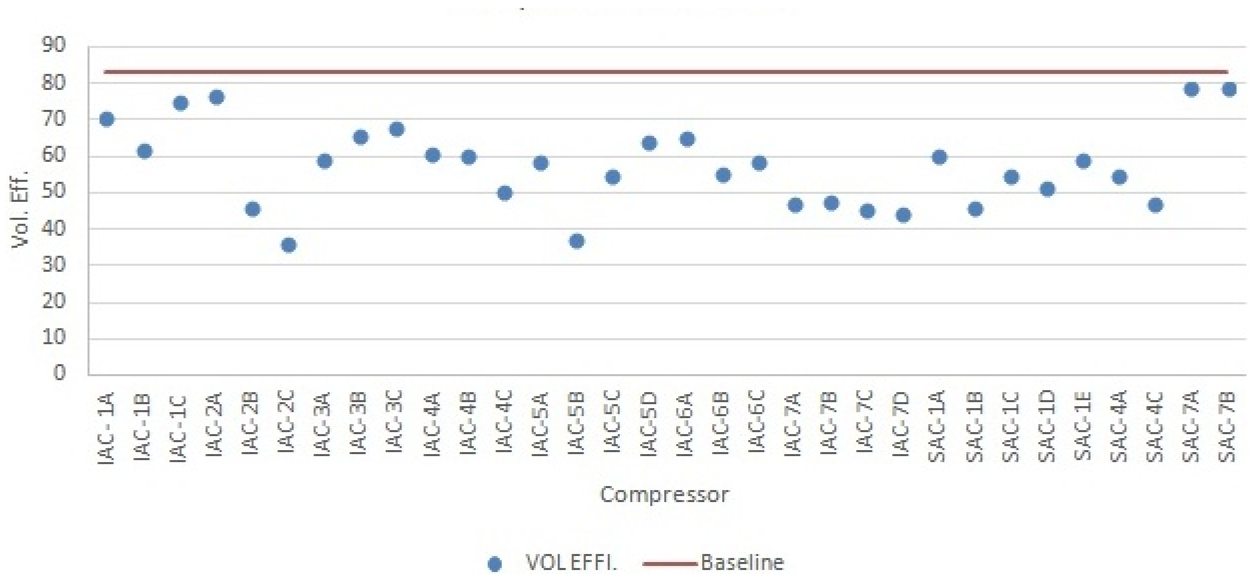


Figure 3.5: Compressor Vs Volumetric efficiency

Base on figure 3.5, it can be observed that are compressor of WTPS are having volumetric efficiency lower than design efficiency shows on base line in figure 3.5. Reasons for less performance of volumetric efficiency may be loosen belt and cylinder head leakage and due to excessive life.

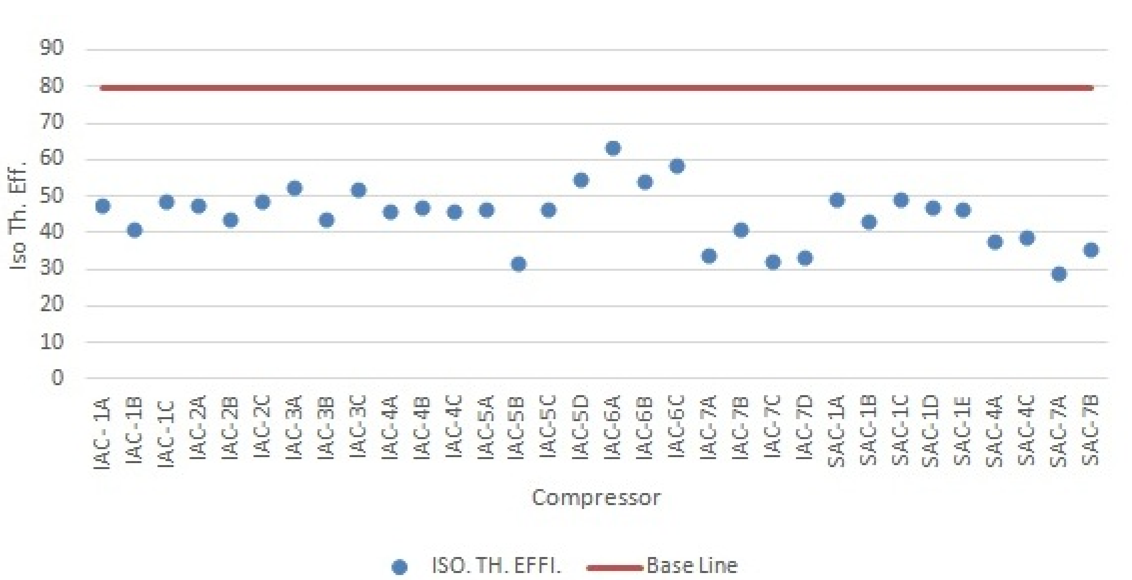
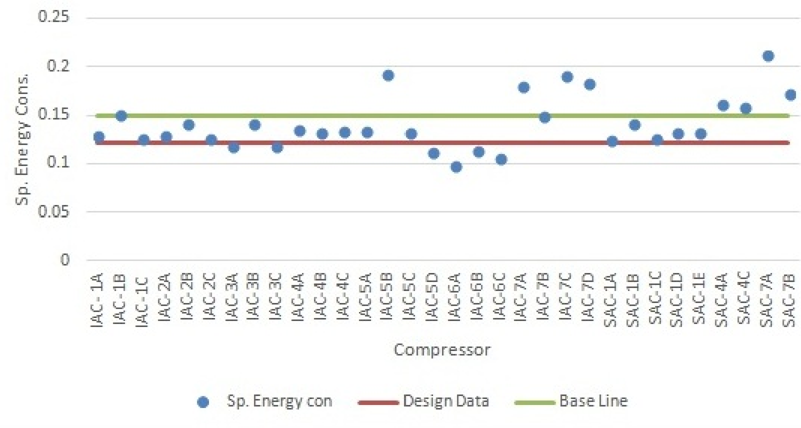


Figure 3.6: Compressor Vs Isothermal Effciency

As shown in figure 3.6 all 32 compressor isothermal efficiency is lower than base line efficiency. As a part of remedial action, it is recommended to carry out proper cleaning of intercooler.



0.15 to 0.12

Figure 3.7: Compresssor Vs Specific energy consumption

As show in figure3.7 its graph of 32 Compressor Vs Specific Energy consumption.Table 3.9 shows performanse of various compressor based on design data(SEC 0.12) and base line data(SEC 0.15).

Table 3.11: Compressor Performance

SEC	Compressor Name	Remark
Greater than 0.15	• IAC-5B, IAC-7D, IAC-7A, SAC-4A, SAC-4C, SAC-7A, SAC-7B	Poor
	• IAC-1A,IAC-1B,IAC-1C,IAC-2A,IAC-2B,IAC-2C,IAC-3A,IAC-4A,IAC-4B,IAC-4C,IAC-5A, IAC-5C, IAC-7A , IAC-7B , SAC-1B, SAC-1C , SAC-1D ,SAC-1E	Satisfactory
Less than 0.12	• IAC-3A,IAC-3C, IAC-5D, IAC-6A,IAC-6B, IAC-6C	Good

Classification of compressor based on Specific energy consumption performance is given in table 3.11. It can be observed from table 3.11 that very few compressors are having performance batter than the design performance. Most of them having satisfactory performance.

3.7 Result

According to analysis given in table 3.11 it has found that performance of many compressor poor. Reason for the moderated performance is also mention. For performance improvement study, in unit 2 one of compressor corrective action are taken to control leakage.Effect of leakage correction on performance of compressor parameter is listed in table 3.12

Table 3.12: Result (Unit -2 IAC-2A)

Sr no	Calculated parameters	Unit	Design	Audit phase	Post-audit phase
1	Percentage of leakage	%	0	9.09	7.97
2	Leakage correction factor	_	1	1.09	1.07
3	Free air delivery	$\frac{m^3}{min}$	13.38	11.57	11.83
4	Temperature correction factor	_	1	0.97	0.98
5	Corrected free air delivery	$\frac{m^3}{min}$	13.38	12.38	12.57
6	Isothermal power	kW	46.09	42.80	43.45
7	Volumetric efficiency	%	83.3	77.09	78.25
8	Specific energy consumption	kWh/m^3/hr	0.122	0.129	0.126
9	Isothermal efficiency	%	74.21	44.50	45.64
10	Actual Isothermal efficiency	%	79.80	47.85	49.08

It can be observed that due to corrective action isothermal efficiency are improve and specific energy consumption is decrease.

