PDHonline Course E369 (2 PDH)

Energy Efficiency in Power Plants

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Energy Efficiency in Power Plant

There are two major threats in terms of energy that world is facing. First is insufficient source of conventional forms of energy and second is impact on environment due to increased consumption of electricity. Increased electricity production causes higher carbon dioxide emission.

Energy audit of power plant will comprehensively identify the degraded plant components and their respective contribution to overall thermal efficiency loss and therefore will be valuable input into the next inspection maintenance scope to implement the necessary corrective actions.

How Energy Audit Of Power Plant Is Helpful?

Energy Audit of power plant results in, resource protection –as less fuel is required for generation of electricity, substantial reduction in CO_2 emission and increased electricity generation from the same amount of fuel. Thermal efficiency of sub-critical pressure thermal power plant is in the range of 36–40% and the same of super critical pressure range thermal power plant is around 40-44 % hence good scope is available to achieve above mentioned goals. Energy Audit of Thermal Power plant is discussed in present content after a brief description of types of power plants.

Types of Power Plant

Thermal Power Plant

Since inception of Rankine cycle, it is used as the standard for steam power plant. The real Rankine cycle used in power plant is very complex than the original simple ideal Rankine cycle. A thermal power plant continuously converts the energy of fossil fuels like coal, oil or gas in to work and ultimately into electricity.

Rankine Cycle consist of four thermodynamic processes, reversible constant pressure heating of water to steam in boiler, reversible adiabatic expansion of steam in turbine, reversible constant pressure heat rejection in the condenser and reversible adiabatic compression of liquid in pump. When all these processes are combined it is known as Ideal Rankine cycle and is shown schematically in figure 1 and thermodynamically on p-v and T-s coordinates in figure 2 and 3 respectively.

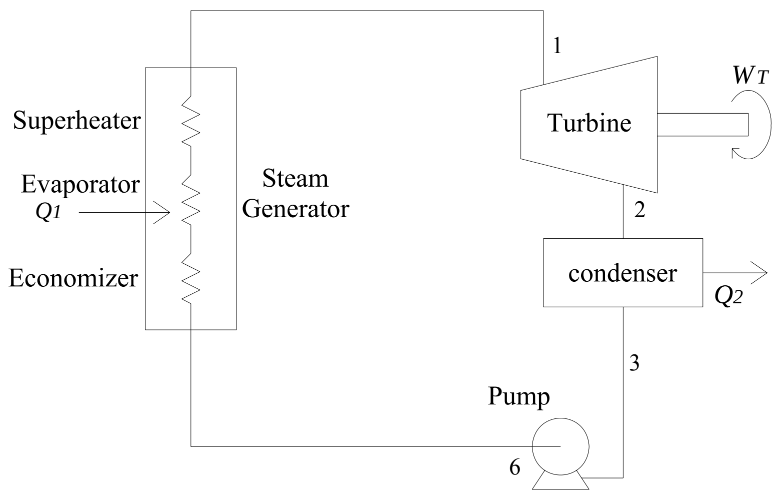
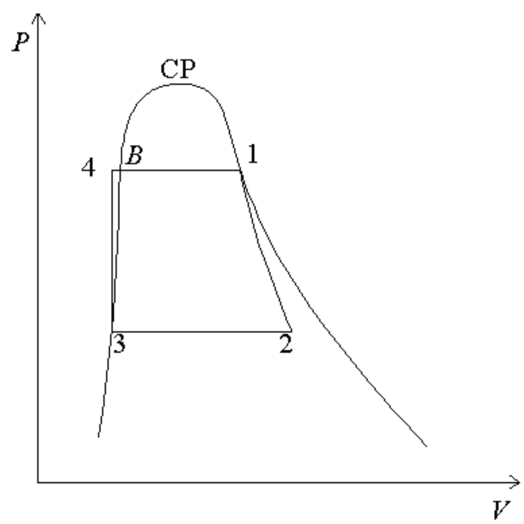


Figure 1 Schematic of thermal power plant



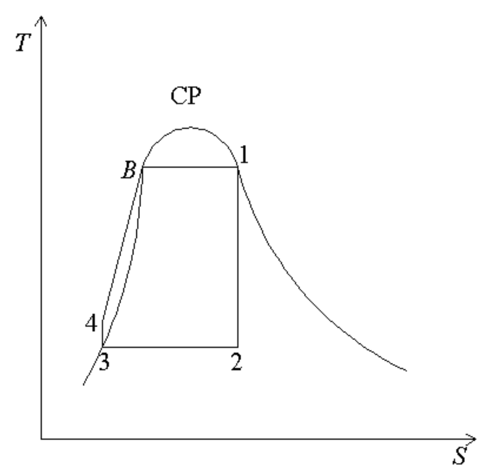


Figure 2 Rankine cycle on p-V coordinates

Figure.3 Rankine cycle on T-s coordinates

The efficiency of the ideal Rankine cycle is given by:

$$\eta = \frac{W_{net}}{Q_1} = \frac{W_T - W_P}{Q_1} = \frac{(h_1 - h_2) - (h_4 - h_3)}{h_1 - h_4}$$

Where W_P = Pump work

W_T = Turbine work

W_{net} = Net work = turbine work – pump work

Q_1 = Heat input

h_1 to h_4 = Enthalpy of steam at terminal points

The combustion gases leaving the boiler are at much higher temperature than saturation temperature at which steam is produced in a steam drum in ideal Rankine cycle resulting in irreversibility. Use of superheat and reheat reduces overall temperature difference between steam and gases and would improve the cycle thermal efficiency. Figure 4 and 5 shows Rankine cycle with superheat and reheat in which *ab* shows temperature drop in combustion gas and *1234* represents superheat cycle and *123456* is reheat cycle. Reheating is carried out at 20 to 25% of initial steam pressure to optimize the performance.

