POWER PLANTS

INSTRUCTOR'S MANUAL

UET

DEPARTMENT OF MECHANICAL ENGINEERING (KSK CAMPUS)

UNIVERSITY OF ENGINEERING & SCIENCE TECHNOLOGY
LAHORE

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List of Experiments

EXPERIMENT NO: 1

Visit to Mini Steam Turbine Power Plant (Model PC-TMS-400A)

EXPERIMENT NO: 2

To determine the thermal efficiency (η_{th}) of a steam boiler and measure its evaporating rate

EXPERIMENT NO: 3

To determine the dryness fraction (x) of steam with the help of throttling calorimeter

EXPERIMENT NO: 4

To determine the thermal efficiency of a super heater and evaluate its performance

EXPERIMENT NO: 5

To determine the thermal efficiency of a steam turbine and evaluate its performance

EXPERIMENT NO: 6
To determine the condenser heat exchange rate and evaluate its performance

EXPERIMENT NO: 7
To determine the overall efficiency of Steam Turbine Experimental Apparatus

EXPERIMENT NO: 8
To determine the overall efficiency of Gas generator set of UET

EXPERIMENT NO: 9
To determine the overall efficiency of Diesel generator set of UET

EXPERIMENT NO: 10
To determine the thermal efficiency of Cooling towers at UET

1. <u>Experiment No -1</u>

1.1 Objective

Visit to Mini Steam Turbine Power Plant (Model PC-TMS-400A)

1.2 Steam turbine power plant

The diagram of the specified steam power plant is given below:

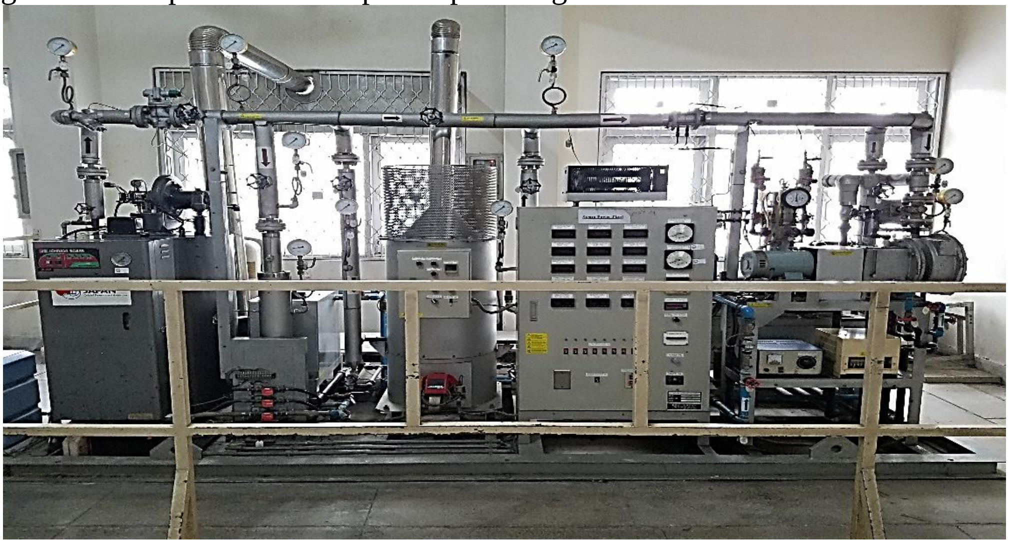

Fig.1. 1. Steam turbine power plant running on kerosene oil

1.2.1 Basic Process

The thermodynamic cycle for the steam turbine is known as the Rankine cycle. This cycle is the basis for conventional power generating stations and consists of a heat source (boiler) that converts water to high pressure steam. In the steam cycle, water is first pumped to elevated pressure, which is medium to high pressure, depending on the size of the unit and the temperature to which the steam is eventually heated. It is then heated to the boiling temperature corresponding to the pressure, boiled (heated from liquid to vapor), and then most frequently superheated (heated to a temperature above that of boiling). The pressurized steam is expanded to lower pressure in a turbine, then exhausted either to a condenser at vacuum conditions, or into an intermediate temperature steam distribution system that delivers the steam to the industrial or commercial application. The condensate from the condenser or from the industrial steam utilization system is returned to the feedwater pump for continuation of the cycle.

The simple Rankine cycle is shown below:

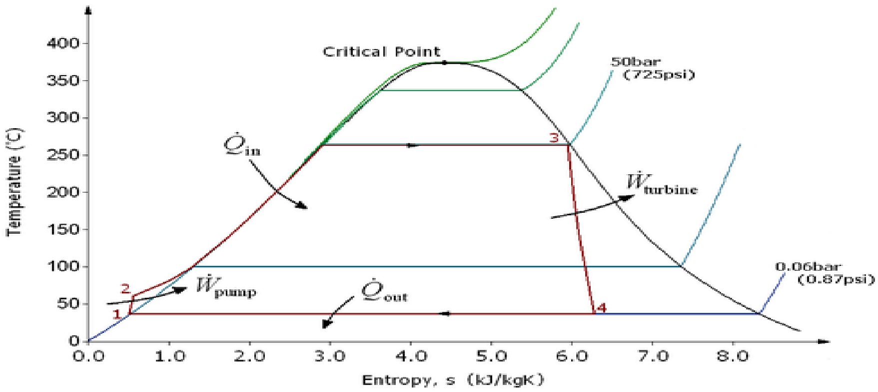

Fig.1. 2. T-s diagram of simple Rankine cycle

1.2.2 Types of steam turbine power plants based on efficiency improvements

Following modifications are done to steam turbine power plant for improving thermal efficiency of the cycle:

1. Super heating the dry saturated steam
2. Reheating of the steam
3. Regeneration with open and closed feedwater heater

1.2.2.1 Steam cycle with super heating

In this cycle, the **dry saturated steam at the boiler outlet is heated in a super heater** so that it becomes extremely hot and becomes super-heated vapor. This increases the vapor quality at turbine outlet as well as thermal efficiency of the cycle. But it needs extra fuel input.

- **Steam at turbine inlet is super-heated**
- **Steam at turbine outlet is wet with high dryness fraction**

Its cycle is shown below:

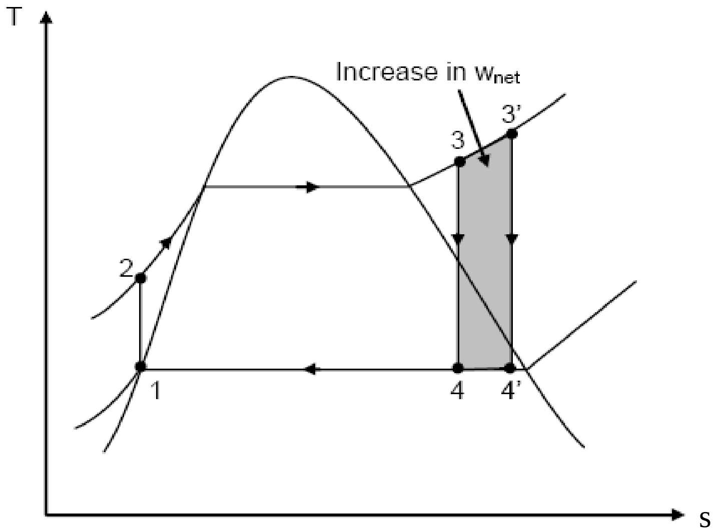

Fig.1. 3. Effect of heating the steam to a higher temperature at the turbine inlet

Its schematic is shown below:

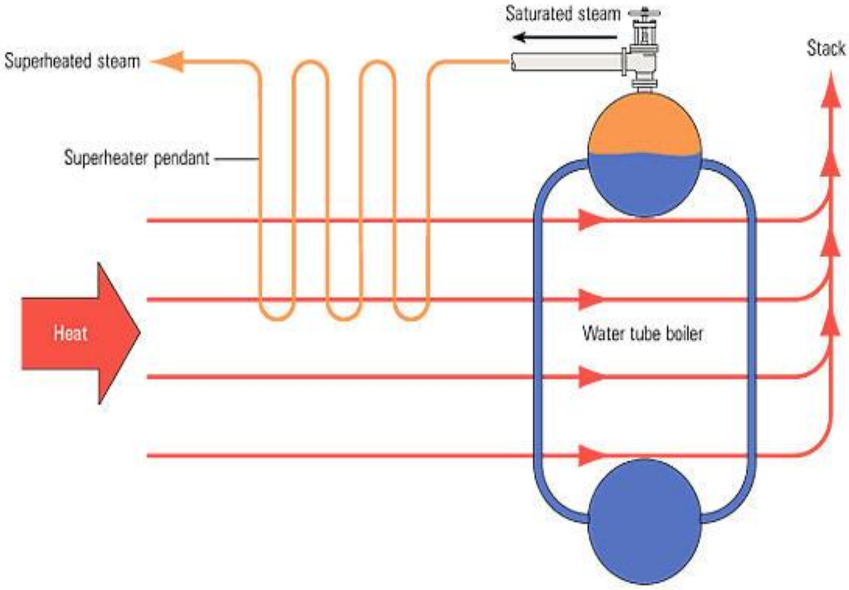

Fig.1. 4. Schematic diagram of a superheater

1.2.2.2 Reheating cycle

In this cycle, the steam is expanded in high pressure turbine at intermediate pressure and then this steam goes into the reheater present inside the boiler which increases the temperature of the steam at constant pressure. This steam goes into the low-pressure turbine to produce more output work.

It increases the thermal efficiency of cycle but more heat input is required and the power plant becomes more complex.

- **Steam at turbine inlet is super-heated**
- **Steam at turbine outlet is wet with high dryness fraction**

Reheat cycle is given below:

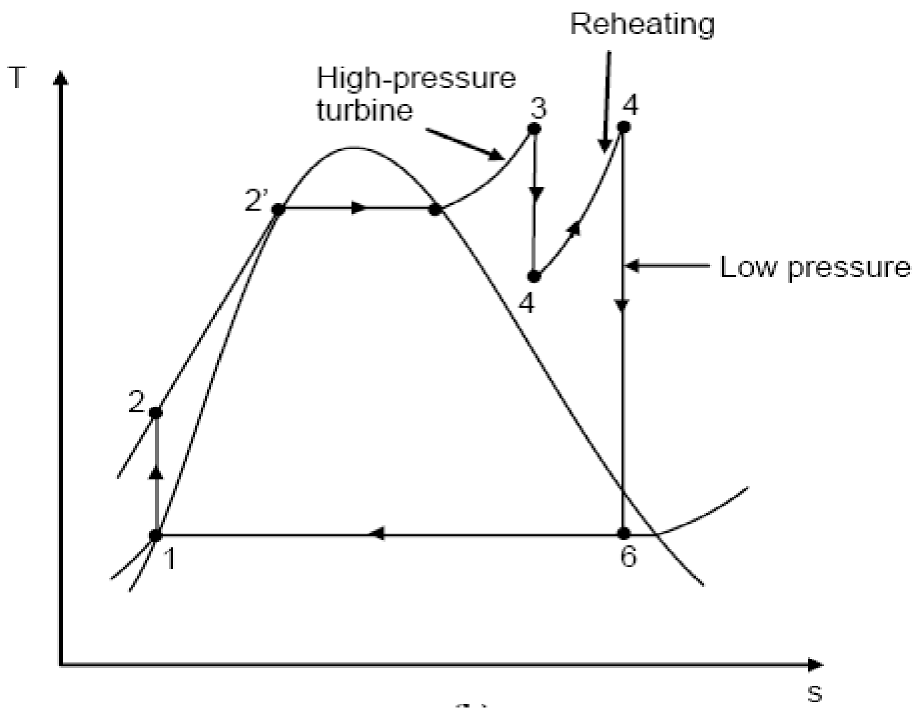

Fig.1. 5. Rankine cycle with reheating of the steam

Its schematic plant layout is shown below:

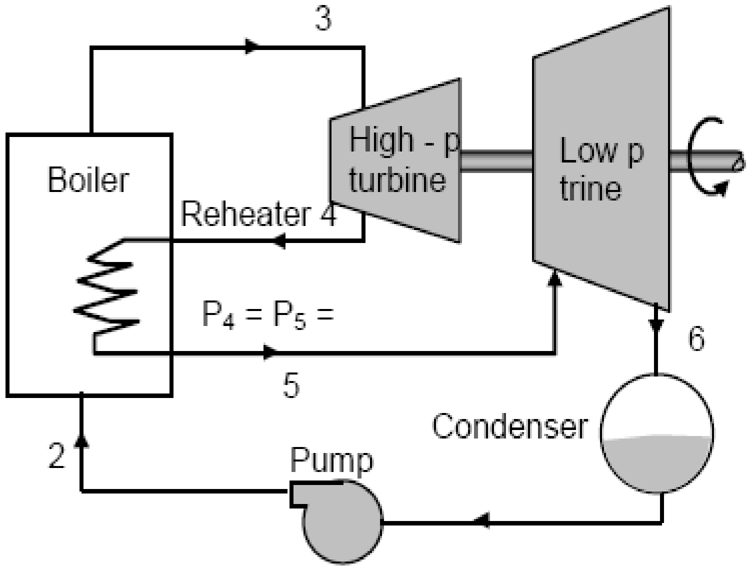

Fig.1. 6. Schematic diagram of the steam power plant with a reheater

1.2.2.3 Regenerative cycle

In this cycle, the steam passing through steam turbine is bleeded at an intermediate stage and it passes through the feedwater heater to heat the feed water coming from condenser.