3.8 Discussion

The compressed air system is not only an energy intensive utility but also one of the least energy efficient.Over a period of time, both performance of compressors and compressed air system reduces drastically.The causes are many there are leakge of system, poor maintenance of intercooler, after cooler. So cleaned intercooler and after-cooler elements and remove scale and sludge. Due to irregular maintains and large percentage of leakage through the system has lead to decrease in volumetric efficiency and isothermal efficiency and hence these leads to increase in specific energy consumption.

Chapter 4

Energy Audit of Air Pre-heater

4.1 Introduction

Air pre-heater is one of the critical equipment in the boiler and its performance has direct affect on boiler efficiency. Air pre-heater transfer heat from flue gas to air by rotors enters the flue gas side. Figure alongside show a means of a rotary matrix in which heat is absorbed by principle sketch of the pre-heater.

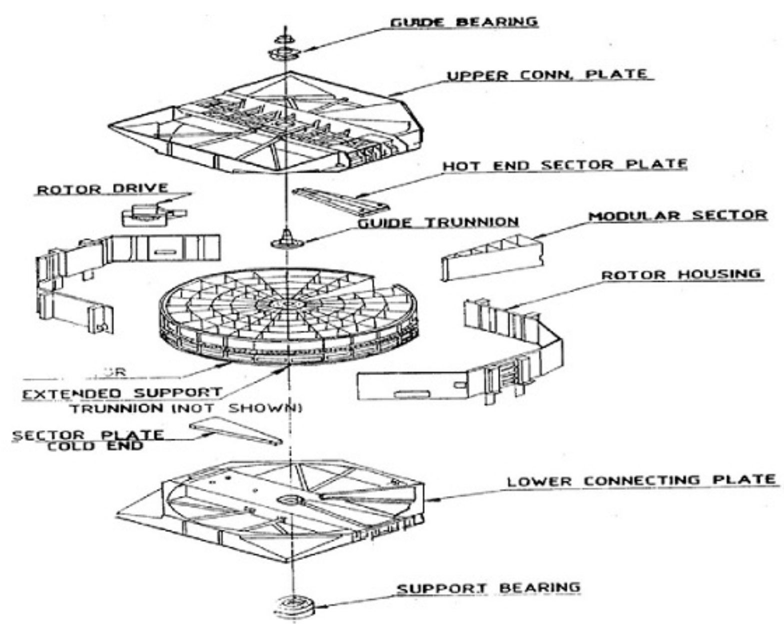


Figure 4.1: Lungstrom air pre-heater[2]

The lungstrom regenerative air pre-heater absorbs waste heat from flue gas and transfer this heat to incoming cold air by means of continuously rotating heat transfer elements of specially formed metal sheets. Thousands of these high efficiency elements are spaced and compactly arranged within so many sector shaped compartments. As the rotor slowly revolves the mass of the elements alternatively through the air and gas passages, heat is absorbed by the elements surfaces passing through the hot gas stream; then, as the same surfaces are carried through the air stream. They release the stored up heat thus increasing the temperature of the incoming air.

4.1.1 Air Pre-heater working principle

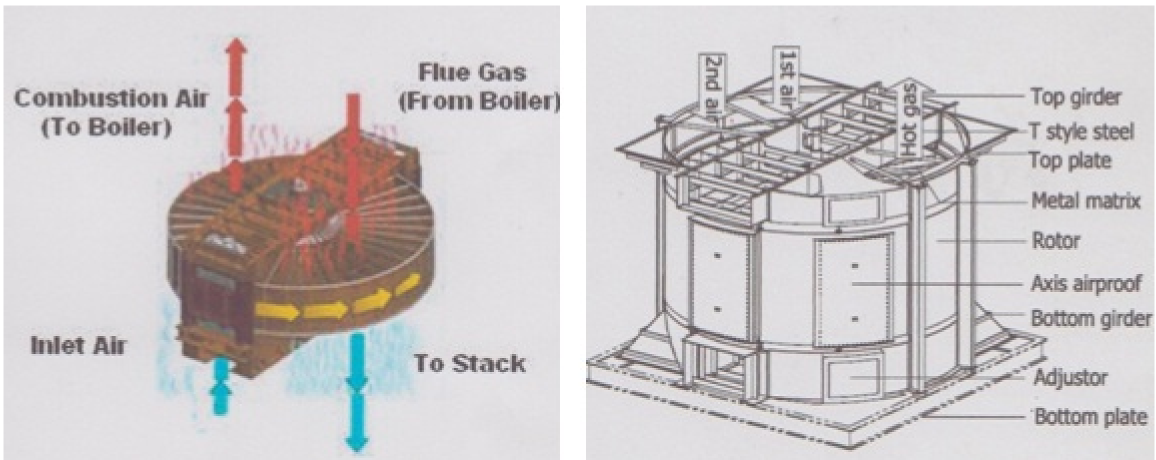


Figure 4.2: Principle of Air pre-heater[9]

Air pre-heater transfer heat from flue gas to air side by rotor enters the flue gas side, figure alongside shows a means of rotary matrix in which heat is absorbed by principle sketch of air pre-heater. The heating element passing through the hot gas stream and transferred to the combustion air stream. As leakage increase, more and more air enters the flue gas path.

As a result, equipment down stream of air pre-heater have to handle increased mass of the flue gas and heanse fans consumed more power. Increased power consumption affects net heat rate. Seal are provide to avoid radial leakage, periphery leakage, and also the axial leakage.

4.2 Literature review

4.2.1 Literature

Energy Audit of Air pre-heater is carried out according to guideline BEE. In this guide line mentioned the methodology of find effectiveness of air pre-heater. It is also possible to find out the percentage of leakage use of measuring O_2 at inlet and outlet of Air and Gas side [1].

A better Approach of find effectiveness of Air preheater by Bostjan Drobnic. In this research paper study of a combination of fluid dynamics and a newly developed three-dimensional numerical model for heat transfer as the basis for a theoretical analysis of a rotary air pre-heater. Special attention was focused on the influences of leakages on the flue-gas parameters in the pre-heater. The numerical analysis and the experimental results showed an obvious dependence of the flue-gas parameters on various seal settings[10].

And also report carried out on Air pre heater by Mr.A.R.Kulkarni, Performance Improvement of Regenerative Air pre-heater. In this report study of most common problem associate with Air pre-heater are Seal leakage, Erosion of heating element at inboard side of HOT end & Cold end side. Also study of poor performance of Air pre-heater, loss in boiler efficiency and reduction in generation due to lost margin of I.D fans[9].

4.2.2 Advantages by use of Air pre-heater

- Stability of Combustion is improved by use of hot air.
- Intensified and improved combustion.
- Permitting to burn poor quality coal.
- High heat transfer rate in the furnace and hence lesser heat transfer area requirement.
- Less un-burnt fuel particle in flue gas thus combustion and both r efficiency is improved.
- Intensified combustion permits faster load variation and fluctuation.
- In the case of pulverised coal combustion, hot air can be used for heating the coal as well as for transporting the pulverised coal to burners.
- This being a non-pressure part will not warrant shut-down of unit due to corrosion of heat transfer surface which is inherent with lowering of flue gas temperature.

4.2.3 Major loss in Air pre-heater

- Air ingress through seals
- Temperature gain difference
- Pressure drop across air pre-heater

4.2.4 Measuring instruments required for test

(A) Flue Gas analyzer

Figure 4.3: Flue Gas Analyzer

- This instrument show in fig4.3 which is used for combustion analysis of boilers, Air pre-heater, furnaces, etc. It s can Measures O_2,CO_2,CO, flue temperature, excess air, etc. Its resolution is 0.1% .Its accuracy is 0.2 %
- (B) **Manometer**

Figure 4.4: Manometer

Manometer is use for measuring pressure. Its range is 0 to 3500 mm H_2O. Its accuracy is 0.2 %. And resolution is 1mm of H_2O.

4.3 Test Procedure

4.3.1 Test set up- operating condition of test runs

The operating conditions for energy audit of air pre-heater are as follows[2].

- No furnace or air heater soot blowing is done during the test.
- Unit operation is kept steady for at least 60 minutes prior to the test.
- Steam coil air heater (SCAPH) steam supply is kept isolated.
- No mill change over is done during the test.
- All air and side damper position should be checked during the test period.
- The test is abandoned in case of any oil support during the test period.
- Regenerative heater should be in service with normal drip cascading.