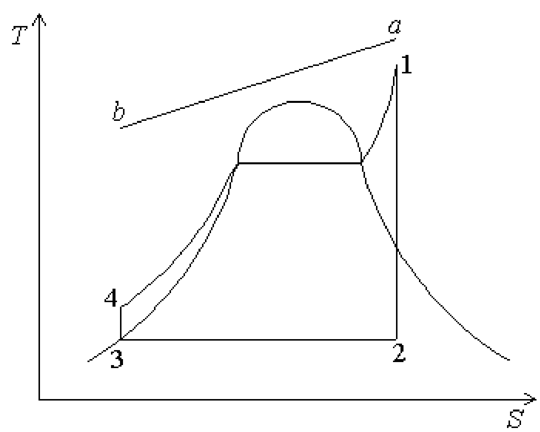


Figure 4 Rankine cycle with superheat

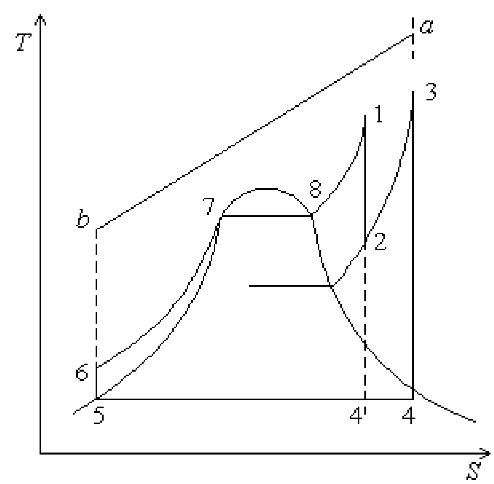


Figure 5 Rankine cycle with reheat

Another method to improve efficiency of ideal Rankine cycle is use of Regeneration through feed water heaters. Feed water heaters are basically of two types – open or closed, they extract live steam and use it's energy to heat the condensate. In most thermal power plants closed feed water heaters are used with at least one open feed water heater to serve the purpose of deaeration. Though regeneration substantially increases thermal efficiency of Rankine cycle, the gain in efficiency successively diminishes with the increase in the number of feed water heaters. The schematic and T-s diagram of regeneration is shown in figure 5 and 6 respectively.

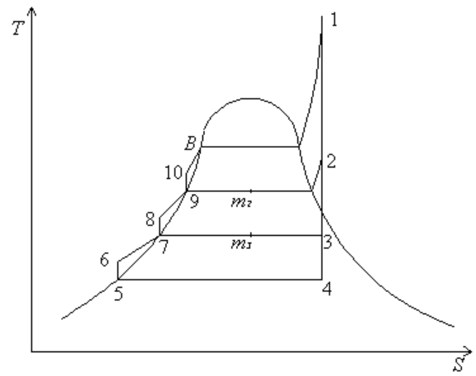


Figure 6 Rankine cycle with Regeneration

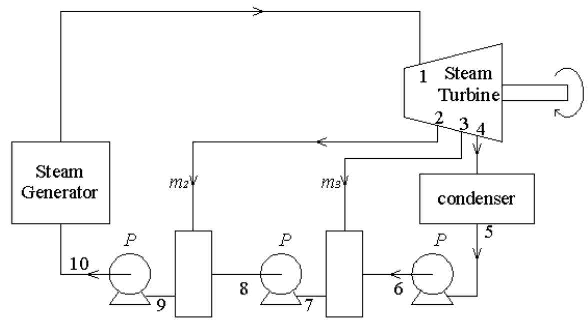


Figure 7 Schematic diagram of Regeneration

The overall efficiency of thermal power plant is given as:

$$\eta_{overall} = \frac{\text{power avaiilable at the generator}}{\text{rate of energy release by the combustion of fuel}} = \eta_{generator} \times \eta_{turbine} \times \eta_{thermal} \times \eta_{boiler}$$

The value of $\eta_{overall}$ is around 35% hence remaining 65% is lost to environment contributed by condenser loss, exhaust gas loss, generator and turbine inefficiency etc. Heat rate and Steam rate are two terms commonly used in thermal power plant. They are defined as following:

$$Heat\,rate = \frac{Q_1}{W_{net}}$$

$$Steam\ rate = \frac{1}{W_{net}} \frac{kg}{kWs}$$

This expresses the cycle efficiency and capacity of plant respectively.

