Energy conservation through controls :-

• Energy Conservation Through Control provides information pertinent to energy-conserving control systems, which is relevant to efficient plant operations.
It also discusses the processes involving energy conversion and examines the laws of thermodynamics.

- Energy Conservation Through Control explores the various aspects of the following:-

1. Combustion Control Systems- Controlling Fuel Flow, Controlling Airflow, Air Pollution Control

2. Steam Plant Management - Steam Turbine Controls , Steam Header Controls , Boiler Controls , Multiple-Boiler Plants

3. Compressor Control Systems –The Thermodynamics of Compression, Compressor Characteristics, Pressure and Flow Controls, Surge Protection, Multiple-Compressor Installations

4. Refrigeration - Mechanical Refrigeration, Deep Cooling, Steam Refrigeration, Brine and Chilled-Water Systems,importance of refrigeration systems in industrial processing and to air-condition buildings. The final step deals with the general features and control problems in energy conservation in heating, ventilating, and air-conditioning (HVAC) system. Plant designers, control engineers, power plant operators, and industrial managers will find it extremely useful.

Computer aided energy management

An **energy management system** (**EMS**) is a system of computer-aided tools used by operators of electric utility grids to monitor, control, and optimize the performance of the generation or transmission system. Also, it can be used in small scale systems like microgrids.

It consists of multiple digital systems such as SCADA and ADMS to manage the energy generation and transmission of power.

The computer technology is also referred to as SCADA/EMS or EMS/SCADA. In these respects, the terminology EMS then excludes the monitoring and control functions, but more specifically refers to the collective suite of power network applications and to the generation control and scheduling applications.

Supervisory Control and Data Acquisition (**SCADA**) is monitoring software used to control the PLC and record data, even from remote locations. ... **SCADA** systems are managed by an operator using an operator interface which allows the individual to monitor and the issue process commands through the **SCADA** computer system.

ADMS short for Advanced Distribution Management Systems is a vital component in optimization and efficient operation of grids. It is basically a software platform that provides visibility and control of all activity of the grid along with data analysis capabilities.

Advantages:-

Businesses and factories that employ energy management solutions usually end up achieving far greater savings than those running their operations without such systems. EMS analyzes all the operations of the company and optimizes them for energy savings. The savings that are generated through the use of energy management systems directly impacts the bottom line. Some of the major advantages of energy management systems are mentioned below.

1. **Improved brand image-** Utilizing energy management systems will result in reduced power consumption and therefore more environmentally friendly processes. Business clients, customers and suppliers do recognize the optimization in processes as it reflects quality in planning and management.
2. **Better productivity and competitive edge-** Reducing the energy consumption through process optimization and efficient load planning not only improves the productivity of industrial processes in general but also allows companies to catch-up to their competition through continuous improvement of processes.

3. **Cost-reduction-** Energy management systems can guarantee a reduction in energy costs by at least 20%. Even with minimal investments and no front-up costs, system supervisors can save around 10% of their overall energy costs. Through a planned and systematic implementation of energy management systems, supervisors can cut cost up to a one-third of their original overhead charges.

4. **Enhance the morale and wellbeing of employees-** When companies make the effort to improve their processes and pay attention to each and every parameter that can be optimized, it has an incredibly positive effect on the work culture of the company. Employees feel inspired to work better in a more efficient environment. By improving the productivity of processes companies also ensure an improvement in the working capabilities of their employees.

An Introduction to ECBC and Energy Efficiency in Building Sector

ECBC

- With the background of high energy saving potential and its benefits bridging the gap between demand and supply, reducing environmental emissions through energy saving and to effectively over come the barrier the Govt. of India has enacted the Energy Conservation Act, 2001.
- The Act provides the much needed legal framework and institutional arrangement for embarking on an energy efficiency drive.
- This includes Energy Conservation Building Code.

- The Act empowers Govt. of India and State Governments to modify ECBC as per climatic conditions of states.
- And to notify the code in Govt. gazette to make it mandatory for commercial buildings having a connected load of
- 500 kW or maximum demand of 600 kVA or above or
- 1000 sq. m of air conditioned area.

Purpose

- The purpose of this code is to provide minimum requirements for energy-efficient design and construction of buildings.

- Building sector -33%
- Commercial sector -8%
- Residential sector-25%
- ECBC compliance building –can save 40 to 60% electricity
- Nation wide mandatory compliance- 1.7 billion KWH
- Its a first step towards Energy conservation
- Developed after extensive research work
- Considered comfort conditions
- Helpful for persons involved in design and construction of ECBC compliant buiding

Scope

- Applicable to building complexes having connected load of 500KW or greater or a contract demand of 600KVA or greater.
- Buildings or complexes having conditioned area of 1000 sq m or more
- It's a voluntary adoption in the country
- Shall become mandatory after gazette notification by any state or central govrnment

Applicable to buildings

- Minimum energy performance standards for design and construction be prescribed.
- Applies to new construction and major renovation.
- Building components included
  - Building Envelope (Walls, Roofs, Windows)
  - Interior and exterior Lighting
  - HVAC system
  - Service water heating and pumping
  - Electrical Systems (Power factor, Tramsformer)

Exemptions to buildings

- Buildings that do not use electricity or fossil fuels
- Equipment and portion of the building systems that use energy primarily for manufacturing processes
- When this code is in conflict to safety, health
- Environment codes shall prevail.

Impact of ECBC – Energy Savings

- Average energy use: For light and HVAC a typical class A office building consumes 200kWh/sq m/Yr.
- Mandatory enforcement of ECBC is likely to reduce the energy use by 30-40% to 120 – 160 200kWh/sq m/Yr.
- Energy saving as per BEE estimate – Saving of 1.7 billion kWh, with national mandatory enforcement, in the first year it self.

Example

- Area of existing office =900 sq m AC area
- Additional area of office=450 sq m proposed to be AC
- Code applies to 450sq m area that is being converted to AC

Impact of ECBC Compliance

- Market Development for Energy Efficient products.
  - Building Insulation
  - Energy Efficient Windows
  - High efficiency HVAC systems
- Improved Design Practices.
  - Lighting and Day Lighting
  - Natural Ventilation/ Free cooling system
- Improved Building performance.
- Lower HVAC load.
- Lesser addition of power generation capacity.

Implementation Plan

- Awareness and technical resources
- Quick implementation guide.
- Compliance resources.

Definition of Commercial Building

- According to energy information administration- Any building that is used for neither residential, manufacturing, nor agricultural purposes.
- Many types of commercial buildings-
  - Office Buildings
  - Hotels
  - Restaurants
  - Retail malls and shops
  - Hospitals
  - Educational Institutes.

Building Envelope

- A well designed building envelope not only help in complying with ECBC code but can also result in first cost saving by taking advantage of day light and correct HVAC system sizing
- Opaque part (walls, roof,slab)
- Fenestration Systems(window,sky light,ventilators and doors that are half Glazed),.

Building Envelope

- Envelope affects the thermal comfort of occupants as well as energy consumption of the building
- Heat Transfer Takes place through walls , window and roof by all the three methods i.e. Conduction , convection of air , Radiation

Building Envelope

- Conductive heat transfer- conductivity of building material used
- Thickness of wall is proportional to thermal resistance. More thickness means less heat transfer.
- Total Resistance $=R_1 + R_2 + R_3 + \ldots\ldots$

R_1 R_2 R_3 are thermal resistance of each layer.