4.3.2 Test duration

For energy audit air pre-heater would be of Four -hour duration, subject to the completion of measurement and sampling at various locations.Two separate test crews sample the gas/air inlet and outlet ducts simulation.

4.3.3 Traverse location

4.3.3.1 Gas side

- The gas inlet traverse plane is located as close as possible to the air heater inlet. This is done to ensure that any air ingress from the intervening duct/expansion joints is not included in air pre-heater performance assessment [2].
- The gas outlet traverse plane is located at a suitable distance downstream the air pre-heater to allow mixing of the flow to reduce temperature and O_2 stratification[2].

4.3.3.2 Air side

- The air inlet traverse plane is located after air heating coils and as close as possible to the air heater inlet. Since the entering air temperature is uniform, a single probe with 2 temperature measurement points in each duct is used for measurement[2].
- The air outlet traverse plane is located at suitable distance downstream the air heater to allow mixing of the flow to reduce the gas stratification. A grid of six measurement points in each duct is used to measure the temperature[2].

4.3.4 Measurement location

Exhaust gas analysis for gas and temperature probe is used to measure parameter at following location.

Table 4.1: Measurement location[9]

Measurement	Temperature	Gas analyses
APH Gas inlet	Yes	Yes
APH Gas outlet	Yes	Yes
APH Air inlet	Yes	No
APH air outlet	Yes	No

4.3.5 Flue Gas Composition & Temperature

- A representative value of flue gas composition (O_2) is obtained by grid sampling of the flue gas at multiple points in a plane perpendicular to the flow at air heater inlet and outlet using a portable gas analyzer. Two complete sets of data are collected for each traverse plane during each test run to ensure data repeatability.
- A typical cross section of the flue duct with an 18-point grid is shown in figure 4.5. Each dot indicates a sampling point for measurement of gas composition and temperature.

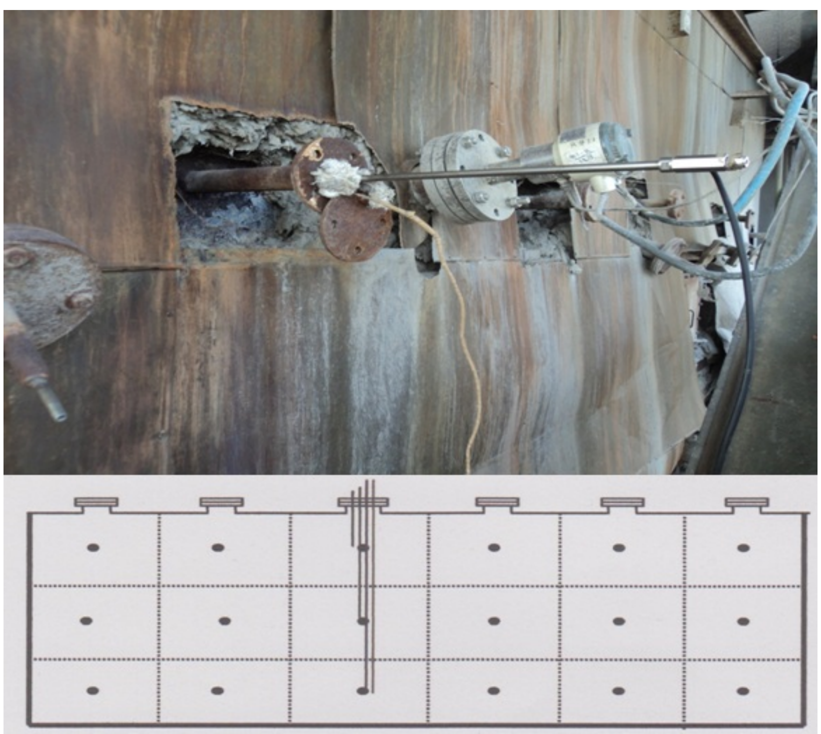


Figure 4.5: Grid measurement[9]

For the grid measurement, single tube probes with portable analyzers are used for traversing duct cross-section. Marking /etching is done on the sampling tubes at D/6, D/2 & 5D/6, if D is the duct depth. The probe is inserted in each port and measurement recorded are at different depth as per marking. Temperatures of flue gas are also measured at the same location using a similar tube temperature probe.

4.3.6 Caluculation

(A) Flue Gas side tempreature drop

$$Flue\,Gas\,Side\,temperature\,Drop = (T_{go} - T_{gi}) \tag{4.1}$$

(B) Air Side temprature drop

$$Air\,side\,temprature\,drop = (T_{ai} - T_{ao}) \tag{4.2}$$

(C) Air Leakage

$$\%\,of\,Air\,leakage = \frac{O_{2outlet} - O_{2inlet}}{21 - O_{2outlet}} \tag{4.3}$$

Air leakges are measured by comaring oxygen content of the flue gas entering and leaving air pre-heater.Air leakage in APH is weight of air passing from the airside to gas side of the air heater. This is an indicator of the condition of the air heater's seals, as the air heater seals wear, air heater leakage increase. The increase in air heater leakage increases the power requirements of the forced draft and induced draft fans, increasing the unit net heat rate and possibly limiting the unit capacity[1].

(D) Corrected Flue gas outlet Temperature from APH

$$Tgnl = \frac{AL * C_{pa} * (T_{go} - T_{ai})}{C_{pg}} + T_{go} \tag{4.4}$$

Here,

T_{gnl}= Gas outlet temperature corrected for no leakage (^{0}C)

C_{pa}= Specific heat of air ($\frac{\text{Kcal}}{\text{kg}^0\text{C}}$)

T_{ai}= Temperature of the air entering the APH (^{0}C)

T_{ao}= Temperature of the air leaving the APH (^{0}C)

T_{go}= Temperature of the gas leaving the APH (^{0}C)

C_{pg}= Specific heat of gas ($\frac{kcal}{kg^0C}$)

Temperature drop is obtained by subtracting the corrected gas outlet temperature from the inlet. Temperature head is obtained by subtracting air inlet temperature from gas inlet temperature. The corrected gas outlet temperature is defined as the outlet gas temperature for no air leakage.[1]

(E) Computed Effectiveness Flue Gas Side

$$\varepsilon_{gas} = \frac{T_{gi} - T_{go}}{T_{gi} - T_{ai}} \tag{4.5}$$

The gas side efficiency is defined as the ratio of the temperature drop, corrected for leakage, to the temperature head and expressed as percentage.

(F) Computed Effectiveness of Air Side

$$\varepsilon_{air} = \frac{T_{ao} - T_{ai}}{T_{gi} - T_{ai}} \tag{4.6}$$

4.4 Measurement set up

Figure 4.6: Set up of APH Audit

4.5 Measured Data

As listed in table4.2 measured data during energy audit of air pre-heater.

Table 4.2: Measured parameter of APH

Sr no	Measured Parameter	Unit	Design	APH A		APH B	
				PAPH	SAPH	PAPH	SAPH
1	Load	MW	210	210		210	
2	Air inlet temperature to APH	^0C	38	38	35	38	35
3	Air Outlet Temperature from APH	^0C	322	264	264	265	250
4	Gas Inlet Temperature to APH	^0C	345	327		327	
5	Gas Outlet Temperature from APH	^0C	141	153.25		172.5	
6	Gas Inlet Oxygen at APH Inlet	%	3.53	3.48		2.47	
7	Gas Outlet Oxygen at APH Outlet	%	4.82	5.41		3.63	
8	Air side pressure Drop	mmWC	64	70	70	70	70
9	Flue gas side pressure Drop	mmWC	169	110		108	

4.6 Calculated parameter

Table 4.3: Calculated parameters

Sr no	Parameters	Unit	Design	APH A		APH B	
				PAPH	SAPH	PAPH	SAPH
1	Flue Gas Side Temperature Drop	^0C	204	173.75		154.5	
2	Air Side Temperature Pick-up	^0C	284	226	229	227	215
3	Corrected Flue gas Temperature from APH	^0C	244	167.17	168.7	181.26	181.46
4	% of Air Leakage	%	8	12.38		6.68	
5	Computed Effectiveness Flue Gas Side	%	66.44	55.3	54.61	50.43	49.84
6	Computed Effectiveness Air Side	%	92.50	78.20	78.42	78.55	73.63
7	Air Side Pressure Drop	mmWC	64	70	70	70	70
8	Flue Gas Side Pressure Drop	mmWC	169	110		108	

4.7 Recommendation to control reduce leakage

Figure 4.7: Insulation of APH

• Figure 4.7 represented condition of insulation of middle and corner portion. It can be observed that insulation structure along with body of air pre-heater is damage. Through this opening air operating air intake take place which decrease performance of air pre-heater.