Figure 8 shows a typical coal fired thermal power plant mentioning all major circuits of it and figure 9 shows steam and water circuit of thermal power plant.

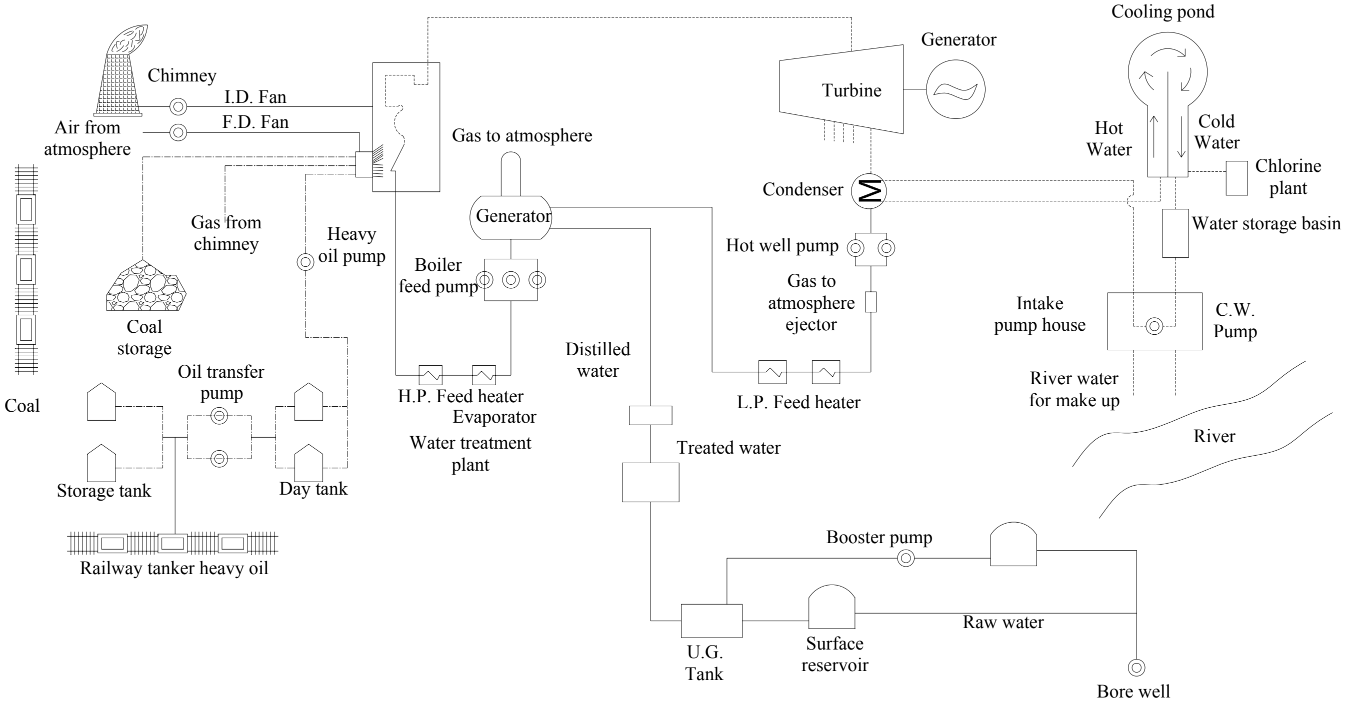


Figure 8 A typical lay-out of thermal power plant

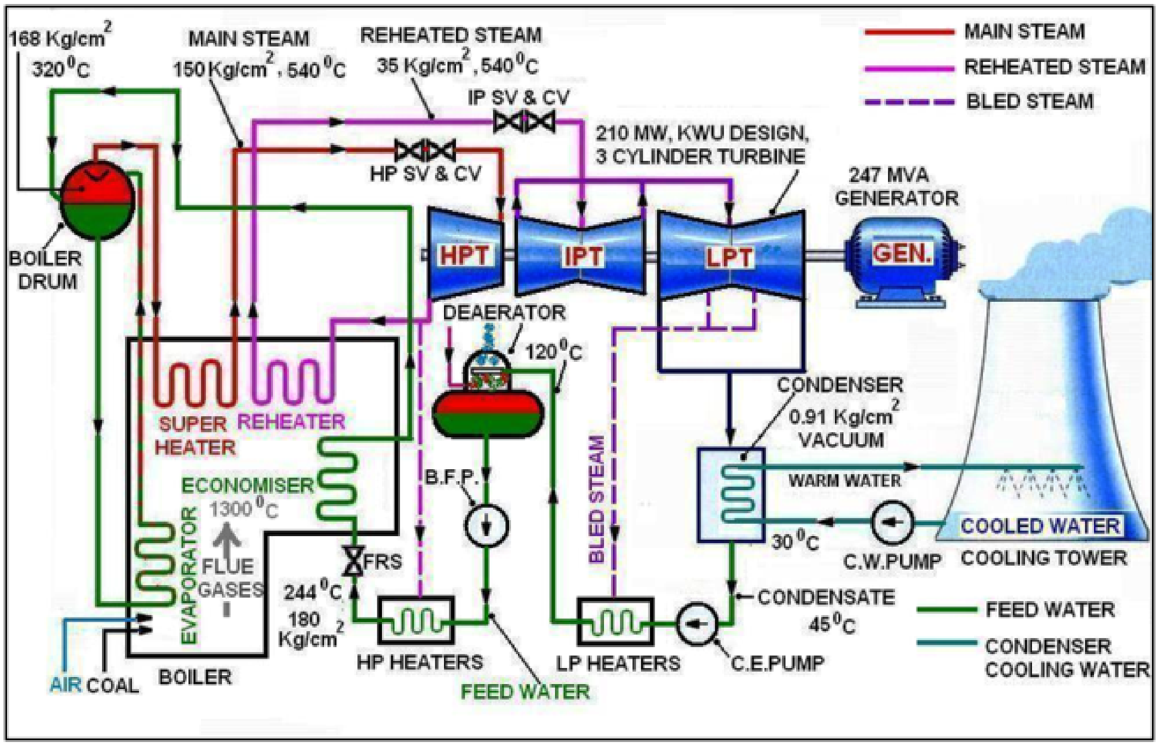


Figure 9 Steam And Water Circuit of Thermal Power Plant

Combined Cycle Power Plant

As there wide difference between combustion temperature and steam temperature there is a limitation in efficiency of the thermal power plant working on Rankine cycle. To achieve higher energy conversion efficiency from the fuel to electricity, combined cycle power plants are used with a high temperature plant as a topping plant over a steam operated power plant. A gas turbine plant either of open or close type is used as a topping plant as it offers the advantages like faster and cheaper installation, quick starting and fast response to load change. Gas turbine alone is not preferred in a utility system because of low cycle efficiency and large exhaust loss.