Building Envelope

- Air Leakage- From doors shall be avoided with the gaskets.
- Building envelope Sealing .
- Insulation of roofs
- Insulation to be protected from sunlight,moisture,wind,and other physical damage

Building Envelope

- Cool Roofs
- It is a roof with reflective coating that has high emissivivity and reflect the suns enegy away from the roof surface.
- Remains 10 to 16 degree cooler than a normal roof under hot summer

Building Envelope

<u>Urban heat Island effect</u>

¬Urban areas are warmer than rural

Why ?

- Modification of land surface
- Waste heat generated by energy usage e.g. AC and refrigeration

<u>Types of roofing</u>

Large sheets of pre made roofing mechanicaly fastened to existing roofing

Building Envelope

- Lime coats white tiles with white cement are being used.

<u>For windows</u>

- Films
- Coatings on glass
- Gas filling between the glass
- Reduction of air leakage

Sky lights

- Surface in the building exposed to sun with slope of less than 60 degrees
- The sky light area should not be more than 5 % of the roof area
- The sun emits visible solar radiation in the form of light and infrared radiation that can not be seen ,but causes heat.

- Special glasses allow the visible light to pass while bypass the infra red radiation.

Importance of Energy Efficient

Envelope Design

- Helps in reducing heating/ cooling load.
- Helps in optimizing daylight.
- First cost and recurring savings.
- Helps in utilizing latest technological advances
- Simulation models greatly helps in designing high performance envelops.

Heating ,Ventilation and Air conditioning(HVAC)

- Natural Ventilation
- Suitable Wind direction & orientation of building
- Opening in the buildings should be well distributed
- Air to enter at low level and out ward at higher level

Heating ,Ventilation and Air

conditioning(HVAC)

- No building should obstruct. the incoming air
- Window of living room should openin open area
- Two window (instead of one)on onewall if that wall is exposed to out side

Heating ,Ventilation and Air conditioning(HVAC)

By Stack Effect

- Natural ventilation by stack effect occurs when inside building is hot and out side is cool.
- Cool air from outside will try to come from out side and hot air shall go out side from the top where ventilators have been provided .
- Hence ,Ventilators should be kept as close to the ceiling as possible.

Energy Conservation in

Ventilation System

- Use of adequate number of ceiling fan(sizes are provided in the Code)
- Use of electronic regulators

Air conditioning(AC)

Different types of Air conditioners

- Central AC plants (Chilled water)
- Package AC plants
- Split type AC
- Window type AC

Controls

Major part in increasing efficiency of AC plant

Design goals

Comfort

Cost effectiveness

Efficiency

Air conditioning(AC)

Controls

¬USE of timers

Can start and stop the system for different schedule

Exceptions :

Cooling systems < 28KW(8tons)

Heating systems<7 KW (2 KW)

Temperature controls/thermostat

For heating and cooling simultaneously:

A band of 3 deg C is desired to be provided

Air conditioning(AC)

Temperature controls/thermostat

- For heating and cooling separately:
- Interlocking between heating and cooling systems to be provided

- Two speed or variable speed drives for fans
- All cooling towers shall have two speed motors or variable speed drives controlling the fans. (having twin circuits)
- To have higher speed when load on system is more and low speed when the load is low

Air conditioning(AC)

- Efficiency of water based chiller system is better than air based chiller.
- Higher speed of any motor means more energy consumption
- (Power is proportional to cube of speed)

<u>Piping and Duct work</u>

- Piping /Ducting of heating and cooling must be insulated

(various values are specified in the code)

- Insulation exposed to weather – protected by Al sheet ,canvas or plastic cover and painted white

Air conditioning(AC)

- Condensers
- Locations : free from interference from buildings etc.from heat point of view
- No other system installed near by
- Soft water for water cooled systems
- Free Cooling;
- Use of economizer :controls the flow of out door air .
- Partial Cooling ; use of cool night time air to pre cool the AC area.

Air conditioning(AC)

- System Balancing

Its balancing of air as per requirement of temperature required in particular area

- Done by using Dampers, splitter vanes

Hydraulic System Balancing

- Its balancing of water supply for cooling a particular area as per design conditions using .
- Minimize Throttling losses

Service water heating and pumping

- <u>For hotels,hospitals</u>: water heating is needed
- <u>As per code mandatory requirements are:</u>
- <u>Solar heating (</u> 1/5 th of the capacity)
- <u>Heat recovery:</u> e.g. DG sets exhaust, AC condenser out let (exception that uses heat recovery for at least 1/5th of the design capacity)
- Minimize electric heating
- Reducing stand by losses
- Reducing heat and evaporation losses in heated swimming pools

Service water heating and pumping

- Temperature control of water: set at 49 deg C
- For each 5.5 degree C reduction in water temperature can save 3-5% in energy costs
- Insulate the storage tank
- Insulate pipes
- Heat Traps: allow cold water to go inside and does not allow hot water to come out side e.g. in Gyser
- Swimming Pools : temperature to be maintained at 32 deg C and shall have a min insulation value of R-2.1

Lighting

- 15% of total energy consumption is for lighting in India
- Shops, office, hospital, OT, home, study room

In Practice :

- Right quality ,
- Right Quantity of light
- To be provided efficiently (with less energy)
- By using right technology and its effective integration

Lighting

Efficient equipment

- Electronic Ballast, CFL ,LED lamps
- Maintaining those efficient equipment

LIGHTING CONTROL

- Automatic On/Off when needed
- Dimming Control(modulate light out put for reducing the intensity of light)
- Timers
- Occupants and motion sensors
- Astronomical time switches

Lighting

- Astronomical time switches :
- WHAT IS THIS ?
- An automatic time switch that makes an adjustment for the length of the day as it varies over the year
- Longitude and latitude are specified and the timer makes changes automatically

Lighting

- Applicable for buildings > 500 sq.m
- With in these buildings all areas <30 sq m enclosed by walls shall have occupancy sensor
- Occupancy sensor to switch off light after 30 min of sensing no occupancy
- Compound light : photo sensor

  astronomical sensor
- Display lighting to have separate control
- Master lighting control for hotel rooms
- Internally illuminated exit signs shall not exceed 5W per face-LED exit sign boards

Electrical Power

- Transformers
- Energy efficient motors
- Power factor correction
- Electrical metering and monitoring
- Power distribution system

Transformer

DRY type transformer

- Where fire hazard are present
- At load centers

Oil type transformer: where no fire hazard

- Since it is at load end it will have low and high power requirement so its no load losses should be minimum.
- Or Losses at 50 percent load should be minimum

Energy efficient motors

- Induction motors are mainly used
- All motors >375W in the building and expected to operate >1500 hours /year(Efficiency >70.2%)
- All motors >50KW and expected to run >500 hours per year shall have efficiency as per IS 2615 for energy efficient motors(94%)
- Optimum loading of motors is at about 75%
- Rewinding reduces efficiency and hence not suitable for energy efficiency.