In open feed water heater, the steam and feedwater directly mix while in closed feedwater heater there is no direct contact.

This modification increases the thermal efficiency of the cycle, but plant becomes more complex and difficult to maintain.

- **Steam at turbine inlet is super-heated**
- **Steam at turbine outlet is wet with dryness fraction less than in reheat cycle**

Cycle with open feedwater heater and its schematic is shown below:

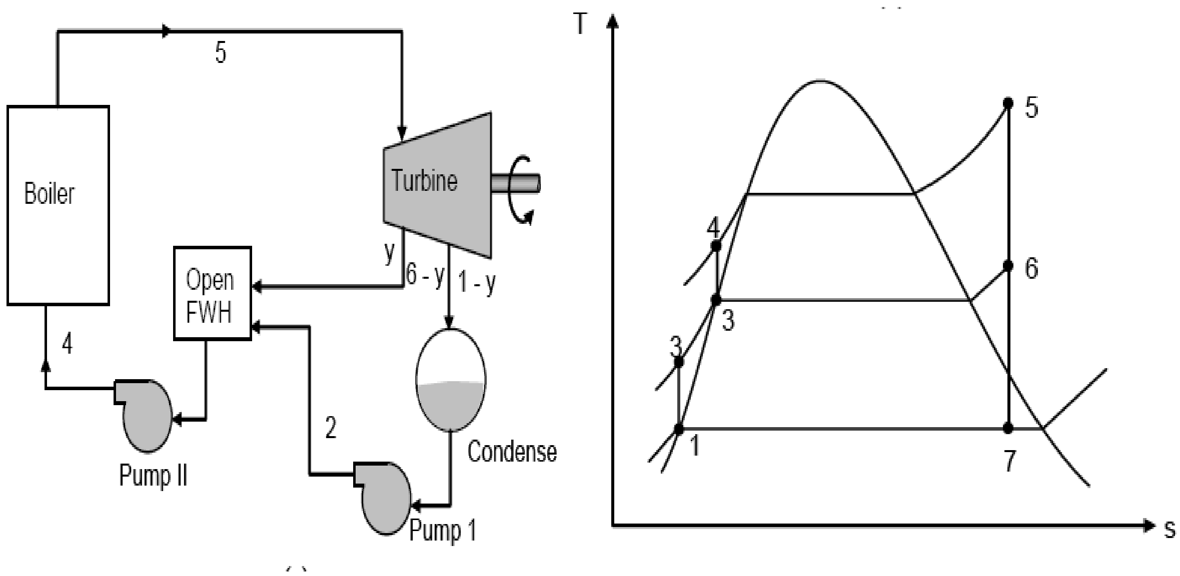

Fig.1. 7. Schematic of steam power plant with regeneration using open feedwater heater and its T-s cycle

Cycle with closed feedwater heater and its schematic is shown below:

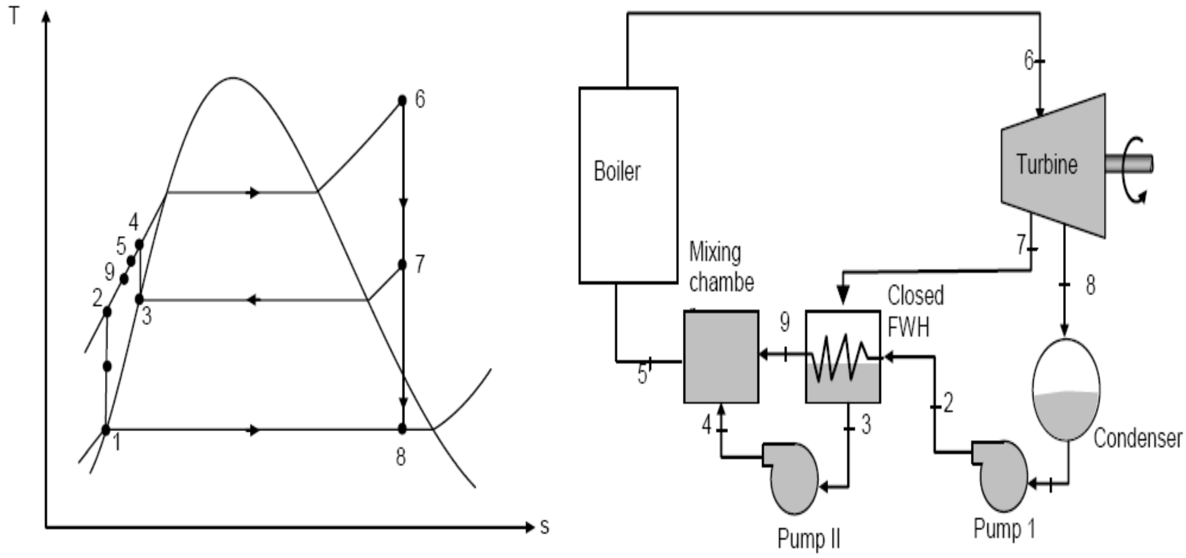

Fig.1.8. Schematic diagram of steam power plant with regeneration using closed feedwater heater and its T-s cycle

1.2.3 Components

A schematic representation of a steam turbine power plant is shown below:

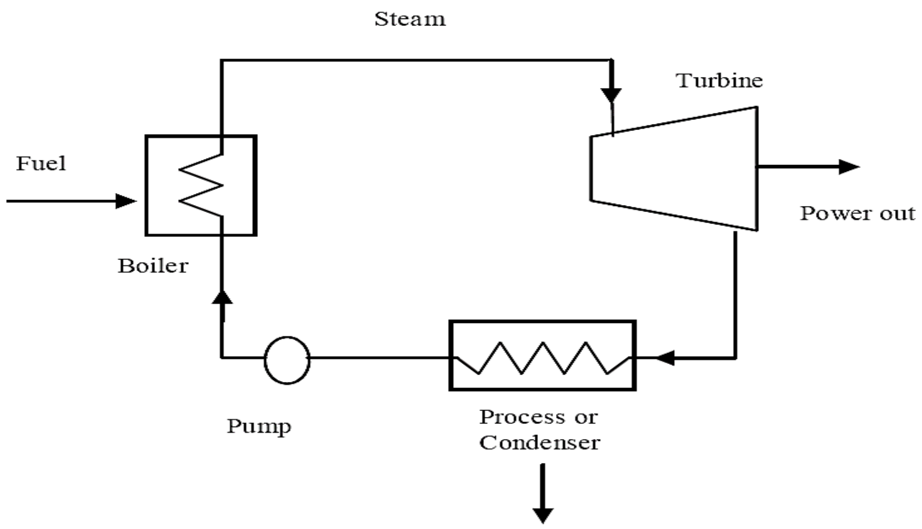

Fig.1. 9. Components of a steam turbine power plant

In the simple schematic shown, a fuel boiler produces steam which is expanded in the steam turbine to produce power. When the system is designed for power generation only, such as in a large utility power system, the steam is exhausted from the turbine at the lowest practical pressure, using a water-cooled condenser to extract the maximum amount of energy from the steam.

2. Experiment No -2

2.1 Objective

To determine the thermal efficiency (η_{th}) of a steam boiler and measure the evaporating rate

2.2 Apparatus

Boiler (Steam generating device)

2.3 Theory

2.3.1 Boiler

It is the component in which water is converted to steam by combusting the fuel. The phase change process occurs in the evaporator part of the boiler at constant elevated pressure so that more heat can be added to the water. Inside a boiler, there may be an economizer which preheats the water by waste flue gases. The superheater present in the boiler heats up the dry saturated steam. There are various types of fuels for running boiler, but coal is used commonly.

2.3.1.1 Types of fuel used in boiler

2.3.1.1.1 Fuel oil boiler

It runs on the fuel oil like diesel and residual fuel. They are very diverse. They are used for both industrial and residential purposes.

2.3.1.1.2 Propane boiler

This runs on the propane gas which is a byproduct of natural gas.

2.3.1.1.3 Natural gas boiler

This boiler uses natural gas to produce steam. These are mostly used for domestic purposes.

2.3.1.1.4 Electric boiler

These boilers use electric heater for steam production. These are very efficient and there is no waste gas.

2.3.1.1.5 Biofuel boiler

This boiler uses wood and other biofuels for steam production. These are least expensive but mostly used for domestic purposes.

2.3.1.1.6 Nuclear boiler

These boilers use nuclear fuel like Uranium or Plutonium for carrying out nuclear fission reaction and the heat released causes the water to boil.

There are some health hazards due to radiation emission and nuclear waste needs to be disposed off properly to save the environment.

2.3.1.1.7 Coal boiler

This is the most commonly used boiler for power plants because of availability of coal and cheap price. But it affects environment by the carbon emissions.

2.3.1.1.8 Boilers running on renewable energy

Renewable energy like solar and wind are used for steam generation and there is no effect on environment since there are no emissions and this energy is renewable and abundantly available.

2.3.1.2 Type of boilers

There are various bases upon which boilers are classified, which are given below:

2.3.1.2.1 According to Relative Passage of water and hot gases

1. **Water Tube Boiler:** A boiler in which the water flows through some small tubes which are surrounded by hot combustion gases, e.g., Babcock and Wilcox, Stirling, Benson boilers, etc.
   Following diagram shows this type:

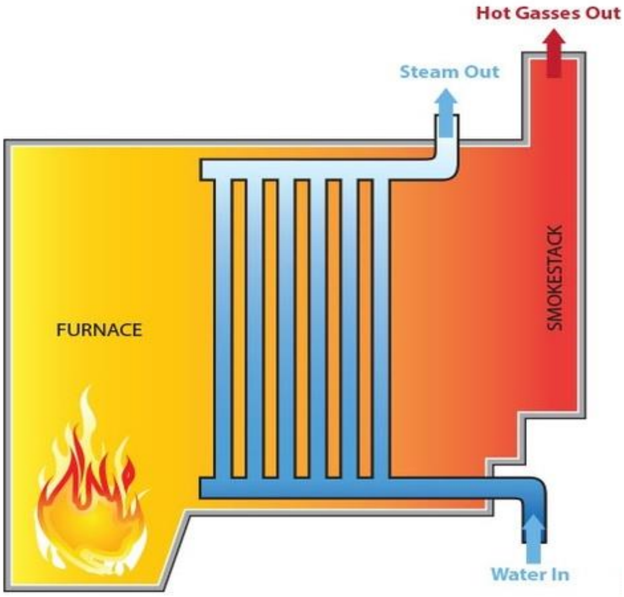

Fig.2. 1. Schematic of a water tube boiler

2. **Fire-tube Boiler:** The hot combustion gases pass through the boiler tubes, which are surrounded by water, e.g., Lancashire, Cochran, locomotive boilers, etc.
   Following diagram depicts this type:

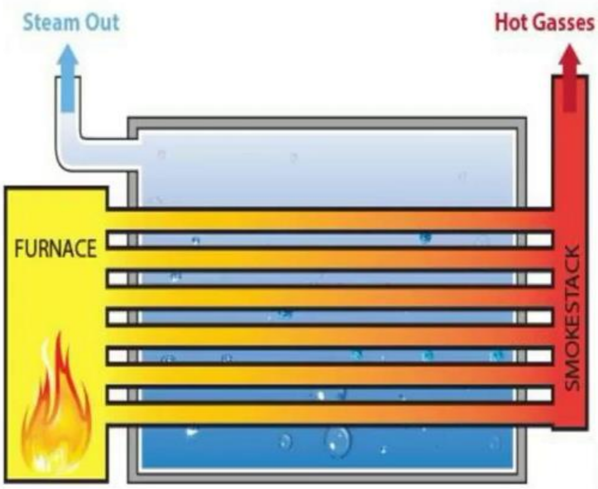

Fig.2. 2. Schematic of a fire tube boiler

2.3.1.2.2 According to Water Circulation Arrangement

1. **Natural Circulation:** Water circulates in the boiler due to density difference of hot and water, e.g., Babcock and Wilcox boilers, Lancashire boilers, Cochran, locomotive boilers, etc.
2. **Forced Circulation:** A water pump forces the water along its path, therefore, the steam generation rate increases, Eg: Benson, La Mont, Velox boilers, etc.
   Following figure explains these types:

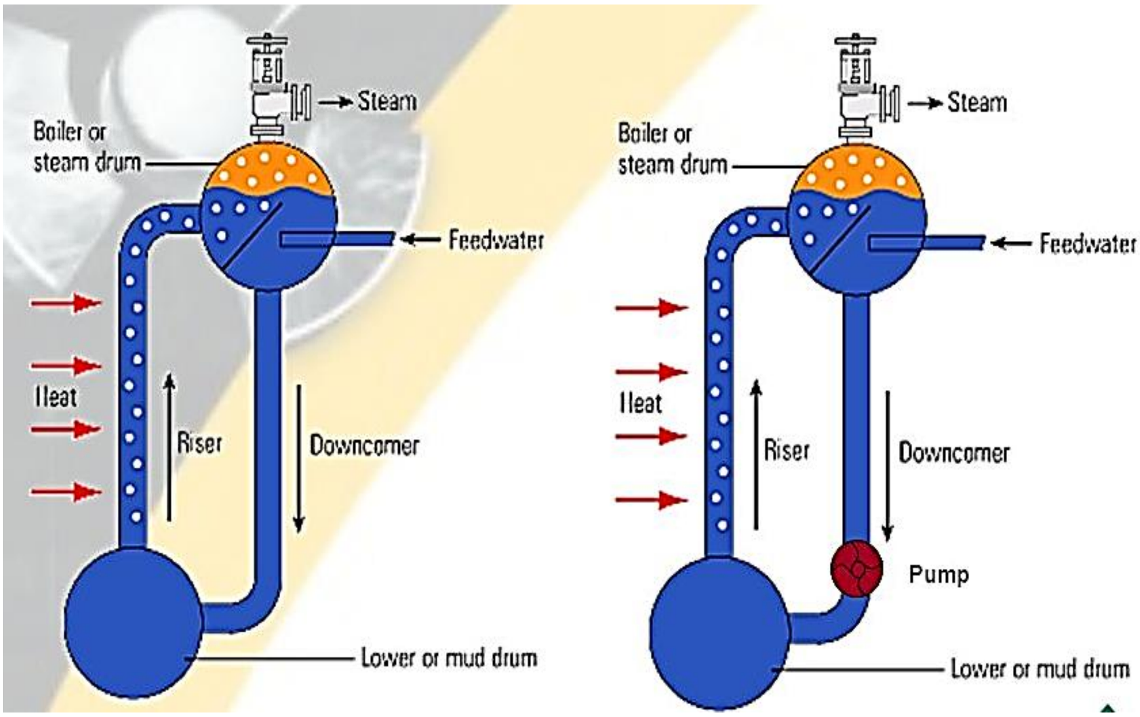

Fig.2. 3. Forced water circulation vs natural water circulation in a boiler

2.3.1.2.3 According to the Use

1. **Stationary Boiler:** These boilers are used for power plants or to process steam in plants. Following figure depicts it:

Fig.2. 4. A stationary boiler

2. **Portable Boiler:** These are small units of mobile and are used for temporary uses at the sites. Following figure depicts it:

Fig.2. 5. A portable boiler

3. **Locomotive:** These are specially designed boilers. They produce steam to drive railway engines. Following figure depicts it:

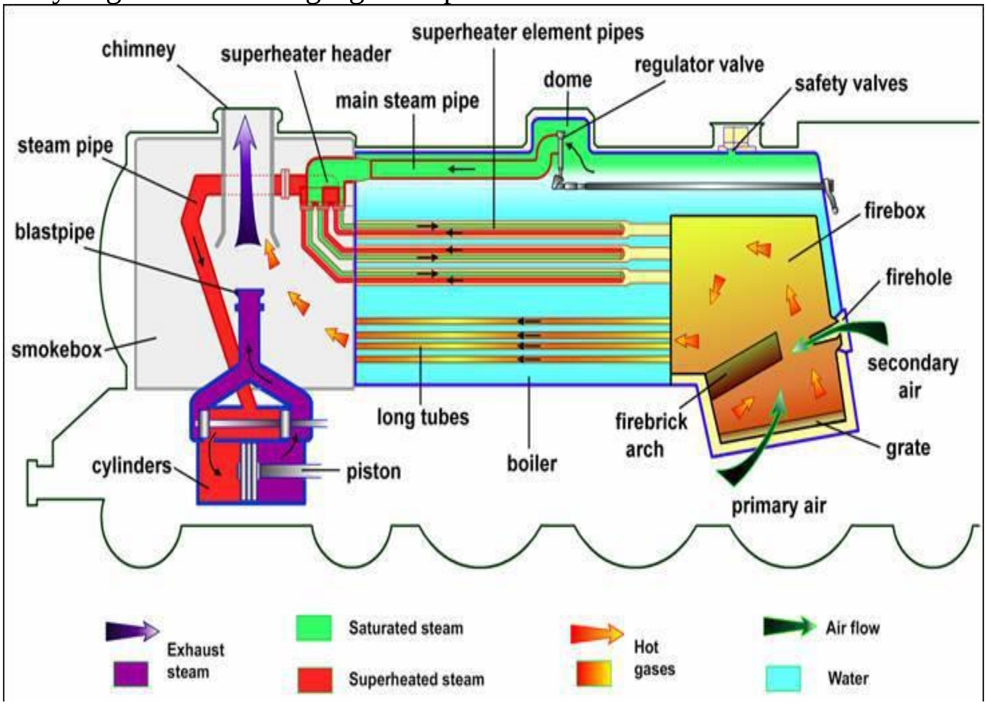

Fig.2. 6. Use of the boiler in locomotive

4. **Marine Boiler:** These are used on ships.
Following figure depicts this type:

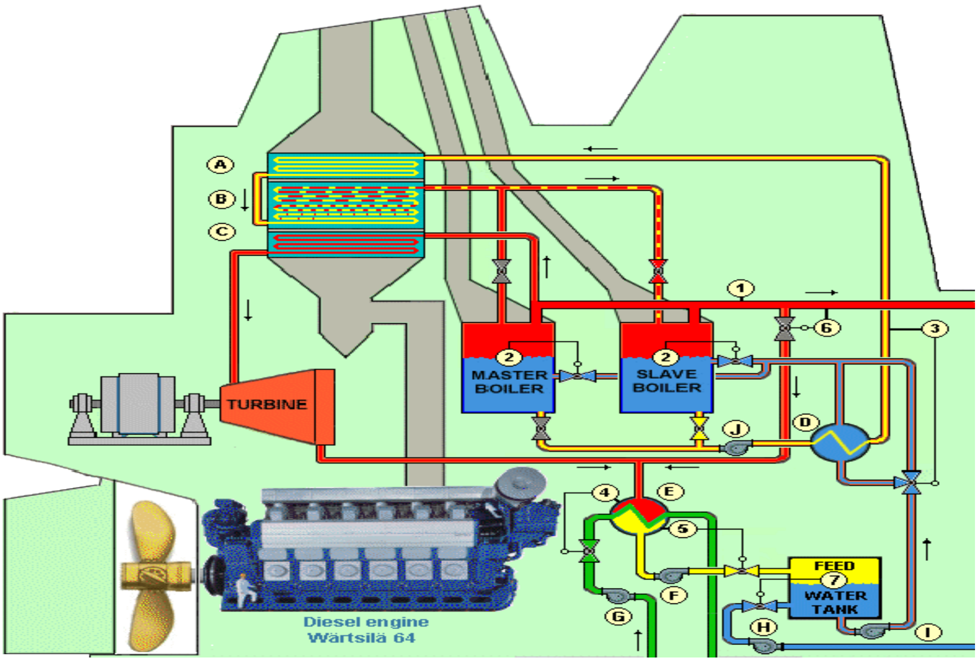

Fig.2. 7. Schematic diagram of the boilers under operation in a ship

2.3.1.2.4 According to Position of the Boilers

1. Horizontal

Fig.2. 8. A boiler in horizontal position

2. Inclined

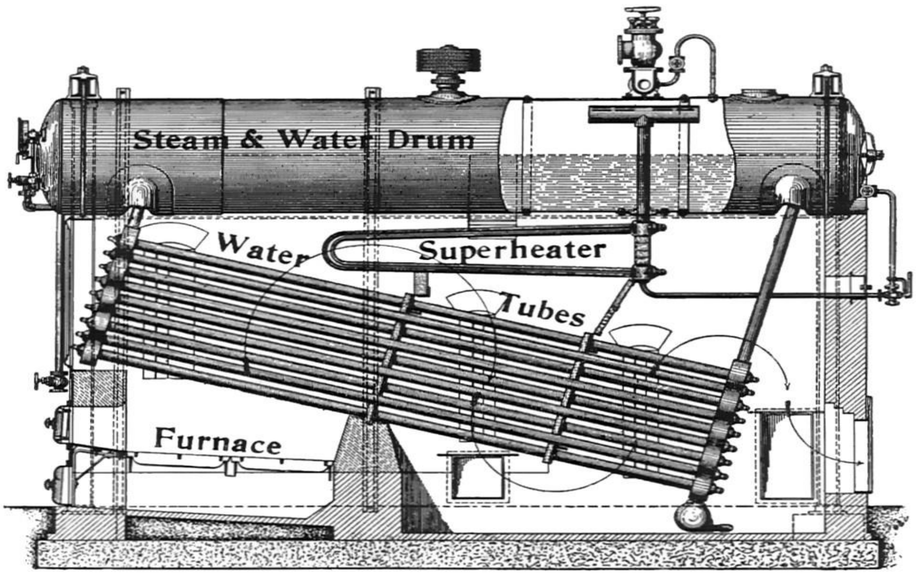

Fig.2. 9. A boiler with inclined water tubes

3. Vertical boilers

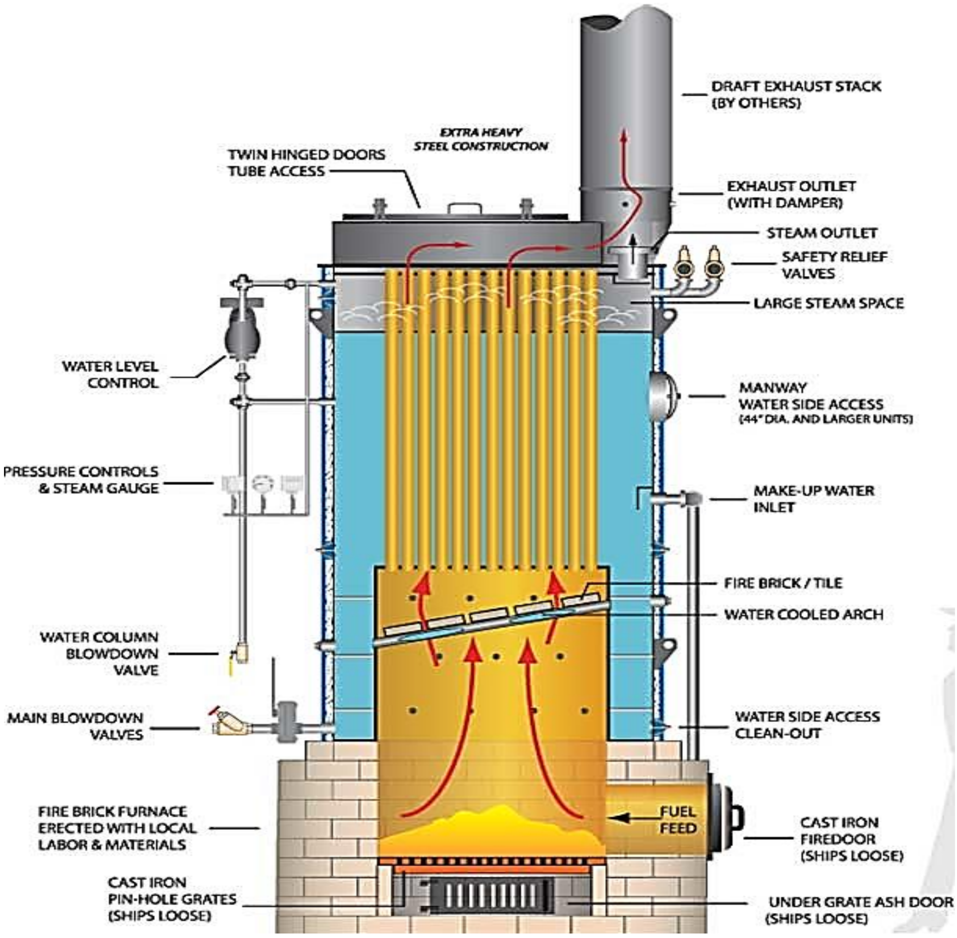

Fig.2. 10. A boiler with vertical fire tubes

2.3.1.2.5 According to the Position of Furnace

1. **Internally fired:** The furnace is located inside the shell, e.g., <u>Cochran</u>, Lancashire boilers, etc.
   Following figure depicts this:
2. **Externally fired:** The furnace is located outside the boiler shell, e.g., <u>Babcock and Wilcox</u>, Stirling boilers, etc.
   Following figure depicts these:

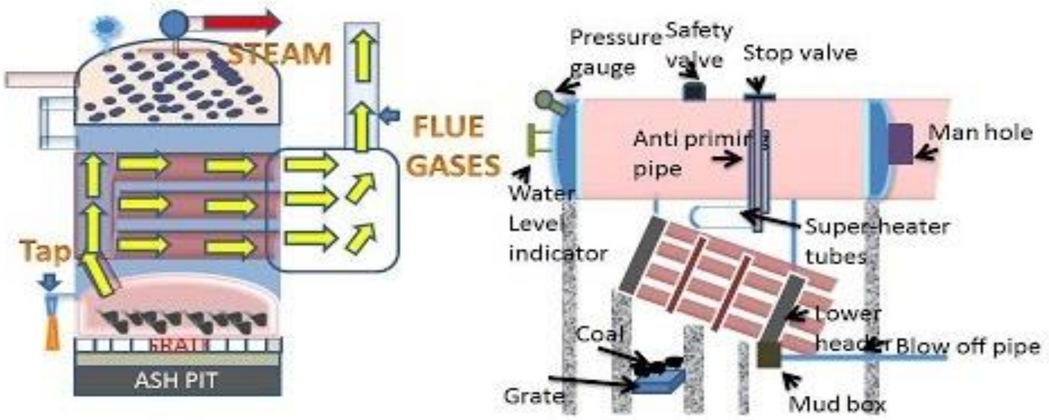

Fig.2. 11. Schematic of internally fired boiler on left side vs externally fired boiler on right side

2.3.1.2.6 According to Pressure of steam generated

1. **Low-pressure boiler**: a boiler which produces steam at a pressure of 15-20 bar is called a low-pressure boiler. This steam is used for process heating.
2. **Medium-pressure boiler:** It has a working pressure of steam from 20 bars to 80 bars and is used for power generation or combined use of power generation and process heating.
3. **High-pressure boiler:** It produces steam at a pressure of more than 80 bars.
4. **Sub-critical boiler:** If a boiler produces steam at a pressure which is less than the critical pressure, it is called as a subcritical boiler.
5. **Supercritical boiler:** These boilers provide steam at a pressure greater than the critical pressure. These boilers do not have an evaporator and the water directly flashes into steam, and thus they are called once through boilers.
   Difference in Rankine cycle of super and subcritical boiler is shown below:

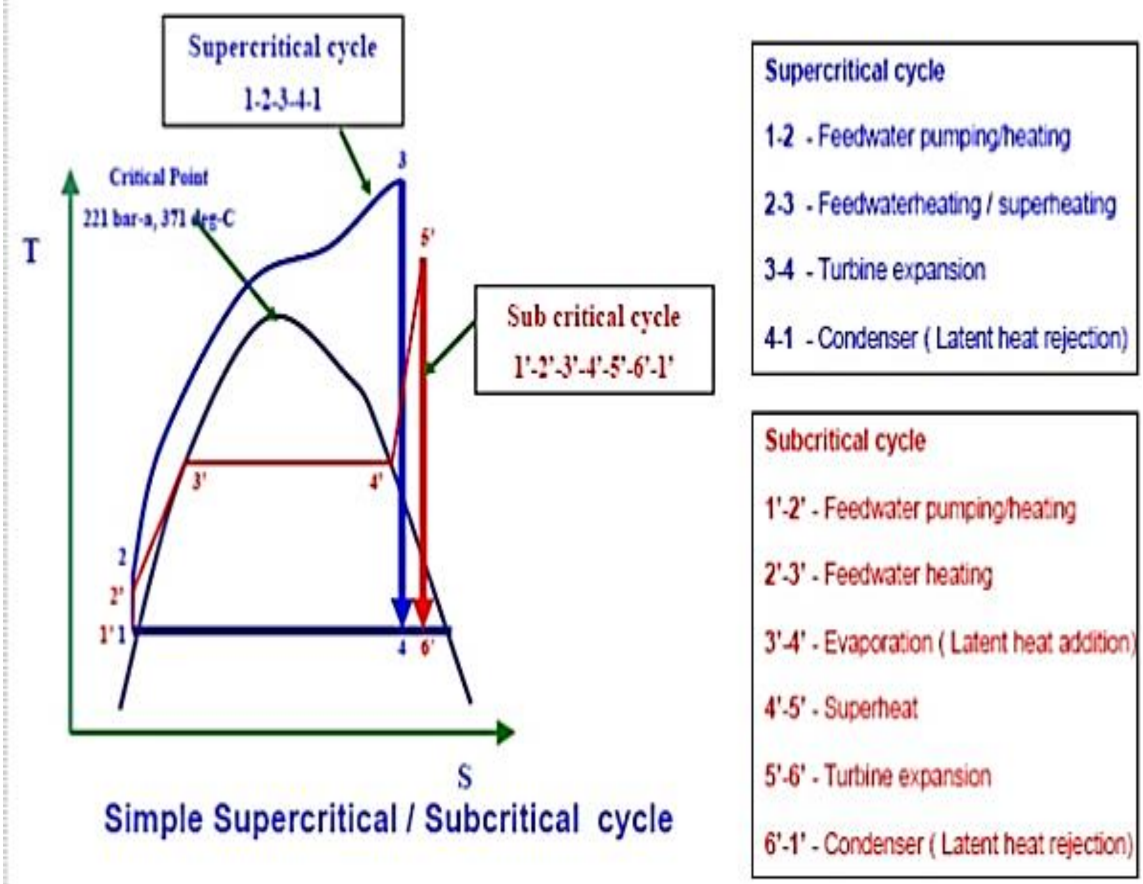

Fig.2. 12. T-s diagram of supercritical and subcritical Rankine cycle

2.3.1.2.7 According to charge in the furnace

1. Pulverized fuel (powdered coal is used)
   It is shown in Fig.2. 13.

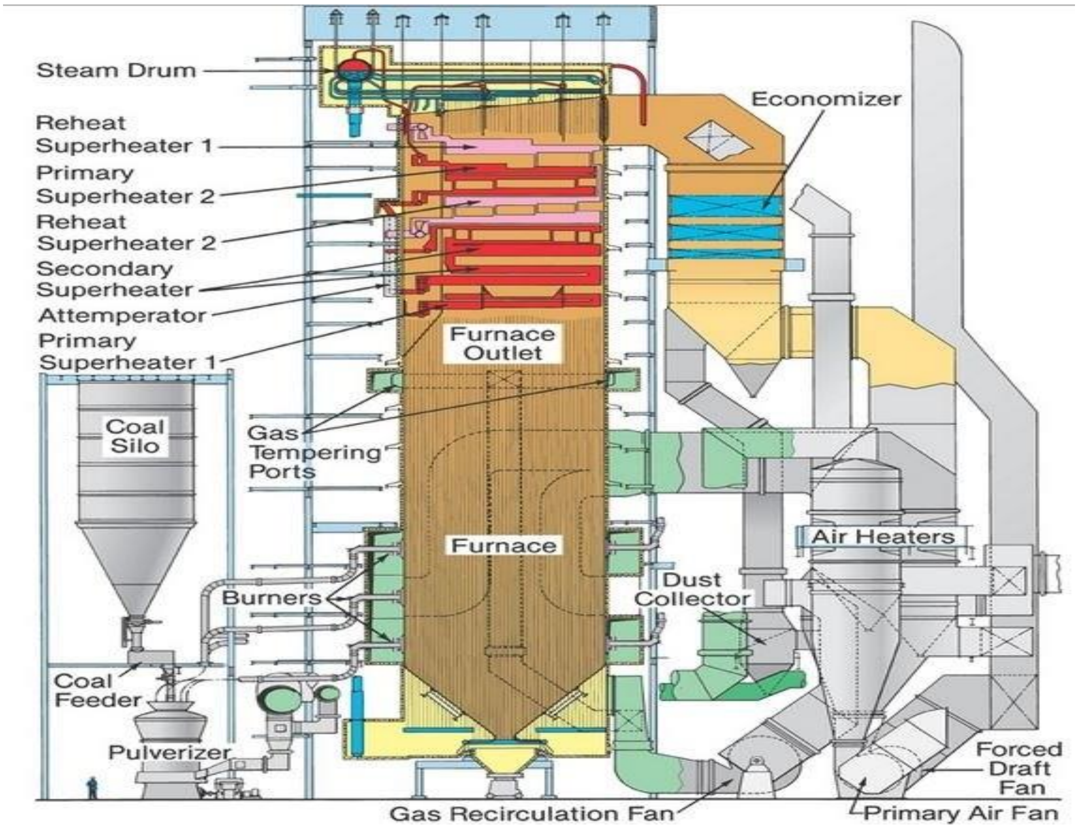

Fig.2. 13. Boiler running on pulverized coal

2. Supercharged fuel (compressed air is used)
   It is shown below:

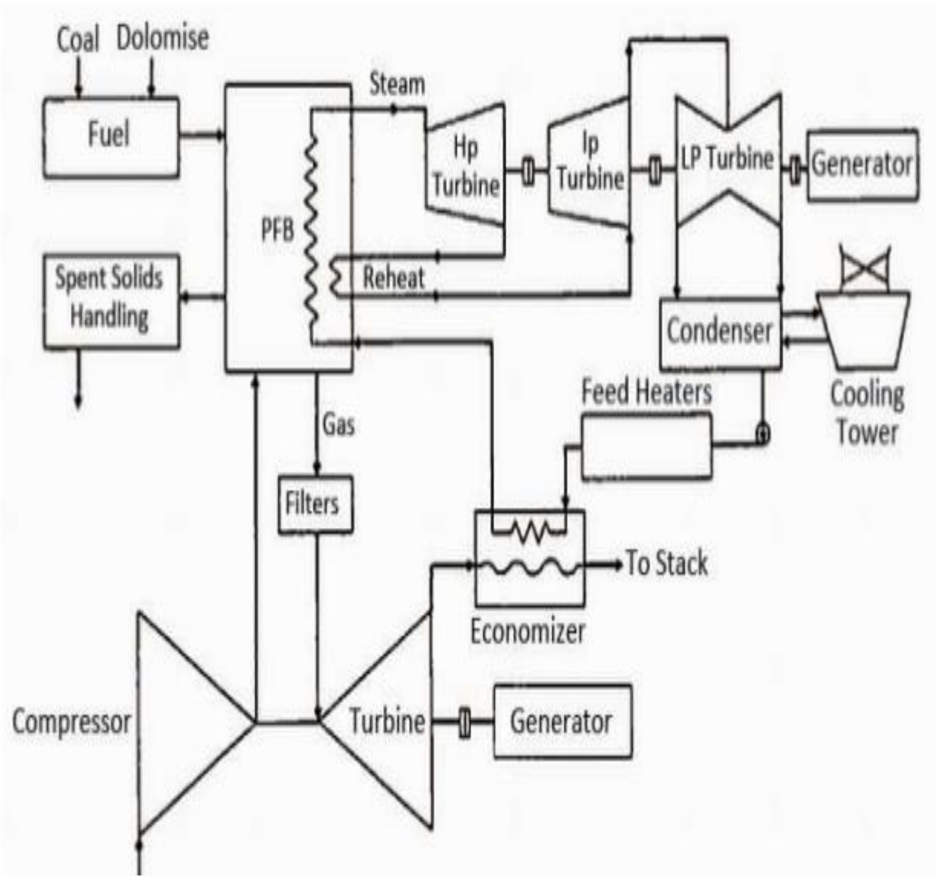

Fig.2. 14. Steam cycle with supercharged boiler

3. Fluidized bed combustion boilers (air is passed through the fluidized bed of fuel)
It is shown below:

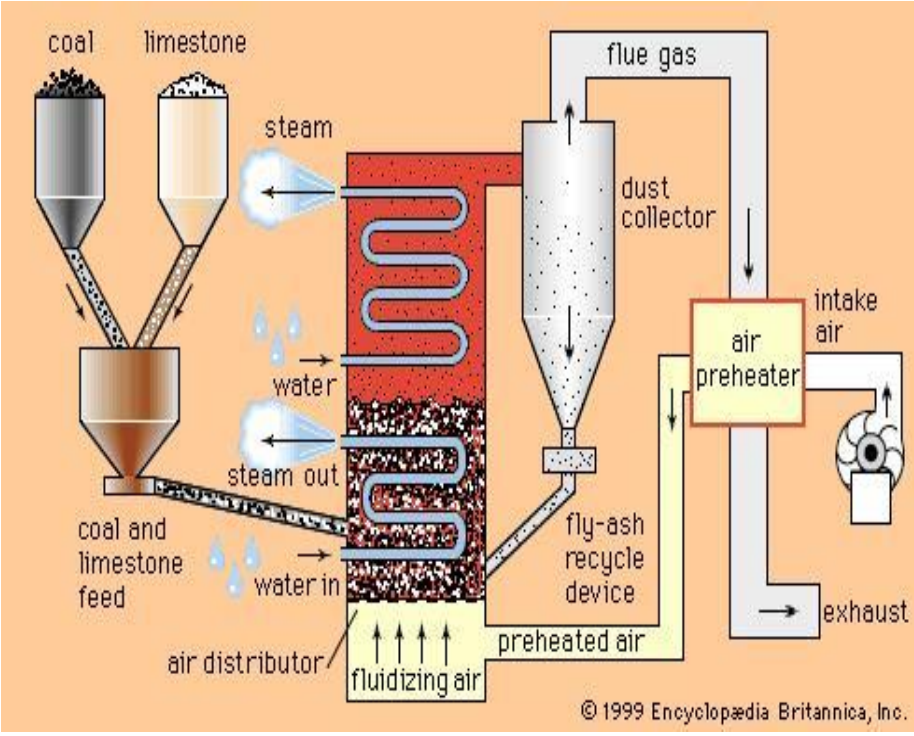

Fig.2. 15. Boiler using fluidized bed of coal and limestone for steam production

2.4 Specification

Maximum Pressure	10 kg/cm^2
Equivalent evaporative quantity	150kg/h
Heat transmission area	3.06 m^2
Rated heat out put	80,850 kcal/h
Potential water quantity	54 L
Fuel consumption	10.8 L/h (kerosene oil)
Fuel tank	90 L
Pressure gauge	15 kg/cm^2

2.5 Procedure

2.5.1 Boiler Starting up

Open water Supply valve. Turn main power ON. Open air purging valve. Open drain valve. After total blow-off, close drain valve and air purging valve. Open fuel valve and press feed water switch. Press combustion switch.

Steam pressure goes up and when it gets set value, combustion stops automatically. Open main steam valve gradually. Note feed water inlet temperature from panel and note pressure of generated steam from the outlet pressure gauge. Note the volume of feed water fed to the boiler and fuel consumed in specific time interval, from integral flow meters on control panel, to determine their volume flow rates.

2.6 Specimen Calculation

Thermal efficiency of the boiler is given by

$\eta_{th} = m_s(h_1-h_6)/m_f \times C.V$

where

m_s = mass flow rate of steam generated $= \rho_w V_w / t$

m_f = mass flow rate of fuel consumed = $\rho_f V_f / t$

C V = 42700(kj/kg)

ρ_f = 820 kg/m^3

η_{th} = 0.0134(2682.85 – 89.8)/0.0011 x 42700

η_{th} = 74.1%

2.7 Observations

Table 2. 1. Main observations table

No of Obs.	p_1 (bar)	T_6 (ºC)	Dryness fraction x	V_w (L)	V_f (L)	t (sec)
1						
2						
3						
4						

Table 2. 2. Effect of of steam and fuel mass flowrates and enthalpy on thermal efficiency

m_s (kg/s)	m_f (kg/s)	h_1 (kj/kg)	h_6 (kj/kg)	η_t (%)

3. Experiment No – 3

3.1 Objective

To determine the Dryness Fraction of steam (x) with the help of Throttling calorimeter.

3.2 Apparatus

Steam generating device
Throttling calorimeter.

3.3 Theory

3.3.1 Dryness fraction/ quality of steam

- It is the ratio of vapor mass to total (vapor and water liquid) mass of steam
- Dry saturated steam has no liquid content i.e., no wetness
- Wet steam has some vapor as well as liquid water content

3.3.2 Throttling process & throttling calorimeter

3.3.2.1 Throttling process

The temperature change of a gas or liquid when it is forced through a valve or porous plug while kept insulated so that no heat is exchanged with the environment. This procedure is called a **Throttling process.**
In this process here is no change in enthalpy from state one to state two, h1 = h2; no work is done, W = 0; and the process is adiabatic, Q = 0.
We can observe that: Pin > Pout, velin < velout (where P = pressure and vel = velocity). These observations confirm the theory that hin = hout. In this process, steam becomes drier and nearly saturated steam becomes, superheated.

3.3.2.2 Throttling calorimeter

It consists a narrow throat (Orifice). Pressure and temperature are measured by pressure gauge and thermometer. The steam after throttling process passes through the heat exchanger and condensate is collected.
It is a vessel with a needle valve fitted on the inlet side. The steam is throttled through the needle valve and exhausted to the condenser.
It is shown below:

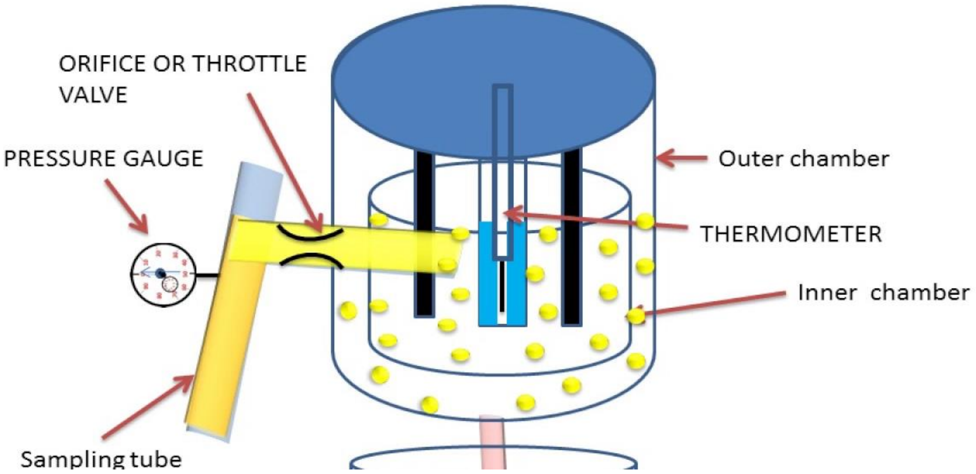

Fig.3. 1. Schematic of a throttling calorimeter

The throttling process on Mollier chart and T-s diagram is shown below:

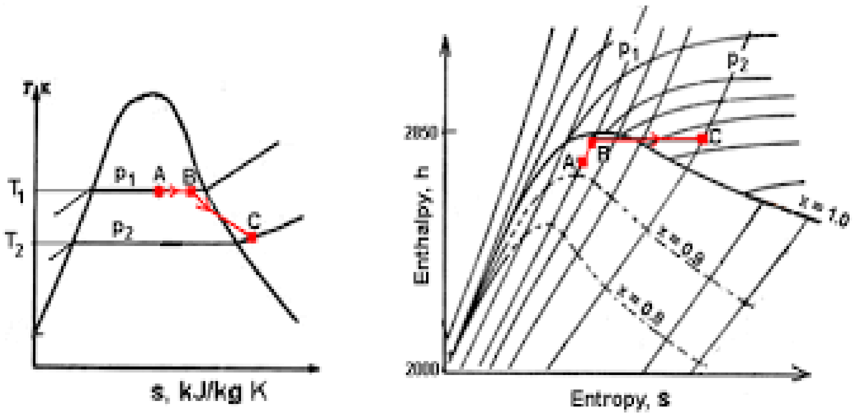

Fig.3. 2. Throttling process on t-s and h-s chart

3.4 Specifications

Pressure gauge	10kg/cm^2, 2kg/cm^2
Throttle type	Needle Valve type

3.5 Procedure

Open needle valve to induce steam to the throttling calorimeter. Then reduce the pressure after expansion by means of needle valve and valve down to designated pressure. 'Designated pressure' means the value where the steam becomes superheated steam in combination with the temperature after the throttle. After the temperature becomes steady, note the pressure before and after the throttle on the respective pressure gauge and note the temperature of outlet superheated steam.

3.6 Specimen Calculation

Dryness fraction = $m_g/m_g + m_f$

For throttling $h_1 = h_2$

$h_1 = h_{f1} + x\, h_{fg1}$

$h_2 = h\,(\text{at } p_2 , T_2)$ from superheated steam table

$x = (h_2 - h_{f1})/h_{fg1}$

$= (2682.85 - 730.213) / 2025.71$

$x = 0.964$

3.7 Observations

Table 3. 1. Effect of pressure at inlet of calorimeter on dryness fraction of steam

No. of obs	**p_1 (bar)**	**p_2 (bar)**	**T_2 (°C)**	**$h_1 = h_2$ (kj/kg)**	**x**
1					
2					
3					
4					

4. Experiment No - 4

4.1 Objective

To determine the efficiency of superheater and evaluate its performance

4.2 Apparatus

Steam Super Heater

4.3 Theory

4.3.1 Superheater

A superheater is present inside boiler. When the steam leaves the evaporator then it passes through the superheater tubes which further heats up the saturated steam to increase its temperature at constant pressure.

The general working principle of superheater is that heat generated by fuel which changes phase of feedwater also increases the temperature of the saturated steam or there may be additional supply of fuel for superheater as shown:

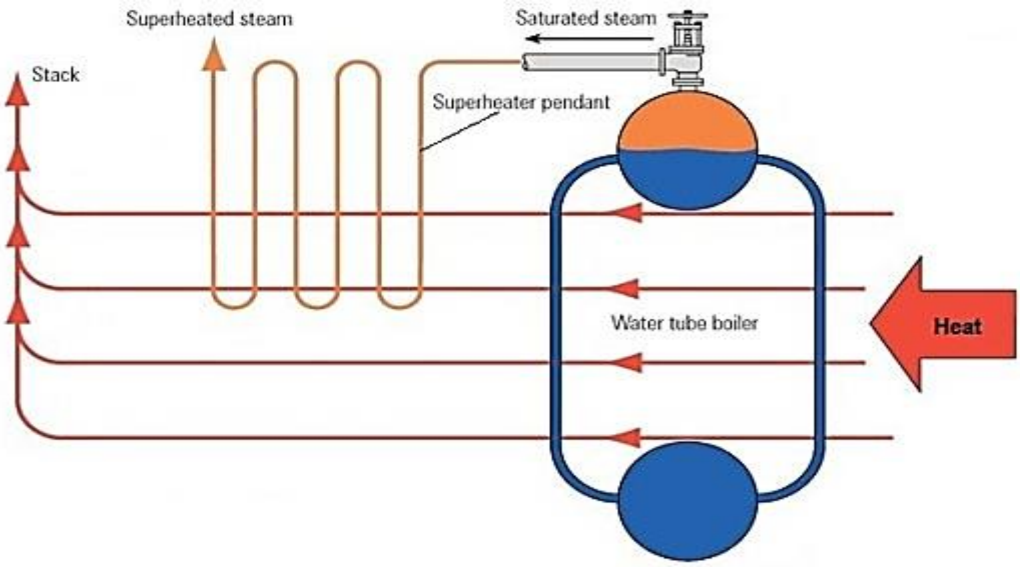

Fig.4. 1. Schematic diagram of a superheater present inside boiler

And the separate fuel supply is shown below:

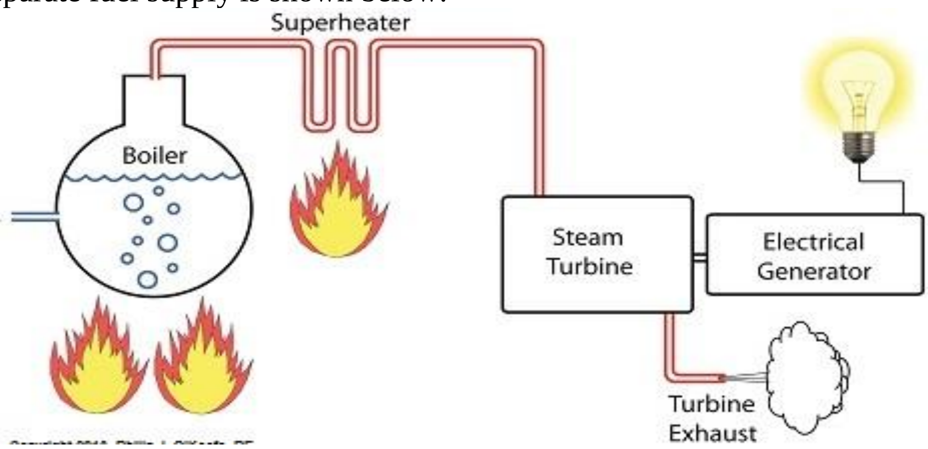

Fig.4. 2. Schematic diagram of a superheater with separate fuel supply

4.3.1.1 Control methods of superheater

For temperature control of superheated steam, we have following methods:

4.3.1.1.1 Excess Air Control

The steam outlet temperature of a convection superheater may be increased at partial load by increasing the excess air supply. The reduced gas temperature decreases the furnace heat absorption for the same steam production. The increased gas mass flow with its increased total heat content serves to increase the degree of superheat.