Figure 10 shows schematic of open gas turbine cycle. The gas enters a compressor where it is compressed and delivered to combustor. Heat is added at constant pressure in combustor (theoretically) and hot gas expands through the turbine and then after mixes with atmosphere and fresh air is supplied to the compressor. The compressor is driven by turbine and difference is available on shaft as net power output. The compression of air in compressor and expansion of gas in turbine are ideally isentropic in nature.

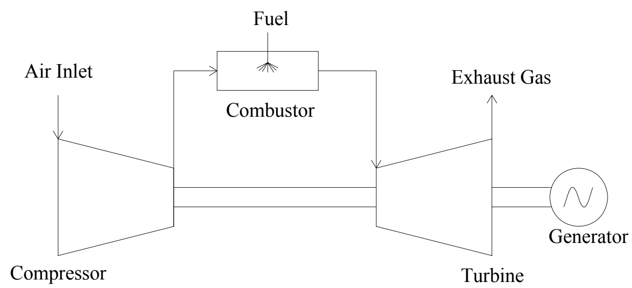


Figure 10 Open cycle gas turbine plant

Figure 11 shows intercooling and reheating on open cycle gas turbine plant and figure 12 shows regeneration on open cycle gas turbine plant. Use of intercooling between two stages of compression increases efficiency of cycle and similarly using staged heat supply increase power out put of turbine. In regeneration the waste heat of exhaust gas of turbine is utilized to increase the temperature of compressed air and hence the efficiency of the plant.