Figure 4.8: Damage of APH

• Measurement of O_2 % at various locations identify the leakages. These will reduce mass flow of gas and in turn reduction of outlet temperature.

4.8 Exergy analysis of Air Pre-heater

As shown in figure 4.9 line diagrame of Air pre-heater.

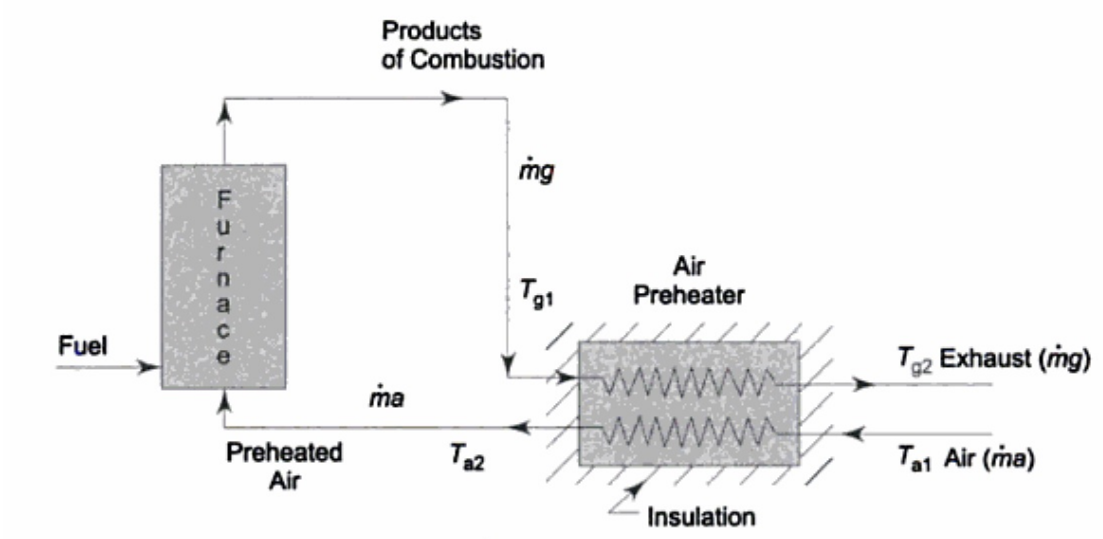


Figure 4.9: Air Pre-heater sketch[5]

As show in table4.4 data taken during energy audit of energy audit of air pre-heater.

Table 4.4: Data related Exergy Analysis

Parameter	Unit	APH-2
T_{a1}	K	308
T_{a2}	K	519
T_{g1}	K	600
T_{g2}	K	426.25
T_O	K	300
m_a	T/hr	672
m_g	T/hr	988

$$(\psi_{g1}\text{-}\psi_{g2})=(h_{g1}\text{-}h_{g2})\text{-To}(S_{g1}\text{-}S_{g2}) \tag{4.7}$$

$$(\psi_{g1}-\psi_{g2}) = C_{pg}(T_{g1}\text{-}T_{g2})\text{-}T_0 * C_{pg} * ln\frac{T_{g1}}{T_{g2}} \tag{4.8}$$

$=1.0465(600\text{-}426.25)\ \text{-}300{*}1.0465{*}\ln\frac{600}{426.25}$

$=74.48\frac{\text{kJ}}{\text{kg}}$

$$Exergy\,transfer\,by\,gas = m_g(\psi_{g1}\text{-}\psi_{g2}) \tag{4.9}$$

$=672{*}10^3{*}74.48$

$=73.57*10^6 \frac{\text{kJ}}{\text{hr}}$

$$(\psi_{a2}\text{-}\psi_{a1})=(h_{a2}\text{-}h_{a1})\text{-To}(S_{a2}\text{-}S_{a1}) \tag{4.10}$$

$$(\psi_{a2}-\psi_{a1}) = C_{pa}(T_{a2}\text{-}T_{a1})\text{-}T_o\text{*C}_{pa}\text{*}ln\frac{T_{a2}}{T_{a1}} \tag{4.11}$$

$=1*(519\text{-}308)\text{-}300*1*\ln\frac{519}{308}$

$=55.54\ \frac{\text{kJ}}{\text{kg}}$

$$Exergy\,gain\,by\,air = m_a*(\psi_{a2}\text{-}\psi_{a1}) \tag{4.12}$$

$=\ 55.54*672*10^3$

$=36.96*10^6 \frac{\text{kJ}}{\text{hr}}$

$$\eta_{II}{=}\frac{Exergy\,gain\,by\,air}{Exergy\,transfer\,by\,gas}*100 \tag{4.13}$$

$=\frac{36.39*10^6}{73.57*10^6}*100$

$\eta_{II}=50.23\%$

4.9 Result

Figure 4.10: Air Pre-heater Performance

Calculated Result (Average of all pre – heaters)			
Sr. no	Performance indicator	Unit	Average Value
1	Effectiveness based in F.G side	%	52.55
2	Pressure Drop across APH F.G Side	mmWC	109.00
3	Pressure Drop across APH Air Side	mmWC	70.00
4	Percentage air leakage	%	9.53
5	Corrected outlet F.G. Outlet temp	^{0}C	174.38
6	Secound law efficiency	%	50.23

4.10 Discussion

The Regenerative Air Pre-heater is the only auxiliary equipment in the power boiler application through which both the gas & air pass through and the leakage is inherent due to pressure differential. As the age of the Air Pre-heater goes by, the erosion of components will result into more leakage and deterioration in performance of Air Pre-heater. In present Air pre-heater some part of the insulation is been damage which has result into gap through which air is ingress and effectiveness of APH is decreased to great extent.

Chapter 5

ENERGY AUDIT OF COOLING TOWER

5.1 INTRODUCTION

Cooling towers are a very important part of Thermal plants. The primary task of a cooling tower is to reject heat into the atmosphere. Cooling Tower is a device for reducing the temperature of a liquid, usually water, by bringing it into contact with an air stream where a small portion of the liquid is evaporated and the major portion is cooled. They represent a relatively inexpensive and dependable means of removing low-grade heat from cooling water. The make-up water source is used to replenish water lost to evaporation. Hot water from heat exchangers is sent to the cooling tower. The water exits the cooling tower and is sent back to the exchangers or to other units for further cooling. Typical closed loop cooling tower system is shown in Figure5.1.

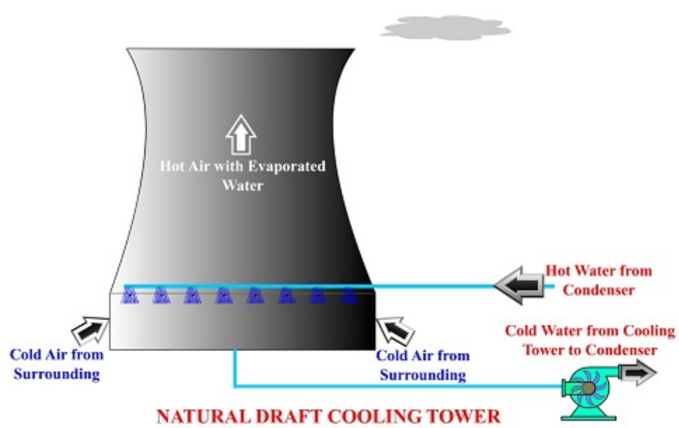


Figure 5.1: Cooling tower system[11]

5.2 Literature review

5.2.1 Literature

Energy audit of cooling tower carried out according to guideline of BEE. In this Guideline methodology of find the effectiveness of cooling tower and measure the evaporation loss and and windage loss and find the heat load[1].