Power Factor correction

- All electricity supplies >100A 3 phase shall maintain their power factor between 0.95 lag to unity at the point of connection
- It reduces system current
- Hence losses(IxIxR losses) are reduced.
- Reduced power consumption of the device
- Reduced electricity bills
- Improved electrical energy efficiency
- Extra KVA availability from the existing supply
- Minimized voltage drop in long cables

How to correct Power Factor

- Minimize operation of idling or lightly loaded motors
- Avoid operation of equipment above its rated voltage
- Replace standard motors as they burnt out with energy efficient motors
- All motors must be operated on almost full load otherwise the P.f. may go low
- Install capacitors in AC circuits

Metering and Monitoring

- Building performance measurement
- Why metering is necessary

  Metering of energy of each major energy consuming gadget.
- Services exceeding load of 1000KVA shall have meters to record KVA,KWH , P.F. ,I ,V,THD
- Between 65KVA and 1000 KVA : shall have meters to record KW,KWH,P.F.
- Up to 65 KVA: shall have meters to record

Power Distribution Losses

- The power cabling : distribution losses to be less that 1 % of total power usage.

Energy Efficiency in Existing Buildings/ facilities

- There is vast scope for energy efficiency improvement in buildings/existing facilities.

- Energy Audit Studies have revealed a savings potential to the extent of 40% in end use such as lighting, cooling, ventilation, refrigeration etc.

- Audits identify the Energy baselines in existing facilities along with Energy Efficiency Measures.

Energy Efficiency Measures

- Energy efficiency measures bring about energy savings due to reduced energy consumptions.
- Energy savings are determined by comparing energy baseline with energy consumed after implementation of EE measures.
- Energy cost savings resulting from EE measures directly benefit building owners and occupants over the life cycle of the building.

Barriers to Energy Efficiency

- Lack of information about comparative energy use.
- Risk due to lack of confidence in performance of new technologies.
- Higher cost of EE technologies.
- Asymmetry in sharing of costs and benefits.- especially in building sector.

Helpful Tips to Architects and Developers

- Select an organization/ consultant with expertise and experience in performing building energy simulation.
- Always inquire for key input parameters and output reports (e.g. thermal specifications of wall, glazing, and roof elements, load and system summary reports.
- Ask simulation consultant to perform parametric studies to evaluate:
  - Relative cost and benefits of selecting key components and technologies (glazing, lighting)
  - Sizing of HVAC system.

UNIT-3

Definition of Energy Audit

- **As per Indian 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 "

Why the Need for Energy Audit

- The three top operating expenses are energy (both electrical and thermal), labour and materials.
- Energy would emerge as a top ranker for cost reduction
- 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

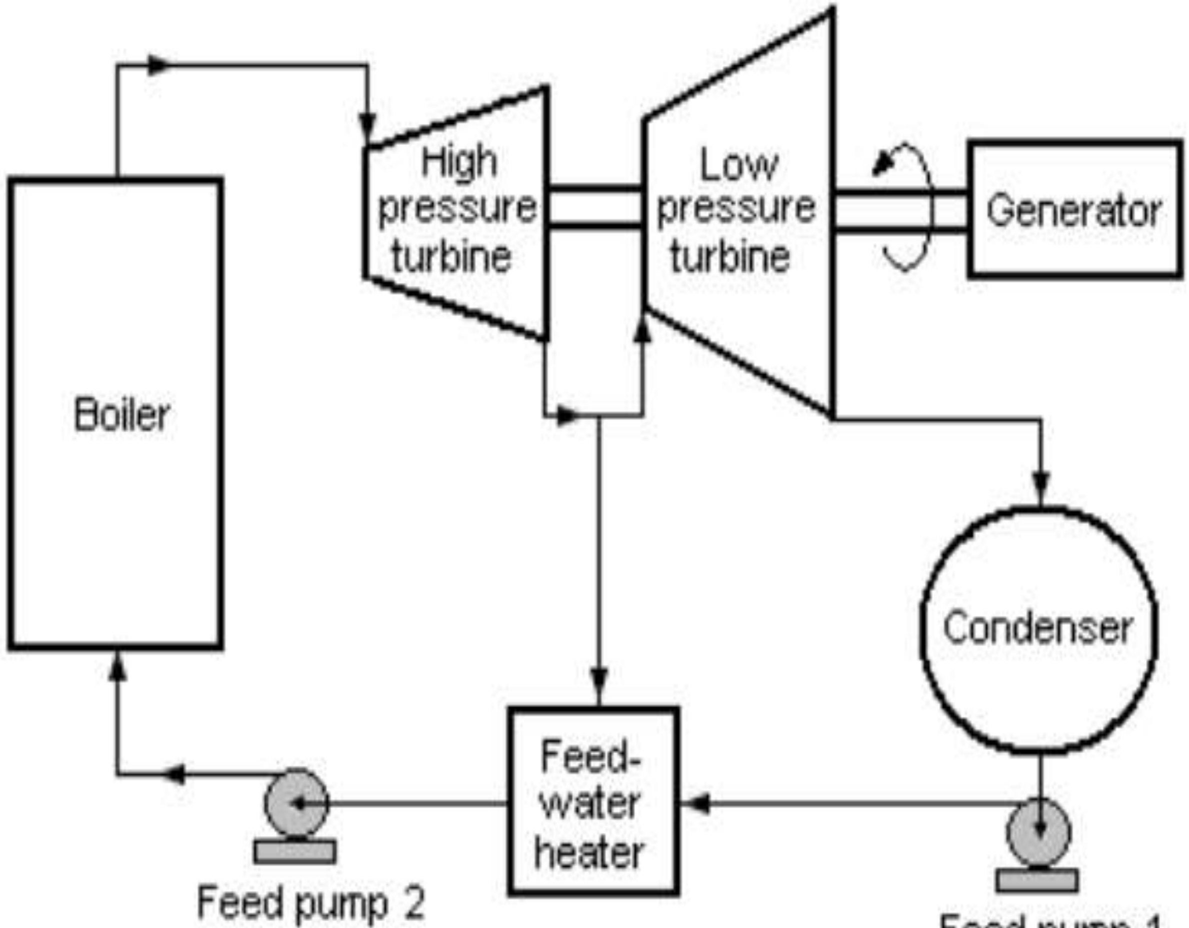


Figure Single Line Diagram of Thermal Power Plant

ELECTRICAL ENERGY AUDIT IN POWER PLANTS

Significance of energy audit

Energy audit represents a most important tool for current energy efficiency analysis in power plant in order to propose adequate measures for energy efficiency improvements. Such an audit involves:

- Systematic data gathering about energy production and consumption,
- Identification of power flow through the plant,
- Defining the measures for improving energy efficiency,
- Economical and technical justification of proposed measures,
- Rating the proposed measures according to the established criteria.

The importance of carried out energy audit regarding electrical energy usage in power plants could be summarized in following:

- Determine locations in power plant with the highest electrical energy losses,
- Cost reduction for electrical energy production using measures proposed in energy audit,
- Increasing of electrical energy production by improvement of efficient usage of turbine cycle and reduction of self-consumption,
- Maintenance planning and improvement of availability,
- Using on-line monitoring for important systems and equipment,
- Benchmarking of most important electrical equipment and systems.

MAJOR AREAS FOR ENERGY AUDIT IN THERMAL POWER PLANTS:

The major areas for conducting energy audit in thermal power plants are :

1.Boilers and associated parts,

2. Turbines and associated parts, 3. Insulation,

4. Draft system /fans (ID fans, FD fans, PA fans and other fans),

5.Cooling system (condensers, cooling towers and cooling water pumping system),

6. Water pumping systems (boiler feed water pumping system, condensate extraction pumping system, DM water pumping system, make up water pumping, raw water pumping system, etc.),

7. Fuel handling system (e.g.: coal handling system, coal mills, fuel oil handling system), 8. Ash handling system, 9. Compressed air system, 10. Air conditioning system, 11. Electrical systems, 12. Electric drives and motors, esp. those of high power (>50kW) and high voltage (6kV), 13.Plant lighting system.