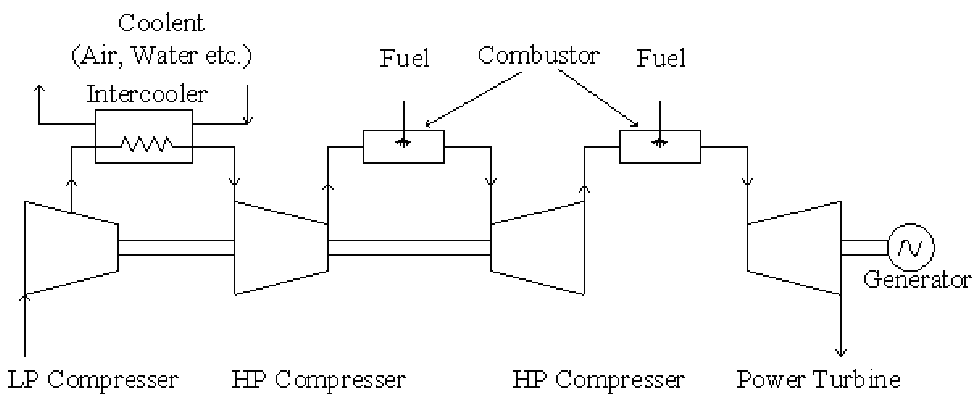


Figure 11 Intercooling and Reheating on Open Cycle Gas Turbine Plant

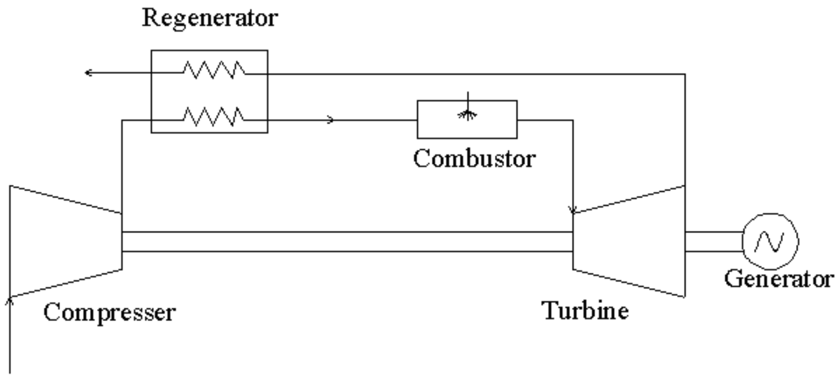


Figure 12 Regeneration on Open Cycle Gas Turbine Plant

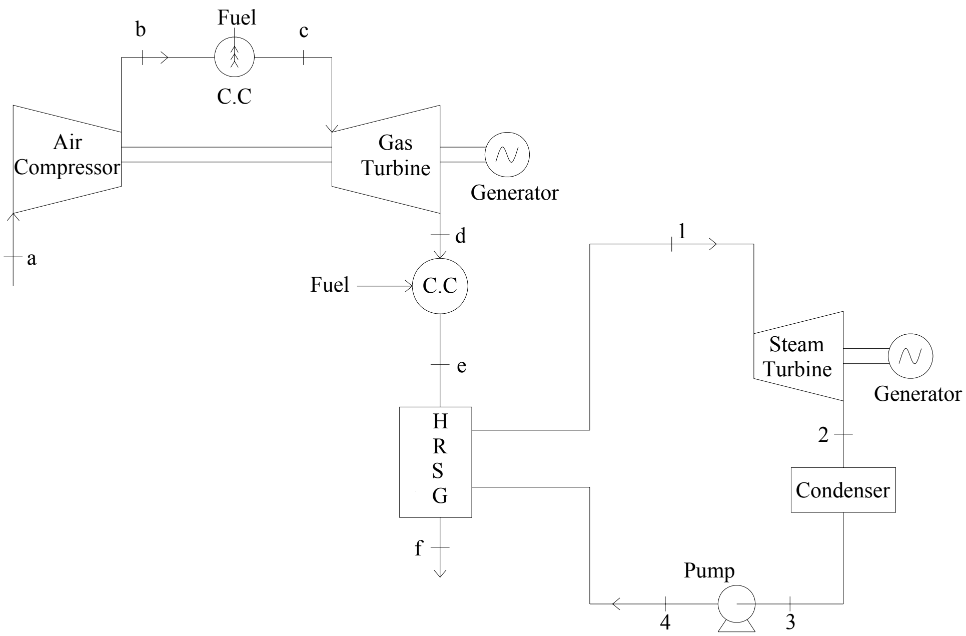


Figure 13 Schematic Flow Diagram of Combined Cycle Power Plant

Figure 13 shows schematic flow diagram of combined cycle consist of air compressor, combustor and gas turbine in topping cycle and heat recovery steam generator, steam turbine, condenser and pump in bottoming cycle. Path of open cycle gas turbine is indicated as *abcdef* Gas leaves the turbine at point *d* is further heated in combustion chamber where fuel is supplied and passes through heat recovery steam generator, which is a conventional steam generator having heat exchangers like evaporator, economizer, superheater, reheater etc. Gas turbine is usually operated with a high air-fuel ratio to make sufficient air available for further combustion. Gas leaves the HRSG at *f*. Path followed by steam cycle is shown as *1234*. Efficiency of combined cycle power plant is in normally 55 to 60%.

Energy audit methods and checklist discussed in present chapters are focused on thermal and combined cycle power plant technology as out of total electricity production 65% is produced by them. They are also applicable to steam cycle of nuclear power plant.

Energy Conservation in Power Plant

Energy conservation in any plant can be achieved by an energy audit which includes *familiarization of plant, first hand observations, historic data analysis, baseline data collection, preparation of flow chart for all service utilities, collection of design and operating data, measurement of various parameters, analysis of energy and material balance, identification of losses, identification of alternative technologies, their technical and economical viability, prioritization, documentation and finally implementation.* Findings of an energy audit of power plant will comprehensively identify the degraded plant components and their respective contribution to overall thermal efficiency loss and therefore will be valuable input into the next inspection maintenance scope to implement the necessary corrective actions. Some useful observations of energy audit of power plant are discussed in detail as below:

Use of Supercritical Pressure Boilers

Definition of problem: Use of supercritical pressure boiler instead of subcritical boilers. (Applicable in case of retrofits or new power plant installation.)

Discussion: Supercritical pressure coal-fired power generators use higher steam temperatures and pressures than sub-critical pressure (221.2 bar) power generation, and are more fuel-efficient (refer Rankine cycle T-s diagram) and environment friendly. Supercritical cycle with reheat and feed water heating has approximately 2 to 3 percent higher efficiency than subcritical cycle. Adopting as supercritical boiler instead of subcritical boiler will reduce fuel consumption and consecutively carbon dioxide emissions reduces by approximately 5 percent. Supercritical boiler is also known as once-through boiler as it does not require drum which adds to quick start and rapid load change. However, supercritical-type generation requires more sophisticated equipment design and high strength material to withstand the high temperatures and pressures. Extremely pure water is required since all solids present are deposited in the tubes or carried to the turbine blades. Availability of high temperature resistance material at economical rate has increased the adoption of supercritical pressure steam generation. Supercritical boiler is a good retrofit in existing plant.