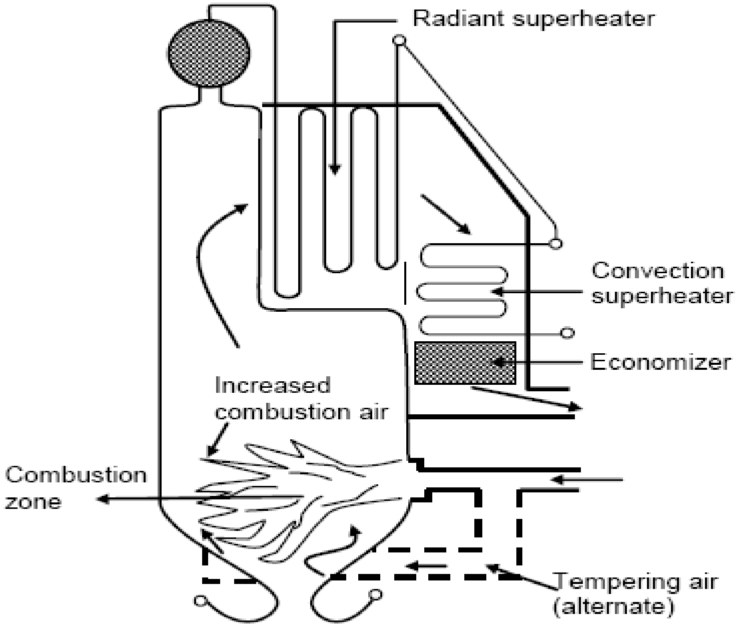

Fig.4. 3. Excess air control in a superheater

4.3.1.1.2 Flue Gas Recirculation

The recirculation of some percentage of the combustion gases serves to control steam temperature in the same manner as does an increase in excess air. By introducing the hot gases below the combustion zone, relatively high efficiency may be maintained.

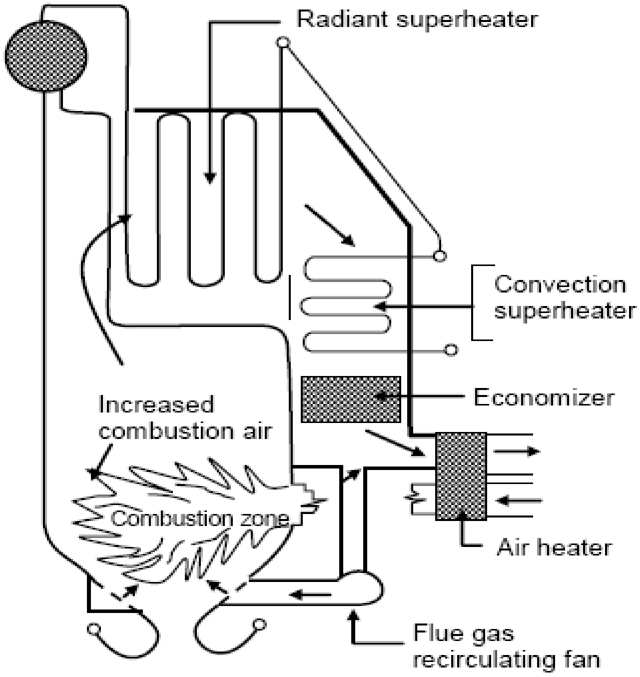

Fig.4. 4. Flue gas recirculation in a superheater

4.3.1.1.3 Gas By-pass Control

The boiler convection banks can be arranged in such a manner that portion of the gases can be by-passed around the superheater elements. The superheater is oversized so that it will produce the required degree of superheat at partial load conditions. As the load increases, some of the flue gases are by-passed.

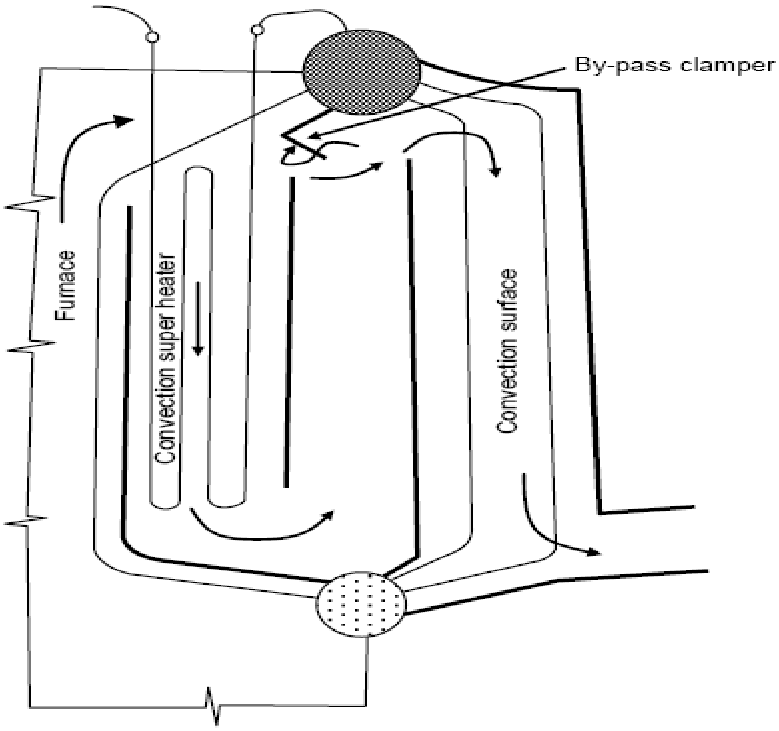

Fig.4. 5. Gas by-pass control in a superheater

4.3.1.1.4 Adjustable Burner Control

With a multiple burner furnace, it is possible to distribute the burners over a considerable burner wall height. This control is obtained by selective firing.
Tilt able furnace may be adjusted to shift the position of the combustion zone.

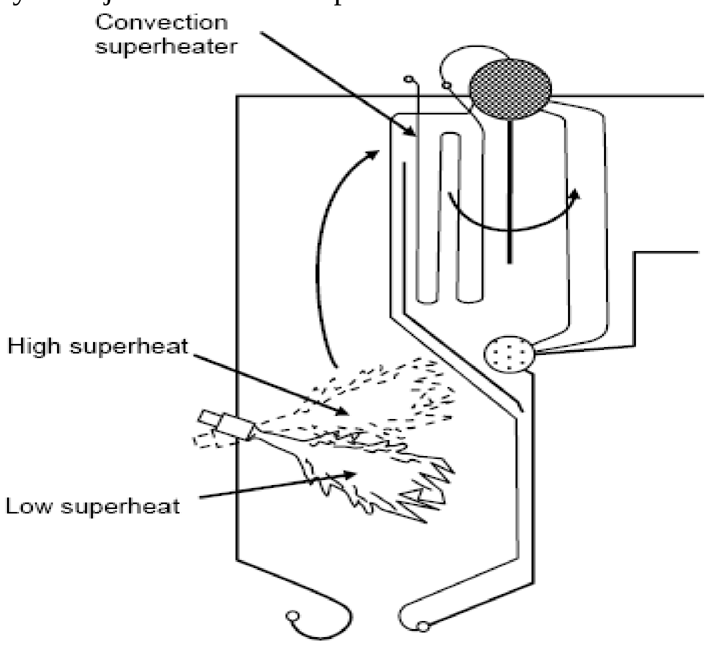

Fig.4. 6. Adjustable burner control in a superheater

4.4 Specifications

Inlet Pressure & Temperature	5kg/cm^2 , Saturated Steam 158 ºC
Outlet Temperature	250ºC
Fuel	Kerosene Oil
Pressure gauge	15kg/cm^2

4.5 Procedure

Close respective valves of super heater and wait for steam generation from steam. Induce steam which goes up to designated pressure by opening valve of super heater inlet. Open drain valve of super heater. After drained thoroughly and steam comes out, close drain valve. Turn power switch ON. Burner starts function and steam is super heated. Note the readings of pressure and temperature before and after the superheater. note the reading of the volume of the fuel consumed in superheater by the integral flow meter on the panel.

4.6 Calculations

$$\eta_{th} = m_s (h_3 - h_2) / m_f \ x \ CV$$

$$= 43.8(2818.7 - 2758) / 0.44 \ x \ 42700$$

$$= 14.1\%$$

4.7 Observations

Table 4. 1. Effect of various temperatures and fuel flowrate on thermal efficiency of a superheater

No. of obs	P_3 (bar)	p_2 (bars)	T_2 (ºC)	m_s (Kg/s)	T_3 (ºC)	m_f (kg/h)	x	h_2 (kj/kg)	h_3 (kj/kg)	η_{th} (%)
1										
2										
3										
4										

5. Experiment No – 5

5.1 Objective
To determine the thermal efficiency of a steam turbine and evaluate its performance

5.2 Apparatus
Steam turbine.

5.3 Theory

5.3.1 Steam turbine
In the steam turbine, the steam is expanded to a lower pressure providing shaft power to drive a generator or run a mechanical process.
There are two basic types of steam turbine **according to blade design**:

1. Impulse turbine
   In this type, steam at high velocity hits the turbine blades and rotates the turbine
2. Reaction turbine
   In this type, steam passes through the blades which are designed like air foil and there is pressure difference between 2 sides of the blade and this causes the shaft to rotate.

Their detail is given below:

- The difference between these two designs is shown in following figure:

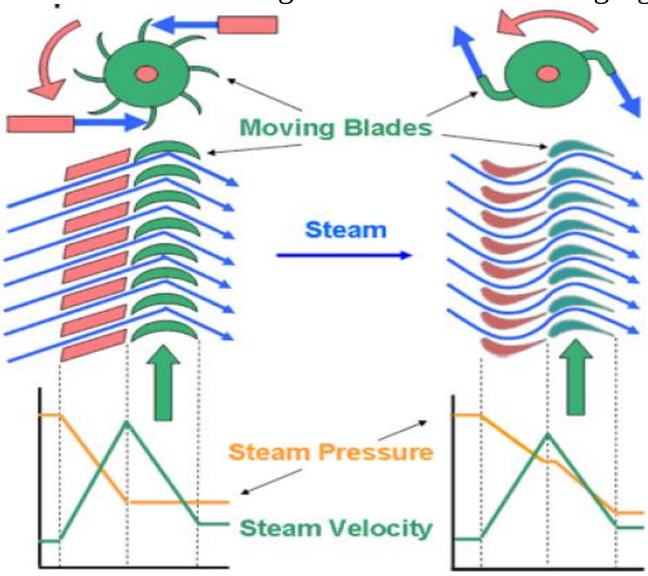

Fig.5. 1. Impulse turbine on left side vs reaction turbine on right side

- In **Impulse turbines**, the steam jets are directed at the turbine's bucket shaped rotor blades where the pressure exerted by the jets causes the rotor to rotate and the velocity of the steam to reduce as it imparts its kinetic energy to the blades. The next series of fixed blades reverses the direction of the steam before it passes to the second row of moving blades.
- In **Reaction turbines,** the rotor blades of the reaction turbine are shaped more like airfoils, arranged such that the cross section of the chambers formed between the

fixed blades diminishes from the inlet side towards the exhaust side of the blades. The chambers between the rotor blades essentially form nozzles so that as the steam progresses through the chambers its velocity increases while at the same time its pressure decreases, just as in the nozzles formed by the fixed blades.