There may be some other sections /equipment in addition to those mentioned above which may need to be added.

Required instruments for performing analysis of electrical energy consumption

The following instruments are required for conducting the electrical energy audit in thermal power plant on previously defined equipment / systems of interest:

- Power analyzer for measurement of electrical parameters such as kW, kVA, pf, V, A and Hz of class 0.5 accuracy (for all systems),
- Stroboscope to measure the speed of the driven equipment and motor (pumps, fans, mills, compressors),
- Tensiometer for belt tension check for belts in coal and ash handling system and compressed air system,
- Temperature indicator & probe (coal and ash handling system, boiler, compressed air system),
- Lux meter for lighting system analysis,
- Available on line instruments at the site (calibrated).

UNIT –III
Energy Efficiency in Thermal Utilities

- Energy performance assessment and efficiency improvement of **Boilers, Furnaces, Heat exchangers, Fans and blowers, pumps, Compressors and HVAC systems, Steam distribution**
- Assessment of **steam distribution losses, Steam leakages, Steam trapping, Condensate and flash steam recovery system**

ENERGY PERFORMANCE ASSESSMENT OF BOILERS

Purpose of the Performance Test

- **To find out the efficiency of the boiler**
- **To find out the Evaporation ratio**

The purpose of the performance test is to determine actual performance and efficiency of the boiler and compare it with design values or norms.

1. Boiler Efficiency

2. Evaporation ratio

1. Boiler Efficiency, $\eta = \dfrac{\text{Heat output}}{\text{Heat Input}} \times 100$

$$= \frac{\text{Heat in steam output (kCals)}}{\text{Heat in Fuel Input (kCals)}} \times 100$$

2. Evaporation Ratio $= \dfrac{\text{Quantity of Steam Generation}}{\text{Quantity of fuel Consumption}}$

Boiler efficiency can be tested by the following methods:

1) **The Direct Method:** Where the energy gain of the working fluid (water and steam) is compared with the energy content of the boiler fuel.

2) **The Indirect Method:** Where the efficiency is the difference between the losses and the energy input.

Direct Method Testing

This is also known as **’input-output method’** due to the fact that it needs only the useful output (steam) and the heat input (i.e. fuel) for evaluating the efficiency.

$$\text{Boiler Efficiency} = \frac{\text{Heat Output}}{\text{Heat Input}}$$

$$\text{Efficiency} = \frac{\text{Heat addition to Steam} \times 100}{\text{Gross Heat in Fuel}}$$

$$\textit{Boiler Efficiency} = \frac{\text{Steam flow rate x (steam enthalpy} - \text{feed water enthalpy)}}{\text{Fuel firing rate x Gross calorific value}} \; x\,100$$

$$\text{Boiler efficiency } (\eta) = \frac{Q \times (H - h) \times 100}{(q \times GCV)}$$

Where **Q** = Quantity of steam generated per hour (kg/hr)

q = Quantity of fuel used per hour (kg/hr)

GCV = Gross calorific value of the fuel (kCal/kg)

H = Enthalpy of steam (kCal/kg)

h = Enthalpy of feed water (kCal/kg)

Merits and Demerits of Direct Method

- **Merits**
  - Plant people can evaluate quickly the efficiency of boilers
  - Requires few parameters for computation
  - Needs few instruments for monitoring
- **Demerits**
  - Does not give clues to the operator as to why efficiency of system is lower
  - Does not calculate various losses accountable for various efficiency levels
  - Evaporation ratio and efficiency may mislead, if the steam is highly wet due to water carryover

Calculate Boiler Efficiency and Evaporation Ratio

Heat output data

Quantity of steam generated (output)	: 8 TPH
Steam pressure / temperature	: 10 $kg/cm^2(g)$/ 180°C
Enthalpy of steam(dry & Saturated) at 10 $kg/cm^2(g)$ pressure	: 665 kCal/kg
Feed water temperature	: 85°C
Enthalpy of feed water	: 85 kCal/kg

Heat input data

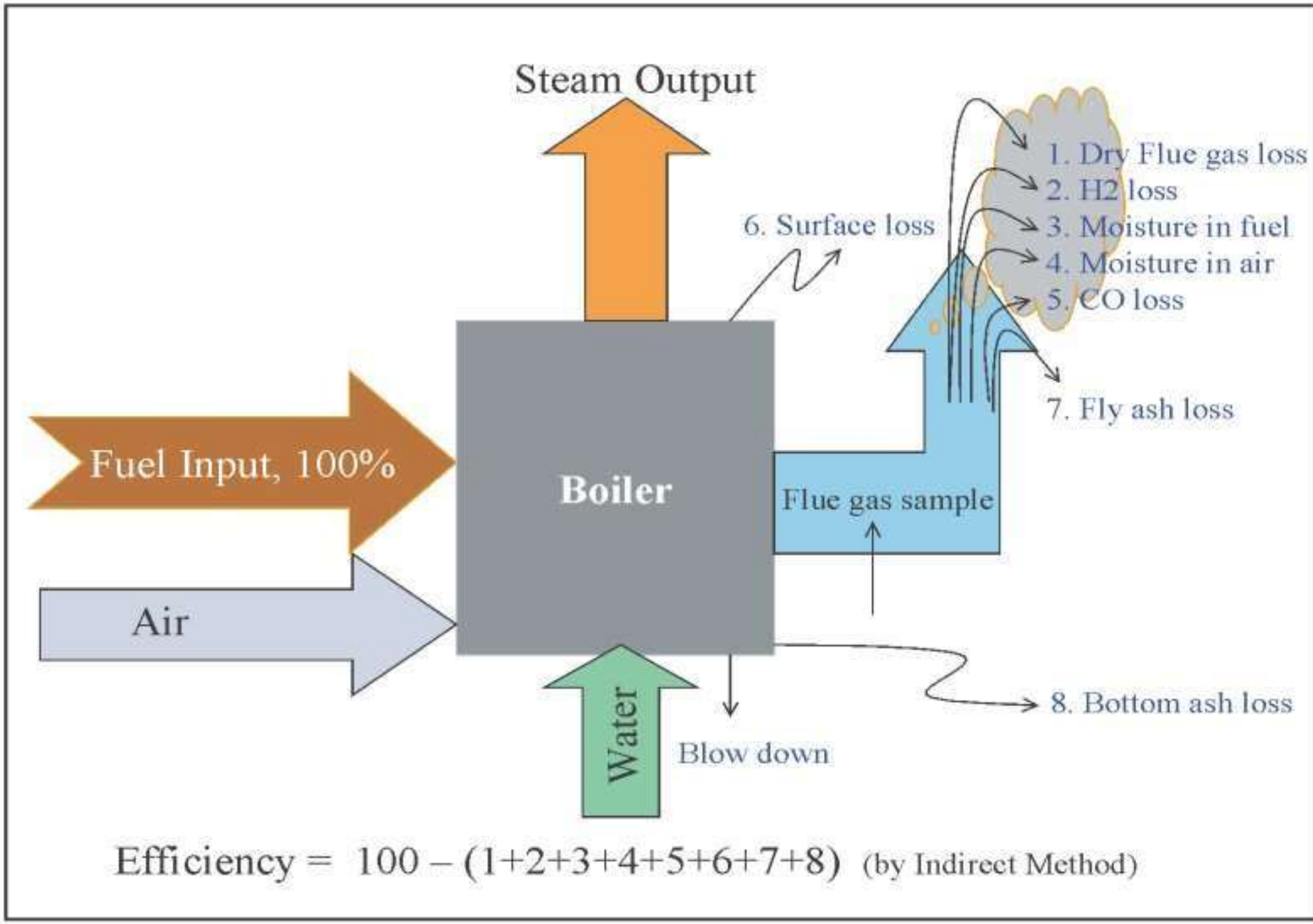
Quantity of coal consumed (Input)	: 1.6 TPH
GCV of coal	: 4000 kCal/kg