Improving condenser performance by condenser tube cleaning

Definition of problem: Select appropriate method to clean the condenser tubes.
Discussion: A condenser degrades primarily due to fouling of the tubes and air in-leakage. Tube fouling leads to reduced heat transfer rates, while air in-leakage directly increases the backpressure of the condenser. Condenser tube cleaning is performed while the unit is on line or off line by mechanical, thermal or chemical method.

More suitable method for online cleaning is described here in which rubber **sponge balls** that flow through the condenser tubes with the coolant. Frictional contact between the balls and tubing scrapes away most of the fouling accumulated on the inside of the tubes. The balls are circulated through the condenser for a few hours each day. Periodical checking and replacement of balls are required as sponge balls eventually lose their surface roughness, or become deformed, and become unable to contact the inside wall closely.

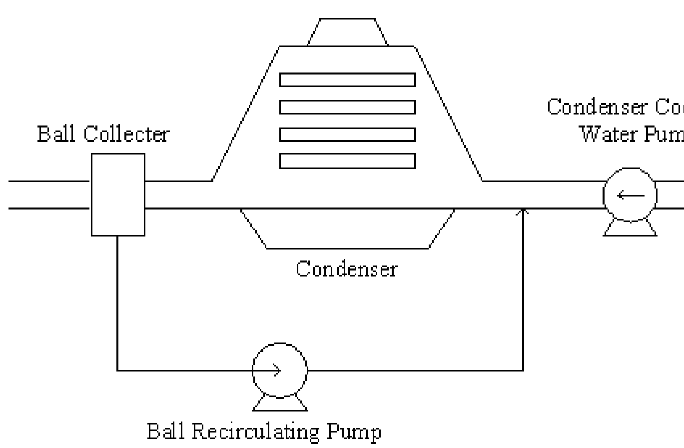


Figure 14 Arrangement Of Ball Type Tube Cleaning System

Figure 14 shows the basic arrangement of typical ball type cleaning system. The main components are a ball injection nozzle, a ball strainer, a ball recalculating pump and a ball collector.

Waste Heat Recovery

Definition of problem: Identify the source of waste heat and utilize it.
Discussion: Before installing any heat recovery system an investigation needs to be carried out to identify the ways to reduce the quantity of waste heat that is produced by improving the efficiency of the process. Heat recovery options are broadly classified into three types:

1. Recycling energy back into the process.
2. Recovering energy for other on-site uses.
3. Recovering energy for electricity generation.

Heat recovery process is further classified as active or passive. Active heat recovery requires input of energy to upgrade the waste heat to a higher temperature while the Passive heat recovery uses a heat exchanger of different type to transfer the heat from higher temperature source to lower temperature stream. The advantage of passive heat recovery device is they do not require significant mechanical or electrical input. Thus they have lower installation costs and generally are simpler to implement and maintain than active heat recovery strategies. In some applications both types of heat recovery devices are used together.

Type of heat recovery is determined by temperature, flow rate, availability over the course of day and year and fouling characteristics. Some waste heat recovery systems are discussed here:

Some examples of waste heat recovery for applicable temperature range are listed here.
Waste heat stream temperature is more than 100°C, waste heat is used for:

- Preheating combustion air
- Preheating boiler make-up water using a feedwater economizer

- Preheating the supply air into a process such as a food dryer by passing its supply air and exhaust through an air-to-air heat exchanger
- Using the flue gases from a furnace or dryer to preheat the material entering in it
- Using waste heat from a process to meet other in-plant needs such as space heating, water heating, recharging the media in desiccant dehumidification, or providing heat to other lower temperature processes

Waste heat stream temperature is in the range of 100°C to 200°C, waste heat is used for:

- Absorption chillers of refrigeration or air conditioning device.

Waste heat stream temperature is more than 200°C, waste heat is used for:

- ORC (Organic Rankine Cycle) which uses working fluid as a refrigerant instead of steam.

Sootblowing Optimization

Definition of problem: Efficient operation of sootblower.

Discussion: Sootblowing is an important part of boiler operation, since a clean heat transfer surface is desirable for achieving high operating efficiency. Fossil fuel-fired power generating units employ soot cleaning devices like sootblowers, sonic devices, water lances, and water cannons or hydro-jets. These soot cleaning devices use steam, water or air to dislodge slag and clean surfaces within a boiler. The number of soot cleaning devices on a given power generating unit can range from several to over a hundred. Manual sequential and time-based sequencing of soot cleaning devices have been the traditional methods employed to improve boiler cleanliness. These soot cleaning devices are generally automated and are initiated by a master control device.