As book of Dr. G.G.Rajan "Troubleshooting, Operation and Maintenance for power plants and allied industries" that work carried out on the cooling tower. As per book Cooling towers constitute the most crucial section of the industry, the effective operation of which controls the other operating parameters such as system pressure, temperature, humidity etc. Cooling water quality is one of the most important parameters that affect the performance of the process units. Cooling water quality is to be monitored to prevent scale formation or corrosion of tube bundles in condensers, coolers etc. Basics of cooling water chemistry and the methods of predicting scaling / corrosive tendency of cooling water is also covered with appropriate example. At the end of the training program, the participants shall be well versed in cooling tower theory, operation and maintenance activities of their own industry[11].

In Mani Sarvanan, The method of energy and exergy analysis. In this pa per, a mathematical model based on heat and mass transfer principle is developed to find the outlet condition of water and air. The model is solved us ingiterative method. Also prove that in Energy and exergy analysis infers that in let air wet bulb temperature is found to be the most important parameter than inlet water temperature[12].

In Gaurav Aggrawal, In study presents development of a simple and efficient mathematical model, in which energy, draft and pressure equation are solved simulation. In this parameter study of wet bulb temperature of inlet air plays a signification role on air and water outlet temperature and effect on evaporation loss, thermal efficiency and exergy destruction and second law efficiency[13].

5.2.2 Cooling tower parameter

The important parameters, from the point of determining the performance of cooling towers are:

(1) Range : This is the difference between the cooling tower water inlet and outlet temperature. A high CT Range means that the cooling tower has been able to reduce the water temperature effectively, and is thus performing well.

$$CT\ Range\ (^0C) = [CW\, inlet\, temp(^0C) - CW\, outlet\, temp(^0C)] \tag{5.1}$$

(2) Approach : This is the difference between the cooling tower outlet coldwater temperature and ambient wet bulb temperature. The lower the approach the better the cooling tower

performance. Although, both range and approach should be monitored, the 'Approach' is a better indicator of cooling tower performance.

$$CT\ Approach(^0C) = [CW\ outlet\ temp(^0C) - Wet\ bulb\ temp(^0C)] \tag{5.2}$$

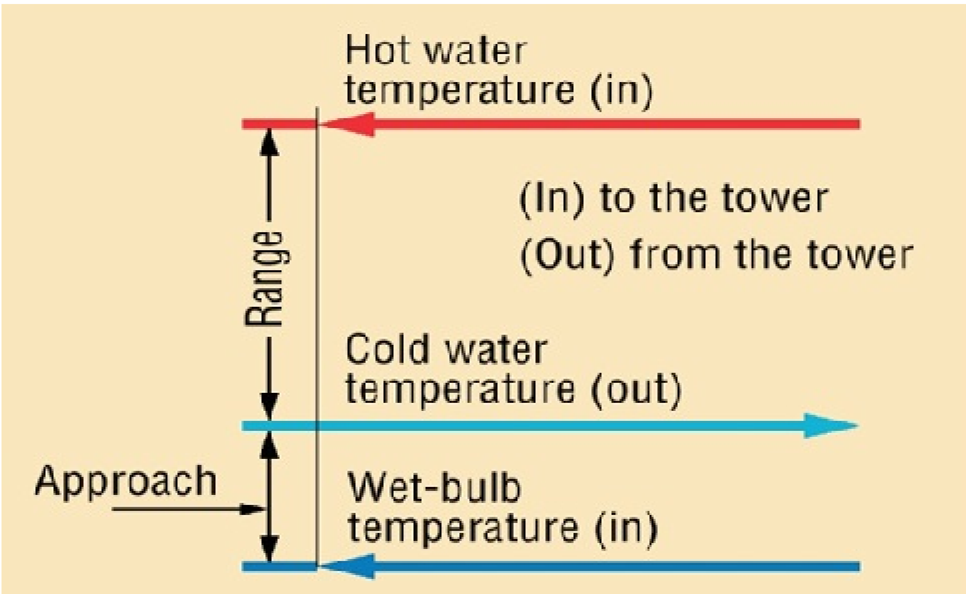


Figure 5.2: Range and Approach

(3) Effectiveness :This is the ratio between the range and the ideal range (in percentage), i.e. difference between cooling water inlet temperature and ambient wet bulb temperature. The higher this ratio, the higher the cooling tower effectiveness.

$$Effectiveness = \frac{Range}{Range+Apporach} \tag{5.3}$$

(3) Effectiveness :This is the ratio between the range and the ideal range (in percentage), i.e. difference between cooling water inlet temperature and ambient wet bulb temperature. The higher this ratio, the higher the cooling tower effectiveness.

$$Effectiveness = \frac{Range}{Range+Apporach} \tag{5.4}$$

(4) Evaporation loss: This is the water quantity evaporated for cooling duty. Theoretically the evaporation quantity works out to 1.8 m^3 for every 1,000,000 kCal heat rejected.

$$Evaporation\ loss = 0.00085x1.8xcirculation\ rate\ (x(T_1\text{-}T_2) \tag{5.5}$$

T_1-T_2= temperature difference between inlet and outlet water

(5) Cycles of concentration (C.O.C): This is the ratio of dissolved solids in circulating water to the dissolved solids in make up water.

(6) Heat load : The heat load imposed on a cooling tower is determined by the process being served. The degree of cooling required is controlled by the desired operating temperature of the process. In most cases, a low operating temperature is desirable to increase process efficiency or to improve the quality or quantity of the product.

$$Heat\,Load = warer\,flow\,rate * (T_1 - T_2) * 4.186 \tag{5.6}$$

here, T_1 = hot water temp. T_2 = Cold water temp

(7) Blow Down loss: Blow down losses depend upon cycles of concentration and the evaporation losses and is given by relation.

$$Blow\,Down\,loss = \frac{\text{Evaporation loss}}{\text{C.O.C-1}} \tag{5.7}$$

5.3 Measuring Instruments for Energy Audit

(1) Ultrasonic flow meter

Figure 5.3: Ultrasonic flow meter

This instrument show in fig which is used for Measures flow of liquid. Flow can measure in Pipe size 50 mm to 6000 mm and up to fluid temperature of 200 0C. Its accuracy is 1 %.

(2) RH meter

Figure 5.4: RH meter

This instrument show in fig which is used for Measures Humidity and DBT. Its range is 0-100% RH. Its accuracy is ±3 %.

(3) DIGITAL TEMP. INDICATOR

Figure 5.5: Digitial temp Indicator

Its contact type temp indicator. Its range is 0- 1200 0C. It's accuracy is ±0.5%. Resolution of this instrument is 0.1°C up to 200°C.

5.4 DATA COLLECTION

5.4.1 Design data

As shown in table 5.1 design data of cooling tower for comparing the measure data were taken in energy audit of cooling tower.

Table 5.1: Design data of cooling tower

Location	0.0 M
Water flow	$3.30*10^7$kg/hr
Air inlet DBT	36.0 ^{0}C
RH	55%
Air inlet WBT	28.0 ^{0}C
Air leaving DBT	41.8 ^{0}C
Air leaving WBT	41..6 ^{0}C
Water outlet temperature	33.0 ^{0}C
Water inlet temperature	43.0 ^{0}C
Heat Load	$1.38 * 10^9$ KJ/hr
Range	10^0C
Approach	5^0C
Effectiveness	66.67 %

5.4.2 Measured data

5.4.2.1 Air side measurement

During energy audit of cooling tower date taken from air side with use of RH meter.

Table 5.2: Air side data

Sr. no	Parameters	Unit	CT 7
1	DBT	^{0}C	25.25
2	RH	%	54.
3	WBT(Phscrometric chart)	^{0}C	18.8

5.4.2.2 Water Side measurement

During energuy audit of cooling tower data taken from water side with use of digitial temp Indicator.

Table 5.3: Water side data

Sr no	Parametrs	Unit	CT 7
1	Hot water Temp.	^{0}C	35.4
2	Cold water Temp.	^{0}C	27.4
3	Water flow rate	kg/hr	26700000
4	C.O.Conclusion	-	1.64

5.4.3 Calculated Parameters

Table 5.4: Calculated data

Sr No	Calculated parameters	Unit	Design data	CT-7
1	Range	^{0}C	10	8
2	Approach	^{0}C	5	8.6
3	Effectiveness	%	66.67	48.19
4	Heat load	kJ/hr	1381380000	894129600
5	Evaporation loss	kg/hr	-	329883.8
6	Blow down loss	kg/hr	-	515443.4
7	Windage loss	kg/hr	-	53400
8	Make up flow	kg/hr	-	898727.3

5.5 Exergy analysis of cooling tower

As shown in table 5.5, data were taken during energy audit of cooing tower 7.