Indirect Method Testing

- The disadvantages of the direct method can be overcome by this method, which **calculates the various heat losses associated with boiler.**
- An important advantage of this method is that the **errors in measurement do not make significant change in efficiency.**
- Thus if boiler efficiency is 90% , an error of 1% in direct method will result in significant change in efficiency. i.e. $90 \pm 0.9 = 89.1$ to 90.9.
- In indirect method, 1% error in measurement of losses will result in Efficiency = $100 - (10 \pm 0.1)$

$$= 90 \pm 0.1 = 89.9 \text{ to } 90.1$$

Indirect Method Testing



The following losses are applicable to liquid, gas and solid fired boiler

L1. Loss due to dry flue gas (sensible heat)
L2. Loss due to hydrogen in fuel (H_2)
L3. Loss due to moisture in fuel (H_2O)
L4. Loss due to moisture in air (H_2O)
L5. Loss due to carbon monoxide (CO)
L6. Loss due to surface radiation, convection and other unaccounted.
L7. Unburnt losses in fly ash (Carbon)
L8. Unburnt losses in bottom ash (Carbon)

Boiler Efficiency by indirect method

$$= 100 - (L1 + L2 + L3 + L4 + L5 + L6 + L7 + L8)$$

Measurements Required for Performance Assessment Testing

a)Flue gas analysis

1. Percentage of CO_2 or O_2 in flue gas
2. Percentage of CO in flue gas
3. Temperature of flue gas

b) Flow meter measurements for

1. Fuel
2. Steam
3. Feed water
4. Condensate water
5. Combustion air

Measurements Required for Performance Assessment Testing

c) Temperature measurements for

1. Flue gas 2. Steam 3. Makeup water

4. Condensate return 5. Combustion air

6. Fuel 7. Boiler feed water

d) Pressure measurements for

1. Steam 2. Fuel 3. Draft

4.Combustion air, both primary and secondary

e) Water condition

1. Total dissolved solids (TDS) 2. pH

3. Blow down rate and quantity

Factors Affecting Boiler Performance

The various factors affecting the boiler performance are listed below:

- Periodical cleaning of boilers
- Periodical soot blowing
- Proper water treatment programme and blow down control
- Draft control
- Excess air control
- Percentage loading of boiler
- Steam generation pressure and temperature
- Boiler insulation
- Quality of fuel

Boiler Terminology

- **Maximum Continuous Rating (MCR)** : Steam boilers rated output is also usually defined as MCR
- **Gross calorific value (GCV):** The amount of heat liberated by the complete combustion, under specified conditions, by a unit volume of a gas or of a unit mass of a solid or liquid fuel, in the determination of which the water produced by combustion of the fuel is assumed to be completely condensed and its latent and sensible heat made available.
- **Net calorific value (NCV):** The amount of heat generated by the complete combustion, under specified conditions, by a unit volume of a gas or of a unit mass of a solid or liquid fuel, in the determination of which the water produced by the combustion of the fuel is assumed to remain as vapour.

- **Blow down:** The removal of some quantity of water from the boiler in order to achieve an acceptable concentration of dissolved and suspended solids in the boiler water.
- **Saturated steam:** It is the steam, whose temperature is equal to the boiling point corresponding to that pressure.
- **Wet Steam:** Saturated steam which contains moisture
- **Dry Steam:** Either saturated or superheated steam containing no moisture.
- **Superheated Steam:** Steam heated to a temperature above the boiling point or saturation temperature corresponding to its pressure

ENERGY PERFORMANCE ASSESSMENT OF FURNACES

- Furnace is by definition **a device for heating materials and therefore a user of energy.**
- Heating furnaces can be divided into **batch-type (Job at stationary position) and continuous type (large volume of work output at regular intervals).**
- The types of **batch furnace include box, bogie, cover, etc.** For **mass production, continuous furnaces are used**. The types of **continuous furnaces include pusher-type furnace, walking hearth-type furnace, rotary hearth and walking beam-type furnace.**
- The primary energy required for reheating / heat treatment furnaces are in the form of Furnace oil, LDO or electricity

Purpose of the Performance Test

- **To find out the efficiency of the furnace**
- **To find out the Specific energy consumption**

The purpose of the performance test is to determine efficiency of the furnace and specific energy consumption for comparing with design values or best practice norms.

Performance Terms and Definitions

1. Furnace Efficiency, η $= \dfrac{\text{Heat output}}{\text{Heat Input}} \times 100$

$$= \frac{\text{Heat in stock (material)} \quad \text{(kCals)}}{\text{Heat in Fuel /electricity} \quad \text{(kCals)}} \times 100$$

2. Specific Energy Consumption $= \dfrac{\text{Quantity of fuel or energy consumed}}{\text{Quantity of material processed.}}$

Furnace Efficiency Testing Method

The energy required to increase the temperature of a material is the product of the mass, the change in temperature and the specific heat. i.e

Energy = Mass x Specific Het x rise in temperature

Furnace Efficiency

The efficiency of a furnace is the **ratio of useful output to heat input.**

The furnace efficiency can be determined by both **direct and indirect method.**

Direct Method Testing

Thermal efficiency of the furnace =

$$\frac{\textbf{Heat in the stock}}{\textbf{Heat in the fuel consumed}}$$

The quantity of heat to be imparted (Q) to the stock can be found from the formula

$$\mathbf{Q = m \times Cp\ (t2 - t1)}$$

Where

Q = Quantity of heat in kCal

m = Weight of the material in kg

Cp = Mean specific heat, kCal/kg°C

t2 = Final temperature desired, °C

t1 = Initial temperature of the charge before it enters the furnace, °C

Indirect Method Testing

Various losses that occur in the fuel fired furnace-

1. Heat lost through exhaust gases either as sensible heat, latent heat or as incomplete combustion
2. Heat loss through furnace walls and hearth
3. Heat loss to the surroundings by radiation and convection from the outer surface of the walls
4. Heat loss through gases leaking through cracks, openings and doors.