Frequent operation of soot blower wastes steam, increases blower maintenance cost, and aggravates the tube erosion. Conversely, far less frequent blowing allows too much soot accumulation and hence decreases efficiency. It may also cause high stack opacity when the fouling area is being blown. Therefore, intelligent adjustment of the cleaning schedule according to the actual cleaning need helps to maintain boiler efficiency.

Reduction in Auxiliary Power Consumption

Definition of problem: Minimize auxiliary power consumption.
Discussion: Auxiliary Power Consumption of is around 6% for 500 MW plant and 8 to 10% for 100 to 250 MW power plants. Various systems contributing to auxiliary power consumptions are shown in figure 15. Plant load factor, operational efficiency of equipment, start up and shut down, age of the plant and coal quality are the key features affecting auxiliary power requirement.

Auxiliaries may consume up to 12% of total generation, hence reduction of even 0.5 - 1.0 % will result in huge savings and additional output of a few Megawatts.

Suggestions on individual auxiliary power consumption devices are given in the following section:

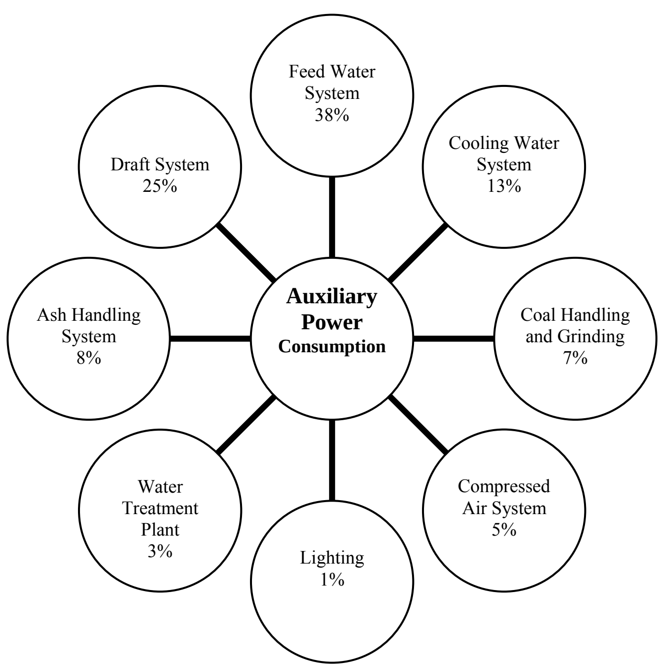


Figure 15 Various Systems Auxiliary Power Consumption

Boiler feed water system

1. Use of speed control in place of valve control
2. Use of variable speed drive boiler feed pump and condensate extraction pump and variable speed drive hydraulic coupling
3. Perform boiler feed pump scoop operation in three element mode instead of DP mode
4. Avoid Recirculation and faulty valve.
5. Replacement of worn out cartridge of boiler feed pump reduces current consumption and short circuit of feed water flow inside the pump.
6. Perform CEP Pressure reduction by Stage removal

Fans and Draft Systems

1. Arresting Air in-leaks in draft system by O2 measurement as
   Excess Air for combustion results in increase of FD, PA & ID fan power
   Leakage in APH results in increase of FD, PA & ID fan power consumption
   Leakage in Duct & ESP body results in increase of ID fan power consumption
2. Comparative analysis of fan performance with respect to design condition and identification of gaps by investigation and observation.

1. Check inlet/outlet duct connections, fan body for holes and cracks.
2. Remove deposits formation in impellers and casings.
3. Treat erosion of impeller blades.
4. Properly maintain Primary Air to Secondary Air ratio to reduce the PA fan power consumption
5. Elimination of damper and inlet Guide vane based capacity control with variable speed control systems.
6. Use of energy efficient fans. Change existing impeller with energy efficient, appropriate sized impeller.

Coal Handling Plant

1. Proper Capacity utilization of loading system and avoiding idle running of conveyors/crushers
2. Use of auto Star Delta starters instead of direct online (DOL) to minimize losses.
3. Observe that crushers are adequately and constantly loaded.

Coal Milling/Grinding System

1. Maintain proper air fuel ratio
2. Periodically test size of coal particles and minimize fines
3. Optimized Mill parameters like ball loading, roller pressure etc with respect to size and quality of coal.

Cooling Water System

Cooling Water Pumps

1. See that pump is operating near to the best efficiency point
2. Avoid mismatch of required head and rated head by proper selection of pump.
3. Avoid circulation of water in stand by systems.
4. Use of booster pump is more advisable for small load at higher pressure.
5. Check seals and packing to minimize waste of water.

Cooling tower

1. Use nozzles to give better distribution over the fill.
2. Follow manufacturers recommended clearances around cooling towers while locating and relocate or modify structures that interfere with inlet and exhaust air.
3. Optimize cooling tower fan blade angle on weather and/or load basis.
4. Correct excessive and/ or uneven fan blade tip clearance.
5. Periodically clean plugged distribution nozzles of cooling tower.
6. Maintain the optimum liquid to gas ratio (normally 1.4 to 1.6).