Table 5.5: Data related for exergy analysis

Sr No	Parameter	Unit	CT-7
1	T_1	^{0}C	35.4
2	P_1	Bar	1.78
3	m_1	kg/s	7416
4	h_1	$\frac{\text{kJ}}{\text{kg}}$	148.4
5	S_1	$\frac{\text{kJ}}{\text{kgK}}$	0.5102
6	T_2	^{0}C	27.4
7	P_2	Bar	1.2
8	m_2	kg/s	7171.91
9	h_2	$\frac{\text{kJ}}{\text{Kg}}$	114.9
10	S_2	$\frac{\text{kJ}}{\text{KgK}}$	0.44048
11	P_0	Bar	1.012
12	T_O	^{0}C	27
13	h_O	$\frac{\text{kJ}}{\text{kg}}$	113.2
14	S_O	$\frac{\text{kJ}}{\text{KgK}}$	0.39449

$$E_i = m_1[(h_1\text{-}h_0)\text{-}T_O(S_1\text{-}S_o)] \tag{5.8}$$

=7416[(148.4-113.2)-300(0.5102-0.3949)

E_i=3040.56 kJ

$$E_o = m_2[(h_2 - h0) - To(S_2 - S_0)] \tag{5.9}$$

=7171.91[(114.9-113.2)-300(0.40048-0.3949)]

E_o=215.15kJ

$$Exergy\,Destruction = mo * To * (Sgen) \tag{5.10}$$

=7171.9*300(0.5102-0.4004)

=236070 W

=236.07 kW

$$Secound\,law\,Efficiency = 1 - \frac{\text{Exergy Destruction}}{\text{Exergy in}} \tag{5.11}$$

=1-$\frac{236.07}{3040.56}$

η_{II}=92.30%

5.6 Summery sheet of cooling tower

5.6.1 Effectiveness of each Unit

Base on figure 5.6 it can be observed that all cooling tower effectiveness compare with design effectiveness.

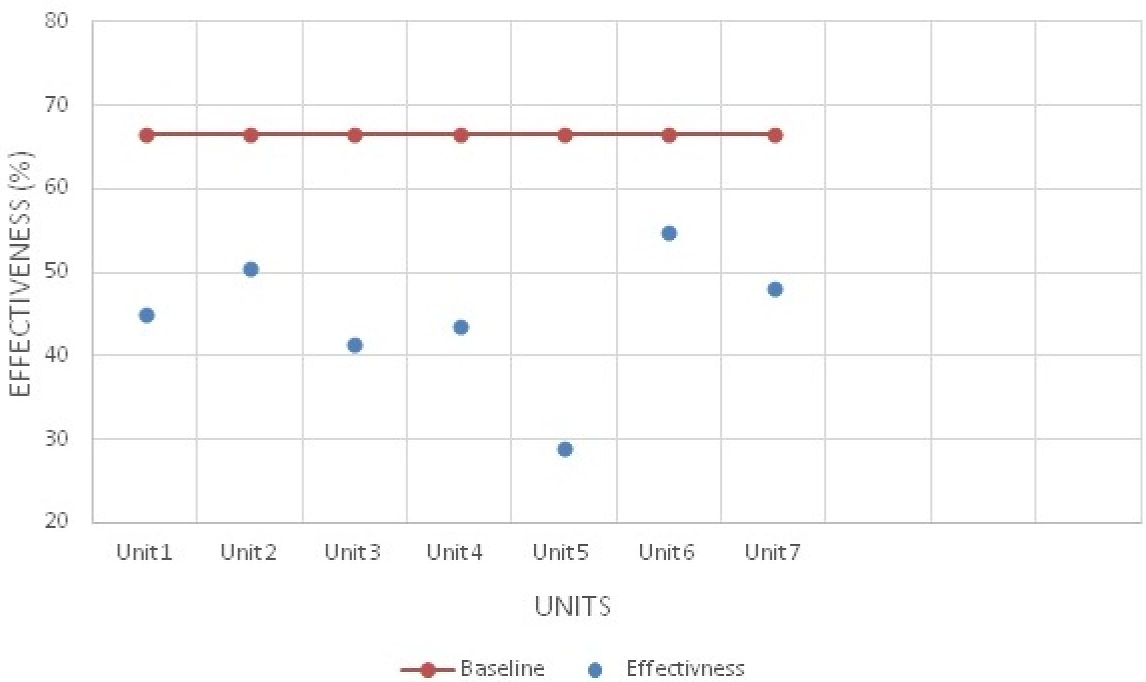


Figure 5.6: Effectiveness V/s Units

As shown in fig 5.6 its graph of effectiveness Vs cooling tower observing fig following suggestion are made. As compare to design effectiveness 66.67% performance of cooling tower 1, 3, 4 and 5 effectiveness is too low.

5.6.2 Heat load Vs Cooling tower

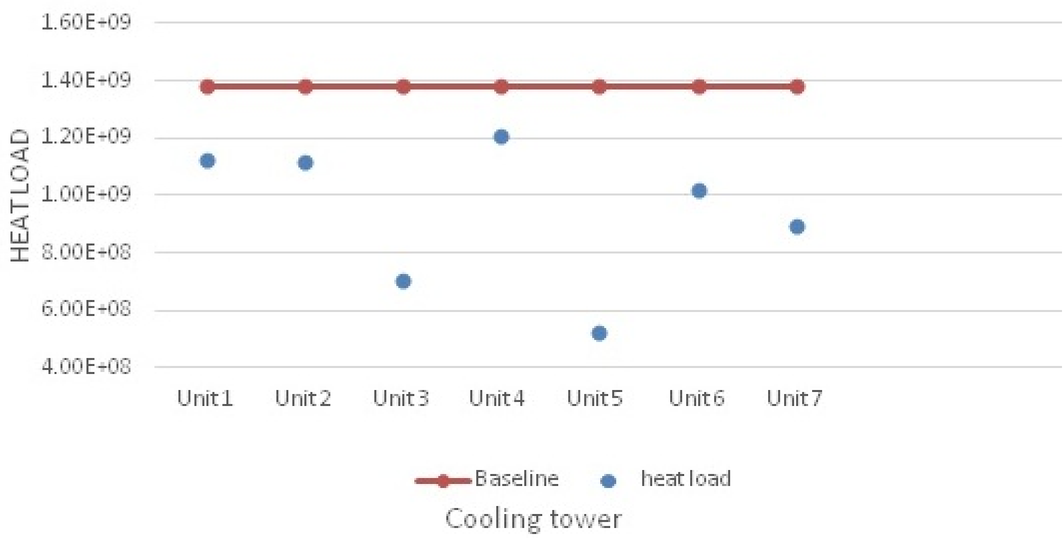


Figure 5.7: Heat load Vs Cooling tower

As shown in fig 5.7 its graph of Heat load Vs cooling tower observing fig suggestion are made that Heat load of cooling tower 3, 5 and 7 are too low.

5.6.3 % of loss water of each unit

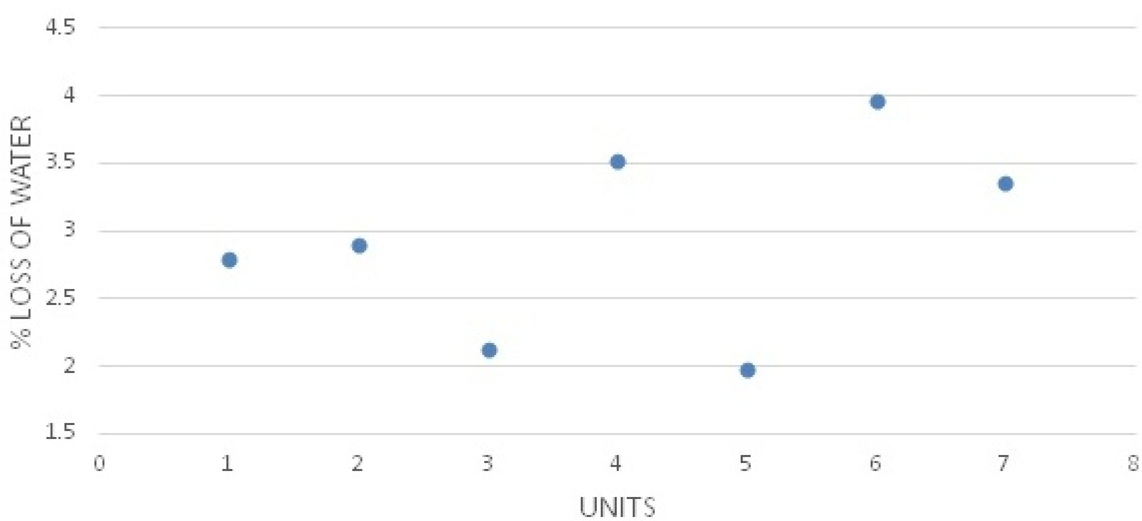


Figure 5.8: % loss of water Vs Unit

As shown in fig 5.8 its graph of % loss of water Vs cooling tower observing fig suggestion are made that in cooling tower 4,6 and 7 more make up water require.