Efficiency= 100 –(all losses)

Measurement Parameters

The following measurements are to be made for doing the energy balance in oil fired reheating furnaces (e.g. Heating Furnace)

i) Weight of stock / Number of billets heated

ii) Temperature of furnace walls, roof etc

iii) Flue gas temperature

iv) Flue gas analysis

v) Fuel Oil consumption

Factors Affecting Furnace Performance

- Under loading due to poor hearth loading and improper production scheduling
- Improper Design
- Use of inefficient burner
- Insufficient draft/chimney
- Absence of Waste heat recovery
- Absence of Instruments/Controls
- Improper operation/Maintenance
- High stack loss
- Improper insulation /Refractories

ENERGY PERFORMANCE ASSESSMENT OF HEAT EXCHANGERS

- **Heat exchangers are equipment that transfer heat from one medium to another.**
- The proper design, operation and maintenance of heat exchangers will make the process energy efficient and minimize energy losses.

Purpose of the Performance Test

- To determine the **overall heat transfer coefficient** for assessing the performance of the heat exchanger.

Performance Terms and Definitions

❑ Overall heat transfer coefficient, U

Heat exchanger performance is normally evaluated by the overall heat transfer coefficient *U that is defined by the equation*

$$\boxed{Q = U \times A \times LMTD}$$

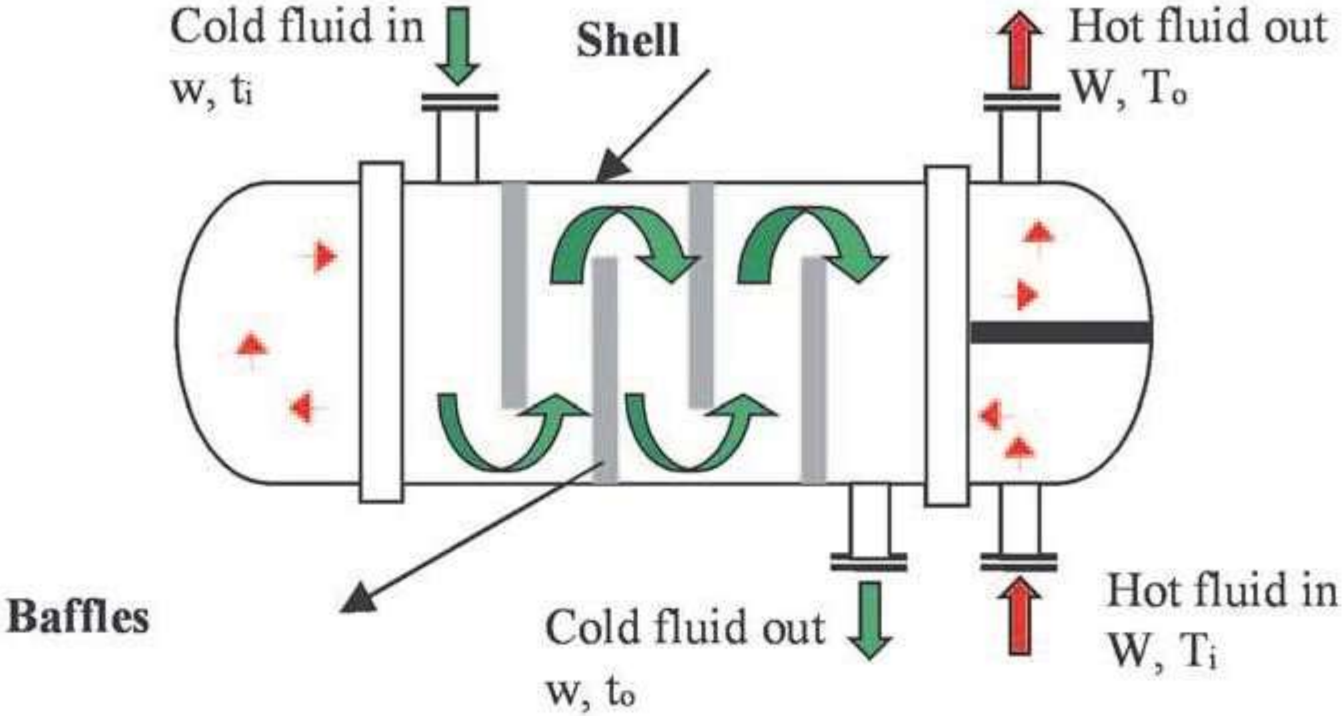
Where

Q = Heat transferred in **kCal/hr**

A = Heat transfer surface area in **m**^{2}

LMTD = Log Mean Temperature Difference in ^{0}C

U = Overall heat transfer Coefficient **kCal/hr/m**^{2}/^{0}C



Shell and tube heat exchanger

For Hot fluid, $Q_h = W \times C_{ph} \times (T_i - T_o)$

For Cold fluid, $Q_c = w \times C_{pc} \times (t_o - t_i)$

Parameters monitored for calculation of overall heat transfer coefficient for heat exchanger

Monitoring and reading of steady state parameters of the heat exchanger under evaluation are tabulated as below:

Parameters	Units	Inlet	Outlet
Hot fluid flow,W	kg/h		
Cold fluid flow,w	kg/h		
Hot fluid Temp, T	^{0}C		
Cold fluid Temp,t	^{0}C		
Hot fluid Pressure,P	bar g		
Cold fluid Pressure, p	bar g		

With the monitored test data, the physical properties of the stream can be tabulated as required for the evaluation of the thermal data

Parameters	Units	Inlet	Outlet
Hot fluid density, ρ_h	kg/m^3		
Cold fluid density, ρ_c	kg/m^3		
Hot fluid Viscosity, μ_h	MpaS*		
Cold fluid Viscosity, μ_c	MPaS		
Hot fluid Thermal Conductivity, k_h	kW/(m. K)		
Cold fluid Thermal Conductivity, k_c	kW/(m. K)		
Hot fluid specific heat Capacity, C_{ph}	kJ/(kg. K)		
Cold fluid specific heat Capacity, C_{pc}	kJ/(kg. K)		

Calculate the thermal parameters of heat exchanger and compare with the design data

Parameters	Units	Test Data	Design Data
Heat Duty, Q	kW		
Hot fluid side pressure drop, ΔP_h	bar		
Cold fluid side pressure drop, ΔP_c	bar		
Temperature Range hot fluid , ΔT	^0C		
Temperature Range cold fluid , Δt	^0C		
Capacity ratio, R	-----		
Effectiveness, S	-----		
Corrected LMTD, MTD	^0C		
Heat Transfer Coefficient, U	$kW/(m^2. K)$		

Monitoring Instruments

Parameters	Units	Instruments used
Fluid flow	kg/h	Flow can be measured with instruments like Orifice flow meter, Vortex flow meter, Venturi meters, Coriollis flow meters, Magnetic flow meter as applicable to the fluid service and flow ranges
Temperature	°C	Thermo gauge for low ranges, RTD, etc.
Pressure	Bar g	Liquid manometers, Draft gauge, Pressure gauges Bourdon and diaphragm type, Absolute pressure transmitters, etc.
Density	kg/m^3	Measured in the Laboratory as per ASTM standards, hydrometer, etc
Viscosity	MpaS	Measured in the Laboratory as per ASTM standards, viscometer, etc.
Specific heat capacity	J/(kg.K)	Measured in the Laboratory as per ASTM standards
Thermal conductivity	W/(m.K)	Measured in the Laboratory as per ASTM standards
Composition+	%wt (or) % Vol	Measured in the Laboratory as per ASTM standards using Chemical analysis, HPLC, GC, Spectrophotometer, etc.