Water Treatment Plant and Water Pumping

1. Avoid over sized pump.
2. Use lever controller for filling the tank and variable speed drives with feedback control.

3. Do impeller trimming to permanently reduce the capacity of pump.
4. Periodically check valves and leakage in gland sealing. Also check for deposition on impeller and casing.
5. Use multiple pumps in parallel operation as per flow requirement.

Compressed air System

1. Reduce discharge air pressure to lowest allowable limit.
2. Install a control system to coordinate more than one air compressors.
3. Screw compressors have better efficiency than reciprocating compressor.
4. Identify and attend leakages and minimize purges.
5. Monitor compressed air distribution system and select lower pressure drop network.

Gas Turbine Inlet Air Cooling

Definition of problem: Inlet air temperature of air compressor of gas turbine.
Discussion: Cooling the turbine inlet air even by a few degrees increases power output substantially. This is because combustion turbines are constant volume machines hence at a given shaft speed they always move the same volume of air while the power developed by turbine depends on the flow of mass through it. Thus during summer air is less dense and power output reduces. By supplying cooler air to the compressor, mass flow rate is increased, resulting in higher output. Another reason of poor performance of gas turbine during summer is power consumption of compressor. The work required to compress air is directly proportional to the temperature of the air, so reducing the inlet air temperature reduces the work of compression and there is more work available at the turbine shaft. The typical Gas Turbine on a hot summer day, for instance, produces up to 20% less power than on a cold winter day.

There is, however, a limitation on the amount of inlet air cooling that can safely be accomplished. If the temperature is allowed to go too low, ice may form on inlet guide vanes which will damage the compressor blades. This phenomenon may occur even when the inlet air temperature is above freezing point of moisture as the suction at a turbine inlet creates low pressure. To avoid this problem, most turbine manufacturers recommend that minimum inlet air temperature of 8°C. Traditionally, mechanical chillers or evaporative coolers are used to cool combustion turbine inlet air. Recently fogging system or absorption chillers are used to cool the inlet air.

Factors affecting the selection and economics of turbine inlet system are listed below:

- Combustion turbine characteristics
- Plant location (Local DB and WB temperature profile)
- Electric power demand profile
- Electric energy selling price profile
- Fuel cost profile

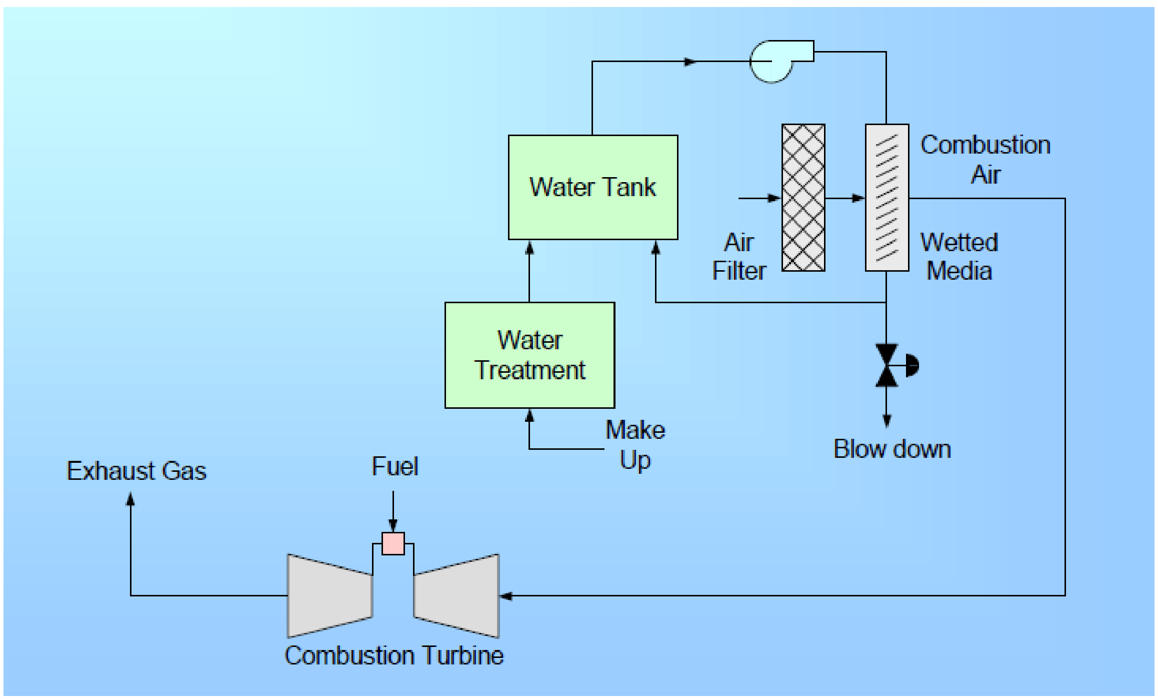


Figure 16 Evaporative Cooling For Air Cooling

Evaporative cooling and fogging systems (refer figure 16) are useful for less humid locations. Their initial and running cost are low and cooling capacity is also low. For more humid locations mechanical chillers are the alternative solution. Absorption chillers are used when the plant is in a combined cycle or cogeneration mode and has access to low pressure steam.