5.7 Suggestion

- Water distribution pipe should be periodically checked for and breakage and leakage.
- By Reduce Cold water temp. approximately 4.0 to 5.0 ^{0}C which will improve the condenser vacuum by 5.0 mmHg for each cooling tower gain. So Saving heat rate approximately 50 to 60 kcal/kWh.
- Air path around the cooling tower should free from any restriction from plantation and vegetation.
- Conduct cooling tower study periodically to observe any deterioration due to time and weather.
- Cooling tower channel and basin should be covered with fish net to prevent from any foreign particle/leaf/material to enter on the cooling system.

5.8 Discussion

Cooling tower effectiveness due decrease of no equal flow distribution in cooling tower system. More than 5mm thick scale in the pipe of cooling tower so becuse of that hot water and cold water can not contact directly. Nozzle falling in the cooling tower . Cooling water pump flow irregular.

Chapter 6

Heat rate analysis

6.1 Introduction

Heat Rate is an important index for assessing the efficiency of a thermal power station. Performance of Thermal power plant is more precisely evaluated by heat rate. It should be the endeavour of any station to improve the operating heat rate and try to bring close to the design station heat rate. Heat rate improvement also helps in reducing pollution from Thermal Power Stations. In this direction, Performance Evaluation is monitoring various parameters related to efficiency of Thermal Power Stations in the country. Data related to heat rate parameters was received from thermal power stations during March-April 2014, which has been compiled, analysed and compared with their design Heat Rate. The results of the analysis of station heat rate so carried out has been highlighted in the enclosed Annexure. Stations analysed in the studies are using coal as primary fuel.

6.1.1 Method for evaluation of Heat rate

There are two methods for calculation of heat rate of a thermal power stations:[15]

- Indirect Method
- Direct Method

6.1.1.1 Indirect method

Indirect method of heat rate analysis is an instantaneous method. This method is adopted when the direct measurement of the coal is not available.

6.1.1.2 Direct Method

Direct method of Heat Rate measurement is done where coal measurement is available. In this method, coal consumption data is averaged for long duration to achieve at accurate value of coal consumption.. This method is employed at almost all stations as standard practice. Operating parmarere such as gross generation, total Coal consumption, average gross calorific value of the Coal and oil, Specific Oil Consumption have been collected from Thermal Power Station authorities on monthly basis. Thereafter, operating station heat rate for each month is calculated as under.

$$Heat\,rate = Sp.\,coal\,consumption * G.C.V\;of\;coal \tag{6.1}$$

here,

Specific coal consumption$=\frac{Total\,coal\,consumption\,in\,amount}{Gross\,Generation\,in\,the\,month}$

Operating Heat Rate thus calculated is then compared with respect to design heat rate and percentage deviation is calculated for evaluating the performance of the station as a whole.

Heat rate deviation$=\frac{(Operating\,heat\,rate-Design\,heat\,rate}{Design\,heat\,rate} * 100$

6.2 Calculated Heat Rate

Table 6.1: Heat rate analysis for various unit WTPS

Parameter	Unit	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
Coal consumption	kg	2722.41	2756.34	3327.63	2486.80	2550.81	2542.62	2485.33
Gross Generaion	kWh	3738	3872	4776	3798	3808	3835	3894
G.C.V	$\frac{\text{kcal}}{\text{kg}}$	3832.41	3841.93	3608.23	3613.15	3611.22	3610.92	3849.27
Heat rate	$\frac{\text{kcal}}{\text{kWh}}$	2791.16	2734.93	2514	2364.96	2419	2394	2456.78
Design Heat rate	$\frac{\text{kcal}}{\text{kWh}}$	2397	2397	2397	2305	2305	2305	2300
Deviation heat rate	%	16.44	14.09	4.88	2.60	4.94	3.86	6.81

6.3 Suggestion

The above table 6.1 indicate that power plant unit heat rate is more than design. Poor performance of cooling tower result in increase of cooling water outlet temperature By reduce the Cooling water outlet temp. Approximately 4.0 to 5.0 ^{0}C which will improve the condenser vacuum by 5 mm o fHg for each cooling tower and because of vacuum heat rate save approximately 50 to 60 kcal/kWh. In air pre-heater by control the excess air can be reduce air leakage and because of that ID and PA fan loading decrease and that affect on control the Heat rate. In compressor by control the leakage of system and because of that power consumption decrease and that affect in improve the heat rate.

6.4 Discussion

From above table 6.1 indicted that heat rate affect parameter is condenser vacuume, Axcees air in APH, Poor insulation , Not operating the units on design parameter, poor mill/burners performance causing high unburnt carbon in fly and bottom ash, leakage in air compressor system and Excessive amount of excess air(O_2).

Chapter 7

Conclusion and Future Work

7.1 Energy Audit of Air compresor

Air compressor leakage is found 9.09 % by controling the cylinder head leakage and checking all the valves for leakage is found 7.97% so 1.12 % leakage can be reduced. So after neglecting the leakage we can reduse the specific energy consumption 0.03kWh/m3hr. And also we can improve the volumetric efficiency 1.16 % and actual isothermal efficiency 1.23%. Base on exergy analysis, second law efficiency of air compressor is 44.18%.

7.2 Energy Audit of Air pre-heater

Due to air ingress in APH leakage found is 9.53% whereas permissible limit is approx 8.0% so effectivness of air side and gas side decrease. And due to air ingress power consumption also increasse.Air pre-heater effectiveness is found 52.55% based on flue gas side where as as per design data effectiveness of gas side is 66.44 % so becuse of air ingress and Pressure drop 13.89 % efficency decrease and same as in air side 14.3% efficency is decreas.Also by use of exergy analysis, second law efficiency of air compressor is 44.18%.

7.3 Energy Audit of cooling tower

Present operating effectiveness of natural draft cooling tower as compare to design value of 66.67 % is 48.19 % and this is lower in performance test. As per design data range is 5 ^{0}C and Aprroch is 10 ^{0}Cbut at actual condition range and Aprroach are 8 and 8.6 ^{0}Crespectively. And also 3.35% loss of water in circulation flow.From performance table, observed that Cold water (CWT) never cross the Dry bulb temperature(DBT) toward approaching to wet bulb temp. This show that heat transfer taken place inside the cooling tower mainly due to sensible heat transfer instead of Evaporative cooling (latent heat transfer) .

7.4 Heat rate analysis

As per heat rate analysis of 7 unit as shown that heat rate of Unit 1, unit 2 and Unit 7 is very high. so by taking imadiate action try to control the heat rate as per design value. By use of Heat rate we prove that overall performance of unit 3 , Unit 4, Unit 5 and Unit 6 are good. From the result obtained it is conclude that heat rate is high compare to design value. The probable resaon observed is that the auxiliary which are use in power plant are not running on specified design value. If those auxiliary are replace or retrofitted than it will minimise the losses occurring and thus the heat rate can be improve. Also by use of good quality of coal whose GCV is high improve the heat rate.

Bibliography

[1] Guideline of BUREAU OF ENERGY EFFICIENCY.

[2] Guideline for energy auditing of thermal power plant by INDO-GERMAN ENERGY PROGRAMME.

[3] Book-1 Energy auditing made simple by P.BALASUBRAMANIAN.

[4] Performance Analysis from the Energy Audit Of A Thermal Power Plant,Ch.Kiran Kumar,G.Srinivasa Rao,International Journal of Engineering Trends and Technology (IJETT) - Volume4 Issue6- June 2013

[5] P.K. Nag Engineering Thermodynamics, Tata McGraw-Hill Education private limited 2010.

[6] A. bejan, N. Dan, D.G. Cacuci and W. Schutz, Advance Engineering Thermodynamics (Third Edition), vol. 23,(1998) 913-928.