Terminology used in Heat Exchangers

Terminology	Definition
Capacity ratio	Ratio of the products of mass flow rate and specific heat capacity of the cold fluid to that of the hot fluid. Also computed by the ratio of temperature range of the hot fluid to that of the cold fluid. Higher the ratio greater will be size of the exchanger
Co current flow exchanger	An exchanger wherein the fluid flow direction of the cold and hot fluids are same
Counter flow exchanger	Exchangers wherein the fluid flow direction of the cold and hot fluids are opposite. Normally preferred
Cross flow	An exchanger wherein the fluid flow direction of the cold and hot fluids are in cross

Effectiveness	Ratio of the cold fluid temperature range to that of the inlet temperature difference of the hot and cold fluid. Higher the ratio lesser will be requirement of heat transfer surface
Fouling	The phenomenon of formation and development of scales and deposits over the heat transfer surface diminishing the heat flux. The process of fouling will get indicated by the increase in pressure drop
Fouling Factor	The reciprocal of heat transfer coefficient of the dirt formed in the heat exchange process. Higher the factor lesser will be the overall heat transfer coefficient.
Logarithmic Mean Temperature difference, LMTD	The logarithmic average of the terminal temperature approaches across a heat exchanger
Overall Heat transfer Coefficient	The ratio of heat flux per unit difference in approach across a heat exchange equipment considering the individual coefficient and heat exchanger metal surface conductivity. The magnitude indicates the ability of heat transfer for a given surface. Higher the coefficient lesser will be the heat transfer surface requirement

ENERGY PERFORMANCE ASSESSMENT OF FANS AND BLOWERS

Purpose of the Performance Test

The purposes of such a test are to determine, under actual operating conditions, the volume flow rate, the power input and the total pressure rise across the fan

Performance Terms and Definitions

- **Static Pressure:** The absolute pressure at a point minus the reference atmospheric pressure.

- **Dynamic Pressure: T**he rise in static pressure which occurs when air moving with specified velocity at a point is bought to rest without loss of mechanical energy. It is also known as velocity pressure.
- **Total Pressure:** The sum of static pressures and dynamic pressures at a point**.**
- **Fan Shaft Power:** The mechanical power supplied to the fan shaft
- **Motor Input Power:** The electrical power supplied to the terminals of an electric motor drive.

Fan Efficiency: The air power static divided by impeller power

$$\text{Static Fan Efficiency } \% = \frac{\text{Volume in } m^3/\text{Sec} \times \text{total pressure in mmwc}}{102 \times \text{Power input to the shaft in (kW)}}$$

Factors that Could Affect Performance

- Leakage, re-circulation or other defects in the system
- Inaccurate estimation of flow resistance
- Erroneous application of the standardized test data
- Excessive loss in a system component located too close to the fan outlet
- Disturbance of the fan performance due to a bend or other system component located too close to the fan inlet

ENERGY PERFORMANCE ASSESSMENT OF WATER PUMPS

- Pumping is the process of addition of kinetic and potential energy to a liquid for the purpose of moving it from one point to another
- This energy will cause the liquid to do work such as flow through a pipe or rise to a higher level.
- A centrifugal pump transforms mechanical energy from a rotating impeller into a kinetic and potential energy required by the system

Purpose of the Performance Test

- Determination of the pump efficiency during the operating condition
- Determination of system resistance and the operating duty point of the pump and compare the same with design.

Performance Terms and Definitions

Pump Capacity

Q = Volume of liquid delivered by pump per unit time,m3/hr or m3/sec

Q is proportional to N

where N- rotational speed of the pump

Total developed head

H = The difference of discharge and suction pressure

The **pump head represents the net work done** on unit weights of a liquid in passing **from inlet of the pump to the discharge of the pump.**

There are three heads in common use in pumps

(i) Static head (ii) Velocity head (iii) Friction head.

The frictional head in a system of pipes, valves and fittings varies as a function of the capacity flow through the system.

System resistance: The sum of frictional head in resistance & total static head.

Pump Efficiency: Fluid power and useful work done by the pump divided by the power input in the pump shaft.

$$\text{Pump efficiency} = \frac{\text{Hydraulic power, } P_h}{\text{Power input to the pump shaft}} \times 100$$

Where,

Hydraulic power $P_h (kW) = Q \times (h_d - h_s) \times \rho \times g / 1000$

Q = Volume flow rate (m^3 / s), ρ = density of the fluid (kg/m^3), g = acceleration due to gravity (m/s^2), ($h_d - h_s$) = Total head in metres

Determination of Pump Efficiency

To determine the pump efficiency, three key parameters are required:

1. Flow
2. Head
3. Power

ENERGY PERFORMANCE ASSESSMENT OF COMPRESSORS

Purpose of the Performance Test

To find out:

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

Performance Terms and Definitions

Compression ratio	:	$\frac{\text{Absolute discharge pressure of last stage}}{\text{Absolute intake pressure}}$
Isothermal Power	:	It is the least power required to compress the air assuming isothermal conditions.
Isothermal Efficiency	:	The ratio of Isothermal power to shaft power
Volumetric efficiency	:	The ratio of Free air delivered to compressor swept volume
Specific power requirement	:	The ratio of power consumption (in kW) to the volume delivered at ambient conditions.

$$\text{Specific power consumption at rated discharge pressure} = \frac{\text{Power consumption ,kW}}{\text{Free Air Delivered, } m^3/hr}$$

$$\text{Volumetric efficiency} = \frac{\text{Free air delivered } m^3/min \times 100}{\text{Compressor displacement, } m^3/min}$$

$$\text{Compressor Displacement} = \frac{\pi}{4} \times D^2 \times L \times S \times \chi \times n$$

D = Cylinder bore, metre

L = Cylinder stroke, metre

S = Compressor speed rpm

χ = 1 for single acting and 2 for double acting cylinders

n = No. of cylinders

$$\text{Specific power consumption} = \frac{\text{Actual power consumed by the compressor}}{\text{Measured Free Air Delivery}}$$

Energy audit of Turbine:

What is Hydraulic Machines?

- Hydraulic machines are defined as those machines which convert either hydraulic energy (energy possessed by water) into mechanical energy (P.E+K.E) or mechanical energy into hydraulic energy.

What is Turbine?

- The hydraulic machines, which converts the hydraulic energy into mechanical energy, are called turbines.
- This mechanical energy is used to in running an electric generator which is directly coupled to the shaft of the turbine.

Types of turbines

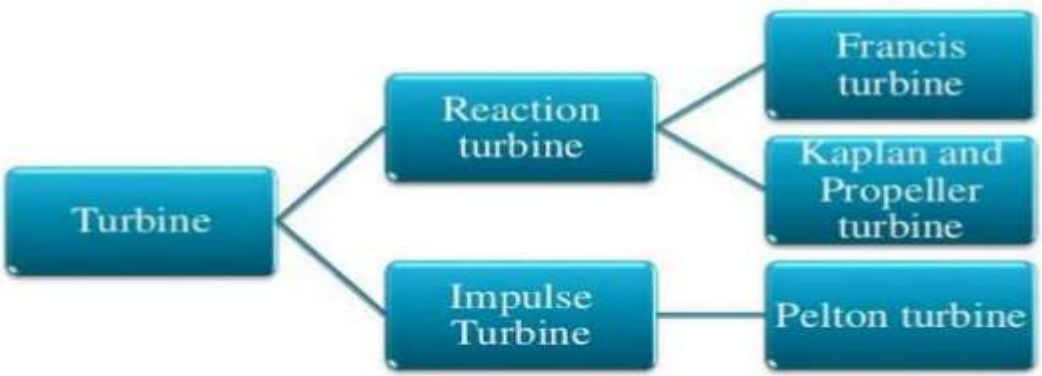
1. Steam Turbines
2. Gas Turbines (Combustion Turbines)
3. Hydraulic Turbines (Water Turbines)

Hydraulic Turbine

- The hydraulic machines, which converts hydro power (energy of water) into mechanical energy, are called Hydraulic Turbines.
- Mechanical energy is used in running an electric generator which is coupled to the turbine shaft.

Classification of Turbines

1. According to type of energy at Inlet
   a) Impulse Turbine - Pelton Wheel
      Requires High Head and Low Rate of Flow
   a) Reaction Turbine - Fancis, Kaplan
      Requires Low Head and High Rate of Flow
2. According to direction of flow through runner
   a) Tangential Flow Turbine - Pelton Wheel
   b) Radial Flow Turbine - Francis Turbine
   c) Axial Flow Turbine - Kaplan Turbine
   d) Mixed Flow Turbine - Modern Francis Turbine



Velocity of Wheel, $u = u_1 = u_2 = \frac{\pi D N}{60}$

Overall Efficiency , $\eta_0 = \eta_m \times \eta_h$ OR $\eta_o = \frac{\text{S.P.}}{\text{W.P.}}$

Water Power, W.P. = $\frac{1}{2} m V^2 = \rho g Q H$

Shaft Power, S.P. = $\rho a V_1 [V_{w_1} + V_{w_2}] \times u = \rho Q [V_{w_1} + V_{w_2}] \times u$

CONDENSER

- The condensing condenser is the most important component of the turbine cycle that affects the turbine heat rate.
- The function of the condenser is to condense exhaust steam from the steam turbine by rejecting the heat of evaporation to the cooling water passing through the condenser.
- Generally, twin shell- double pass- surface type condensers are employed for higher capacity units.

DATA COLLECTION…..
CONDENSER SPECIFICATIONS

- Heat load considered for design
- Design inlet cooling water temperature/ Design TTD
- Cleanliness factor/ Cooling water temperature raise
- Condenser back pressure
- Cooling water flow/ Cooling water side pressure drop
- No of cooling water pass/ Total heat transfer area
- No. of tubes - Condensing zone - Air cooling zone
- Tube dimensions: - Tube OD x thickness - Length of tube
- Tube material: - Condensing zone - Air cooling zone
- Water box design pressure

INSTRUMENTS REQUIRED

- Power Analyzer: Used for measuring electrical parameters of motors such as kW, kVA, pf, V, A and Hz
- Temperature Indicator & Probe
- Pressure Gauge: To measure operating pressure and pressure drop in the system
- Stroboscope: To measure the speed of the driven equipment and motor
- Ultra sonic flow meter or online flow meter
- Sling hygrometer or digital hygrometer
- Anemometer, PH Meter.
- In addition to the above, calibrated online instruments can be used

PERFORMANCE of CONDENSERS

Parameters to be monitored

Particulars	Design/ PG test value	Actual (@ different interval) 1	2	3	4	Avg	Remarks
Unit load							
Frequency							
Condenser back pressure, mmwg							
Cooling water flow, m^3/h							
Cooling water inlet temperature, °C							
Cooling water outlet temperature, °C							
Cooling water temperature raise, °C							
Cooling water in /out pressure							
Pressure drop across the condenser							

PERFORMANCE of CONDENSERS

Parameters to be monitored …….

Particulars	Design/ PG test value	Actual (@ different interval)					Remarks
		1	2	3	4	Avg	
Cooling water flow, m^3/h							
Condenser heat load (estimated)							
Pressure							
Temperature							
Enthalpy							
Flow							
Condensate site (outlet of condenser)							
Pressure							
Temperature							
Enthalpy							
Saturation temperature							
Saturation and inlet water temperature difference							
LMTD							
TTD							
Condenser effectiveness							

PERFORMANCE of CONDENSERS

The following needs to be computed:

1. Condenser heat load = Q x T x Cp

Parameter	Details	Unit
Q	Water flow rate	Kg/h
T	Average CW temperature rise	oC
Cp	Specific heat	kcal/kg oC

2. Calculated condenser vacuum = Atmospheric pressure – Condenser back pressure
3. Deviation in condenser vacuum= Expected condenser vacuum - Measured condenser vacuum
4. Condenser TTD = Saturation temperature – Cooling water outlet temperature

CONDENSER PERFORMANCE

5. Condenser Effectiveness =

$$\frac{\text{Rise in cooling water temperature}}{\text{Saturation temperature - Cooling water inlet temperature}}$$

6. Condenser heat duty in kcal/h =

Heat added by main steam + heat added by reheater + heat added by SH attemperation + heat added by RH attemperation + heat added by BFP - 860 x (Pgen + Pgen losses + heat loss due to radiation)

7. Condenser tube velocity (m/s) =

$$\frac{\text{Cooling water flow rate } (m^3/h) \times 10^6}{3600 \times \text{tube area } (mm^2) \times (\text{no. of tubes per pass - no. of tubes plugged per pass})}$$

CONDENSER PERFORMANCE

8. Determination of actual LMTD

$$\text{LMTD TEST} = \frac{\text{Tout} - \text{Tin}}{\text{Ln}\ \dfrac{\text{Tsat} - \text{Tin}}{\text{Tsat} - \text{Tout}}}$$

9. LMTD expected = LMTD test x ft x fw x fq

ft : Correction for cooling water inlet temperature

fw : Correction for water flow rate and

fq : Correction for cooling water heat load

LMTD Corrections..

ft: Correction for cooling water inlet temperature

$$ft = \left(\frac{\text{Saturation Temperature during test} - \text{LMTD during test}}{\text{Saturation Temperature design} - \text{LMTD design}}\right)^{0.25}$$

fw: Correction for water flow rate

$$fw = \left(\frac{\text{Tube velocity during test}}{\text{Tube velocity design}}\right)^{0.50}$$

fq: correction for cooling water heat load

$$fq = \left(\frac{\text{Condenser design duty}}{\text{Condenser duty during test}}\right)$$

OBSERVATIONS

- Condenser Tubes in operation Vs total tubes installed
- Cleaning system operation Online/offline
- Filtering system for cooling water, Strainers checking regularity
- Regular monitoring system for performance Comparison of LMTD, TTD, heat load, condenser vacuum, flow, temperatures, pressures with design / PG test- arriving the factors causing deviation
- Cooling water flow
- Accurate metering of vacuum
- Pressure drop on water side and choking

Waste Heat Recovery

- Waste heat recovery refers to heat recovery from other utilities onsite.
- There are several waste heat recovery opportunities for both direct and indirect systems.
- These opportunities should be analysed to determine the potential system-wide efficiency improvement and therefore energy savings.

Some of the sources of waste heat include:

- air conditioning exhaust air
- refrigeration compressors
- air compressors

This waste heat can be recovered in several ways, such as:
boiler feedwater pre-heating
combustion air preheating — can often just be a simple redirecting of HVAC exhaust air towards a burner inlet
process heating e.g. product preheating
use of thermal storage
direct heating of heat-transfer medium such as hot water or steam
cascading — multiple processes with successively lower heating requirements can use the heat waste from the process at a higher temperature.