[7] Optimizing reciprocating compressor Design parametes base on First lasw,Mahmood Faezaneh-Gurd,Amir Niazmand, Mahdi DEYMIDASHTEBAYAZ. U.P.B. Sci. Bull., Series D, Vol. 75, Iss. 4, 2013(ISSN 1454-2358)

[8] Technical data book of 210 MW TPS Wankbori.

[9] Performance improvement in regenerative Air pre-heaater by Mr A.R.Kulkarni (Vol 1, Mech-well industriesltd)

[10] A numerical model for the analyses of heat transfer and leakages in a rotary air preheater, Bostjan Drobnic, Janez Oman, Matija Tuma, International Journal of Heat and Mass Transfer 49 (2006) 5001–5009

[11] COOLING TOWERS Troubleshooting, Operation and Maintenance for power plants and allied industries by Dr G.G.Rajan

[12] ENERGY AND EXERGY ANALYSIS OF COUNTER FLOW WET COOLING TOWERS, by Mani SARAVANAN, Rajagopal SARAVANAN, and Sankaranarayanan RENGANARAYANAN (THERMAL SCIENCE: Vol. 12 (2008), No. 2, pp. 69-78)

[13] COOLING TOWERS Troubleshooting, Operation and Maintenance for power plants and allied industries by Gaurav Aggarwal, S S Kachhwaha,R S Mishra. Journal of Scientific & Industrial Reserch (Vol. 69,April 2010, pp. 284-292.

[14] Perry's Chemical Engineers Handbook (Page: 12-17)

[15] Performance review of Thermal Power station 2004-2005 Page No 13.1

[16] Energy Savings Toolbox – An Energy Audit Manual and Tool.

[17] Energy Audit of 250 MW Thermal Power Stations PTPS, Panipat by Vikrant Bhardwaj , Rohit Garg , Mandeep Chahal , Baljeet Singh.

Appendix A

TITLE - A

	V	I	PF	KW/TIME	KWH	T1	T2	temp corr. Factor	load time	unload time	% of leak	leak corr. Factor	VOLUME	TIME TAKEN	FAD	COR. FAD	ISOTHERMAL POWER	VOL EFFI.	Sp. Energy con	ISO. TH. EFFI.
IAC - 1A	421	139	0.87	8.53	88.08	32	37	0.98	4	40	9.09	1.09	9.57	5.81	10.60	11.37	39.30	70.77	0.13	47.97
IAC -1B	427	142	0.86	9.95	90.21	32	37	0.98	4	40	9.09	1.09	9.57	6.62	9.30	9.98	34.49	62.11	0.15	41.11
IAC -1C	426	146	0.85	8.34	91.46	32	37	0.98	4	40	9.09	1.09	9.57	5.47	11.25	12.08	41.74	75.17	0.13	49.07
IAC-2A	406	147	0.88	8.53	96.19	29	37	0.97	5	45.5	9.90	1.10	9.57	5.32	11.57	12.39	42.81	77.10	0.13	47.85
IAC-2B	414	160	0.83	9.95	62.73	33	40	0.98	9.5	45.5	17.27	1.17	9.57	9.52	6.47	7.41	25.62	46.13	0.14	43.91
IAC-2C	417	158	0.84	8.34	44.08	29	37	0.97	5	45	10	1.1	9.57	11.35	5.42	5.81	20.08	36.17	0.13	48.99
IAC-3A	423	140	0.88	7.14	66.94	28	32	0.99				1	9.57	6.4	9.62	9.49	32.80	59.07	0.12	52.69
IAC-3B	415	167	0.85	8.54	89.89	28	33	0.98				1	9.57	5.7	10.80	10.62	36.71	66.11	0.14	43.91
IAC-3C	406	147	0.88	7.15	77.72	28	35	0.98				1	9.57	5.52	11.15	10.90	37.66	67.82	0.12	52.11
IAC-4A	423	140	0.88	4.29	78.96	33	40	0.98	3.27	75.18	4.17	1.04	4.87	3.26	9.61	9.79	33.82	60.90	0.13	46.05
IAC-4B	415	167	0.85	4.17	76.51	33	42	0.97	3.27	75.18	4.17	1.04	4.87	3.27	9.58	9.69	33.50	60.33	0.13	47.08
IAC-4C	406	147	0.88	4.20	65.45	29	42	0.96	3.27	75.18	4.17	1.04	4.87	3.85	8.14	8.13	28.08	50.57	0.13	46.13
IAC-5A	421	139	0.87	7.90	75.60	33	50	0.95	3.13	75.18	4.00	1.04	9.37	6.27	9.61	9.47	32.73	58.94	0.13	46.55
IAC-5B	427	142	0.86	6.53	69.35	33	45	0.96	3.4	75.18	4.33	1.04	9.37	5.65	6.00	6.02	20.81	37.48	0.19	32.27
IAC-5C	426	146	0.85	7.83	69.91	32	50	0.94	3.13	75.18	4.00	1.04	9.37	6.72	8.97	8.81	30.44	54.81	0.13	46.81
IAC-5D	430	88	0.85	6.68	69.95	32	50	0.94	3.3	75.15	4.21	1.04	9.37	5.73	10.52	10.35	35.77	64.41	0.11	54.98
IAC-6A	449	161	0.88	5.91	61.67	32	37	0.98				1	9.57	5.75	10.71	10.53	36.40	65.55	0.10	63.46
IAC-6B	442	164	0.72	6.90	60.88	32	37	0.98				1	9.57	6.8	9.05	8.91	30.78	55.43	0.11	54.36
IAC-6C	435	159	0.88	6.40	60	32	37	0.98				1	9.57	6.4	9.62	9.46	32.70	58.89	0.11	58.60
IAC-7A	401	130	0.86	5.04	81.73	30	35	0.98	4	35	10.26	1.10	4	3.7	6.95	7.54	26.06	46.94	0.18	34.29

	V	I	PF	KW/TIME	KWH	T1	T2	temp corr. Factor	load time	unload time	% of leak	leak corr. Factor	VOLUME	TIME TAKEN	FAD	COR. FAD	ISOTHERMAL POWER	VOL EFFI.	Sp. Energy con	ISO. TH. EFFI.
IAC-7B	430	127	0.9	4.18	68.71	30	35	0.98	4	35	10.26	1.10	4	3.65	7.05	7.65	26.42	47.58	0.15	41.35
IAC-7C	412	82	0.9	5.32	84	30	35	0.98	4	35	10.26	1.10	4	3.8	6.77	7.34	25.38	45.70	0.19	32.49
IAC-7D	430	90	0.9	5.11	78.62	30	35	0.98	4	35	10.26	1.10	4	3.9	6.60	7.16	24.73	44.53	0.18	33.82
SAC-1A	423	114	0.9	7.50	72.82	33	40	0.98	3.27	78.12	4.02	1.04	9.2	6.18	9.58	9.74	33.65	60.60	0.12	49.69
SAC-1B	415	167	0.9	8.54	63.10	33	40	0.98	3.27	75.18	4.17	1.04	9.2	8.12	7.29	7.42	25.65	46.19	0.14	43.70
SAC-1C	406	147	0.9	7.61	66.46	33	38	0.98	3.27	75.18	4.17	1.04	9.2	6.87	8.61	8.83	30.51	54.94	0.13	49.36
SAC-1D	414	160	0.8	7.92	65.10	33	40	0.98	3.28	75.25	4.18	1.04	9.2	7.3	8.11	8.26	28.53	51.38	0.13	47.13
SAC-1E	417	158	0.8	7.99	75.14	33	38	0.98	3.26	74.12	4.21	1.04	9.2	6.38	9.28	9.51	32.87	59.19	0.13	47.03
SAC-4A	446	155	0.9	5.36	85.76	30	40	0.97	9.8	44.4	18.08	1.18	4.5	3.75	7.72	8.82	30.49	54.91	0.16	38.23
SAC-4C	417	158	0.8	5.04	72.344	29	40	0.96	7	45	13.46	1.13	4.5	4.18	6.93	7.58	26.20	47.18	0.16	38.94
SAC-7A	438	123	0.9	5.36	160.8	30	35	0.98				1	4	2	12.87	12.66	43.73	78.76	0.21	29.24
SAC-7B	435	127	0.9	4.38	131.4	30	35	0.98				1	4	2	12.87	12.66	43.73	78.76	0.17	35.79