- The stationary nozzles accelerate the steam to high velocity by expanding it to lower pressure. A rotating bladed disc changes the direction of the steam flow, thereby creating a force on the blades that, because of the wheeled geometry, manifests itself as torque on the shaft on which the bladed wheel is mounted. The combination of torque and speed is the output power of the turbine. A reduction gear may be utilized to reduce the speed of the turbine to the required output speed for the generator.
- The internal flow passages of a steam turbine are very similar to those of the expansion section of a gas turbine. The main differences are gas density, molecular weight, isentropic expansion coefficient, and to a lesser extent, the viscosity of the two fluids.
- Compared to reciprocating steam engines of comparable size, steam turbines rotate at much higher rotational speeds, which contribute to their **lower cost per unit of power developed**. In addition, the inlet and exhaust valves in reciprocating steam engines cause steam pressure losses that don’t contribute to power output. Such losses do not occur in steam turbines. Because of these design differences, steam turbines are more efficient than reciprocating steam engines operating from the steam at the same inlet conditions and exhausting into the same steam exhaust systems.

5.3.1.1 Condensing turbine

This power-only utility turbine exhaust directly to condensers that maintain vacuum conditions at the discharge of the turbine. An array of tubes, cooled by water from a river, lake or cooling tower, condenses the steam into (liquid) water. The vacuum conditions in the condenser are caused by the near ambient cooling water causing condensation of the steam turbine exhaust steam in the condenser.
It is shown below:

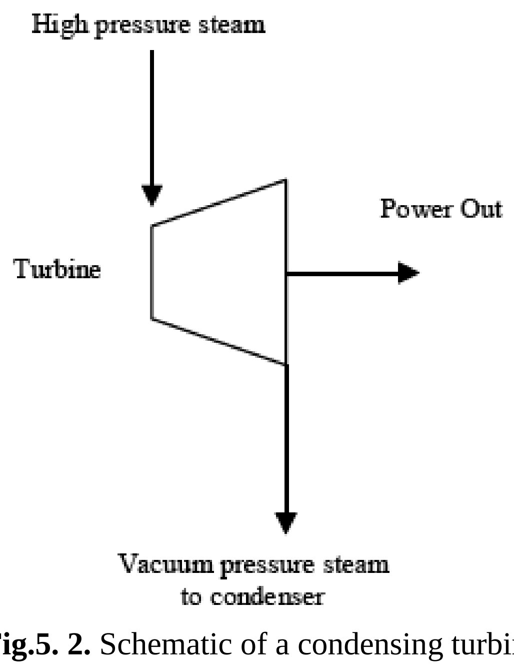

Fig.5. 2. Schematic of a condensing turbine

5.3.1.2 Non-Condensing turbine

A non-condensing turbine (also referred to as a back-pressure turbine) exhausts some or all its steam flow to the industrial process or facility steam mains at conditions close to the process heat requirements, as shown below:

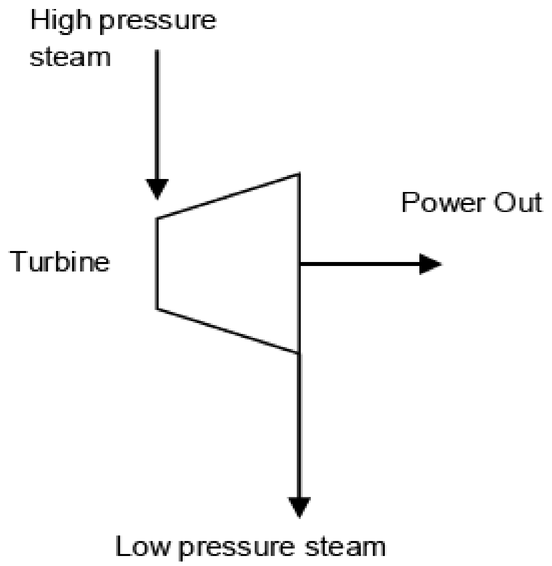

Fig.5. 3. Schematic of a non-condensing turbine

5.3.1.3 Extraction turbine

An extraction turbine has one or more openings in its casing for extraction of a portion of the steam at some intermediate pressure. The extracted steam may be used for process purposes, or for feedwater heating, as is the case in most utility power plants. The rest of the steam can be expanded to below atmospheric pressure to a condenser, or delivered to a low-pressure steam application as illustrated below:

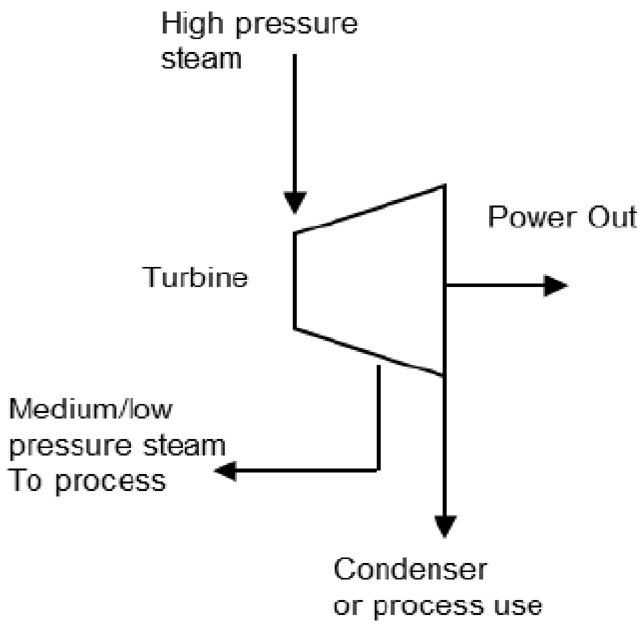

Fig.5. 4. Schematic of an extraction turbine

5.3.1.4 Material of turbine blades

A major problem involved in turbine design is reducing the creep experienced by the **blades** (the tendency of a material to deform under the influence of stresses with time). Because of the high temperatures and high stresses of operation, steam turbine materials become damaged in course of time. To limit creep, thermal coatings and superalloys with **grain boundary strengthening** are used in blade designs.

Protective coatings are used to reduce the thermal damage and to limit oxidation. These coatings are often stabilized zirconium dioxide-based ceramics. Using a thermal protective coating limits the temperature exposure of the nickel superalloy. This reduces the creep on the blades. Oxidation coatings limit efficiency losses caused by a buildup on the outside of the blades, which is especially important in the high-temperature environment.

The nickel-based blades are alloyed with aluminum and titanium to improve strength and creep resistance. The microstructure of these alloys is composed of different regions of composition.

Refractory elements such as rhenium and ruthenium can be added to the alloy to improve creep strength. The addition of these elements reduces the diffusion of the gamma prime phase, thus preserving the fatigue resistance, strength, and creep resistance.

Different grades of stainless steel are also used in steam turbines when the temperature of steam is limited to 620°C.

5.4 Specification

Out Put	Maximum 0.6 kW
Rotational Speed	3000 rpm
Governor	Electro magnetic rotational speed detector Digital PID Controller
Inlet/outlet Pressure gauge	10 kg/cm^2, 5 kg/Cm^2

5.5 Procedure

Start boiler and set steam pressure to the turbine by means of reducing valves. The designed steam condition of turbine is approximately 5kg /cm^2 G (read value on a pressure gauge) 200 ºC of superheated steam. Turbine out put can be obtained by varying the generators load resistance. But, at that time, do not set steam pressure higher than 8kg/cm^2. And steam flow must not be more than 120kg/hr. Note the readings of the turbine inlet pressure and temperature, turbine outlet pressure and temperature, voltage and current of the generator

5.6 Specimen Calculation

$$\eta_t = V\,I / \eta_g\, m_s(h_{in} - h_{out})$$
$$= 0.107 / 0.517 \times 0.1216(2739.4 - 2711)$$
$$= 59.6\%$$

5.7 Observations

Table 5. 1. Effect of turbine inlet and outlet enthalpy; and steam flowrate on thermal efficiency of steam turbine

No of obs	p_{in} (bar)	T_{in} (ºC)	h_{in} (kj/kg)	P_{out} (bar)	T_{out} (ºC)	h_{out} (kj/kg)	m_s (kg/s)	VI (kw)	η_g (%)	η_t (%)
1										
2										
3										
4										

6. Experiment No - 6

6.1 Objective
To determine the Condenser heat exchange rate and evaluate its performance

6.2 Apparatus
Condenser heat exchanger

6.3 Theory

6.3.1 Condenser
It is a heat exchanger that removes heat from the steam at the turbine outlet and changes the steam to saturated water.
Following are the purposes of using condenser:
1. To keep the low back pressure at turbine outlet so as to rise turbine work output
2. To reduce the volume of expanded steam at turbine outlet

6.3.1.1 Types of condenser and their construction
There are two primary types of condensers that can be used in a power plant:
1. Direct Contact
2. Surface

Direct contact condensers condense the turbine exhaust steam by mixing it directly with cooling water.
Steam surface condensers are the most commonly used condensers in modern power plants. The exhaust steam from the turbine flows on the shell side (under vacuum) of the condenser, while the plant's circulating water flows in the tube side. The source of the circulating water can be either a closed-loop (i.e. cooling tower, spray pond, etc.) or once through (i.e. from a lake, ocean, or river). The condensed steam from the turbine, called condensate, is collected in the bottom of the condenser, which is called a hotwell. The condensate is then pumped back to the steam generator to repeat the cycle.
A typical surface condenser is shown below:

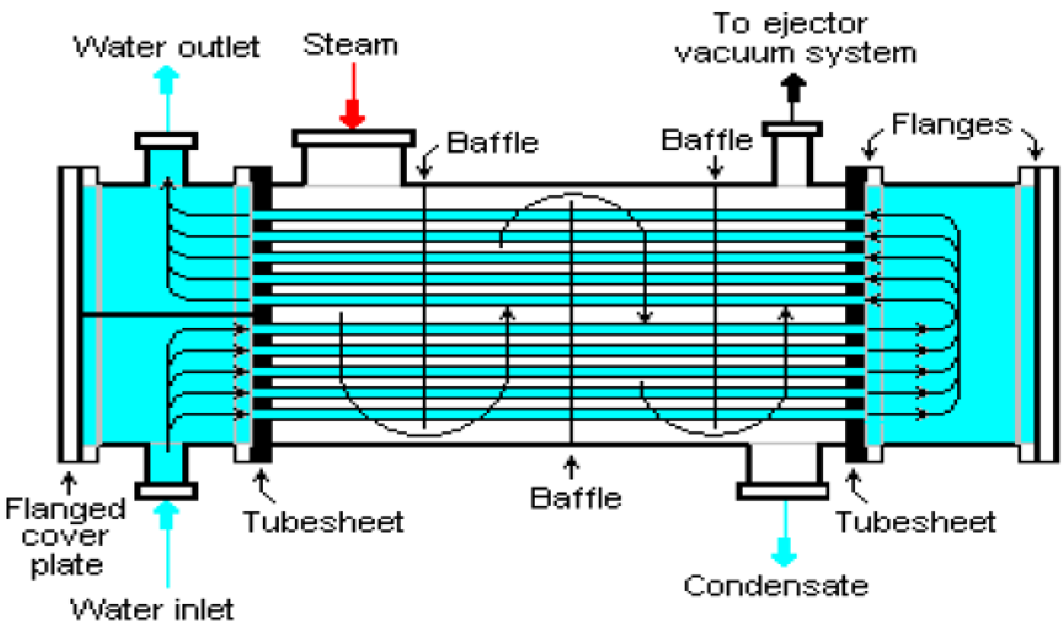

Fig.6. 1. Shell and tube heat exchanger

A jet condenser which is a direct contact condenser is shown below:

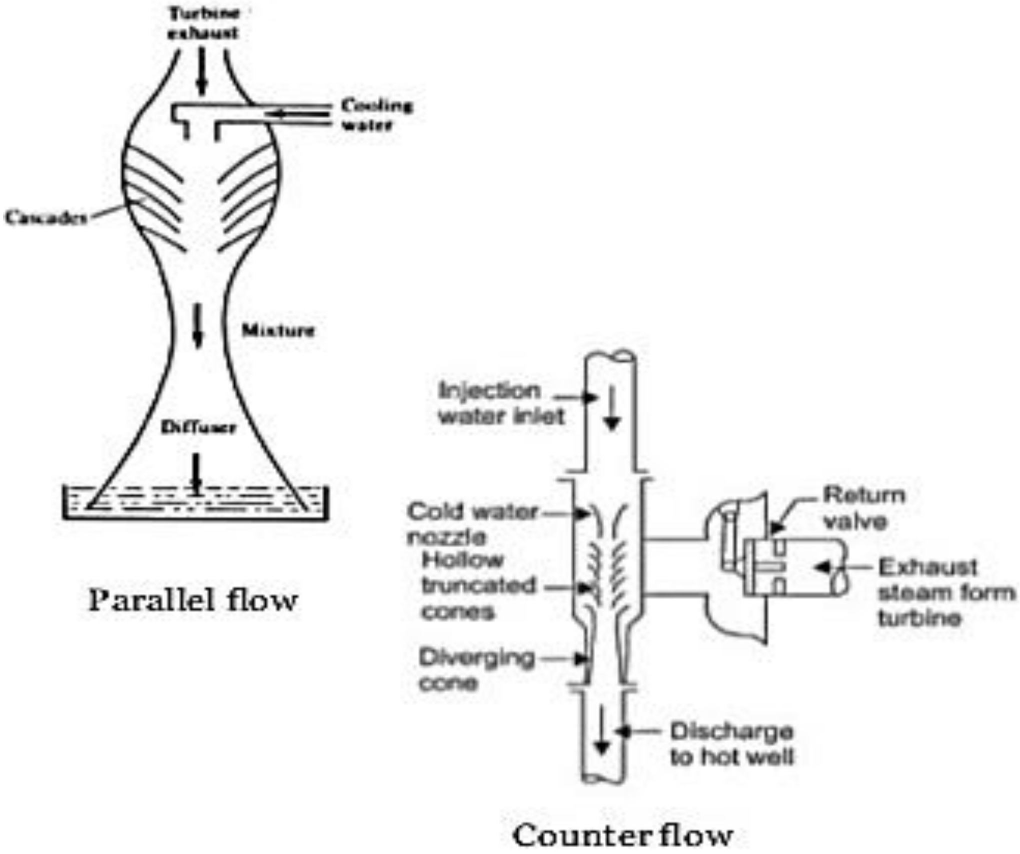

Fig.6. 2. Schematic of a jet condenser

6.3.1.2 Condenser components and their functions

6.3.1.2.1 Shell

The shell is the condenser's outermost body and contains the heat exchanger tubes. The shell is fabricated from carbon steel plates and is stiffened as needed to provide rigidity for the shell. When required by the selected design, intermediate plates are installed to serve as baffle plates that provide the desired flow path of the condensing steam. The plates also provide support that help prevent sagging of long tube lengths.

For most water-cooled surface condensers, the shell is under vacuum during normal operating conditions.

6.3.1.2.2 Hotwell

At the bottom of the shell, where the condensate collects, an outlet is installed. In some designs, a sump (often referred to as the hotwell) is provided. Condensate is pumped from the outlet or the hotwell for reuse as boiler feedwater.

6.3.1.2.3 Vaccum system

For a steam ejector, the motive fluid is steam.

For water-cooled surface condensers, the shell's internal vacuum is most commonly supplied by and maintained by an external steam jet ejector system. Such an ejector system uses steam as the motive fluid to remove any non-condensable gases that may be present in the surface condenser. The Venturi effect, which is a particular case of Bernoulli's principle, applies to the operation of steam jet ejectors. Motor driven mechanical vacuum pumps, such as the liquid ring type, are also popular for this service.

A typical ejector is shown below:

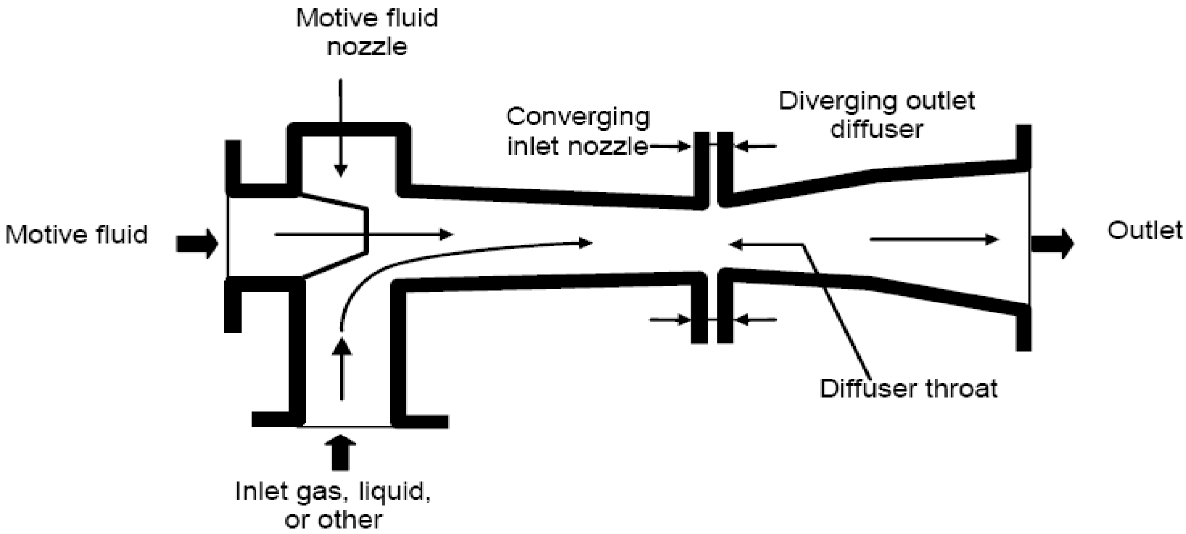

Fig.6. 3. Schematic of a typical jet ejector

6.3.1.2.4 Tube sheets

At each end of the shell, a sheet of sufficient thickness usually made of stainless steel is provided, with holes for the tubes to be inserted and rolled. The inlet end of each tube is also bell mouthed for streamlined entry of water. This is to avoid eddies at the inlet of each tube giving rise to erosion, and to reduce flow friction. Some makers also recommend plastic inserts at the entry of tubes to avoid eddies eroding the inlet end. In smaller units some manufacturers use ferrules to seal the tube ends instead of rolling. To take care of length wise expansion of tubes some designs have expansion joint between the shell and the tube sheet allowing the latter to move longitudinally. In smaller units some sag is given to the tubes to take care of tube expansion with both end water boxes fixed rigidly to the shell.

6.3.1.2.5 Tubes

Generally, the tubes are made of stainless steel, copper alloys such as brass or bronze, cupro nickel, or titanium depending on several selection criteria. The use of copper bearing alloys such as brass or cupro nickel is rare in new plants, due to environmental concerns of toxic copper alloys. Also depending on the steam cycle water treatment for the boiler, it may be desirable to avoid tube materials containing copper. Titanium condenser tubes are usually the best technical choice; however, the use of titanium condenser tubes has been virtually eliminated by the sharp increases in the costs for this material. The tube lengths range to about 17 m for modern power plants, depending on the size of the condenser. The size chosen is based on transportability from the manufacturers‟ site and ease of erection at the installation site.

6.3.1.2.6 Waterboxes

The tube sheet at each end with tube ends rolled, for each end of the condenser is closed by a fabricated box cover known as a waterbox, with flanged connection to the tube sheet or condenser shell. The waterbox is usually provided with man holes on hinged covers to allow inspection and cleaning.

These waterboxes on inlet side will also have flanged connections for cooling water inlet butterfly valves, small vent pipe with hand valve for air venting at higher level, and hand operated drain valve at bottom to drain the waterbox for maintenance. Similarly, on the outlet waterbox the cooling water connection will have large flanges, butterfly valves, vent connection also at higher level and drain connections at lower level. Similarly, thermometer pockets are located at inlet and outlet pipes for local measurements of cooling water temperature.

6.4 Specification

Type	Shell and tube type
Exchange heat quantity	105,000 kcal/h
Steam flow rate	180 kg/h
Heat transmission area	1.0 m^2
Water receiving tank	100L
Cooling water flow rate	Screw type flow meter

6.5 Procedure

Measure inlet and outlet temperature of cooling water. Measure the volume flow rate of the cooling water from the flow meter on the control panel.

6.6 Observations

Table 6. 1. Effect of various temperatures and water flowrate on condenser heat exchange rate

No of Obs.	Tw2 (ºC)	Tw3 (ºC)	Q_w (m^3/s)	m_w (kg/s)	heat exchange rate (MJ/h)
1					
2					
3					
4					

7. Experiment No –7

7.1 Objective

To determine overall efficiency of steam power plant.

7.2 Apparatus

Steam Turbine Power Plant

7.3 Theory

7.3.1 Basic Process in a steam power plant

The thermodynamic cycle for the steam turbine is known as the Rankine cycle. This cycle is the basis for conventional power generating stations and consists of a heat source (boiler) that converts water to high pressure steam. In the steam cycle, water is first pumped to elevated pressure, which is medium to high pressure. It is then heated to the boiling temperature corresponding to the pressure, boiled (heated from liquid to vapor), and then most frequently superheated (heated to a temperature above that of boiling). The pressurized steam is expanded to lower pressure in a turbine, then exhausted either to a condenser at vacuum conditions. The condensate from the condenser or from the industrial steam utilization system is returned to the feedwater pump for continuation of the cycle. The simple Rankine cycle is shown below:

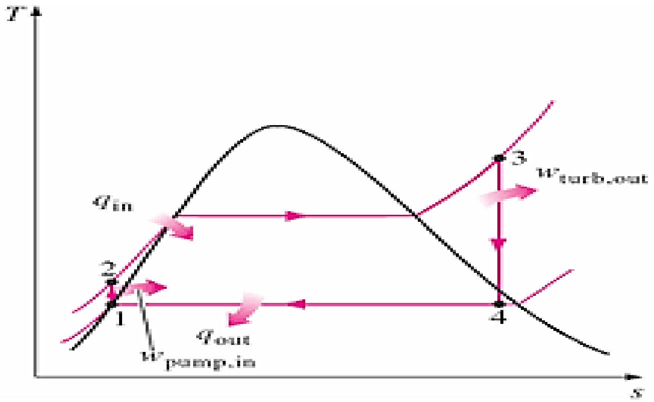

Fig.7. 1. T-s diagram of simple ideal Rankine cycle

7.3.2 Basic components of a steam power plant

A schematic representation of a steam turbine power plant is shown below:

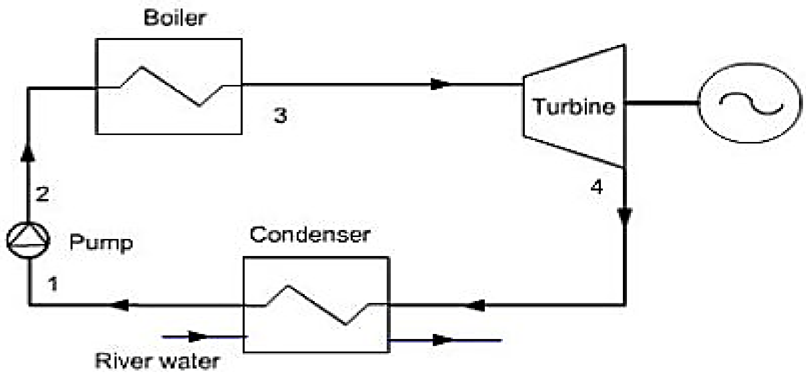

Fig.7. 2. Components of a steam turbine power plant

In the simple schematic shown, a fuel boiler produces steam which is expanded in the steam turbine to produce power. When the system is designed for power generation only, such as in a large utility power system, the steam is exhausted from the turbine at the lowest practical pressure, using a water-cooled condenser to extract the maximum amount of energy from the steam.

7.3.3 Overall efficiency of steam power plant

Overall efficiency of steam turbine power plant is the product of efficiency of all components of the power plant.
It is given as:

$$\eta = 1-(Qout/Qin) = Wout/Qin$$

Where Wout and Qin are shown in Fig.7. 1.

7.3.4 Efficiency improvement

Following are the fundamental ways of improving efficiency by rising temp. at which heat is added or lowering temp. at which heat is rejected.
It can be done through (super heating), (reheating) and regeneration.
Following are ways of improving efficiency of the steam turbine power plant.

7.3.4.1 Lowering the Condenser Pressure (Lowers $T_{low,\,av}$)

Steam exists as a saturated mixture in the condenser at the saturation temperature corresponding to the pressure inside the condenser. Therefore, lowering the operating pressure of the condenser automatically lower the temperature of the steam, and thus the temperature at which heat is rejected. The effect of lowering the condenser pressure on the Rankine cycle efficiency is illustrated in below figure:

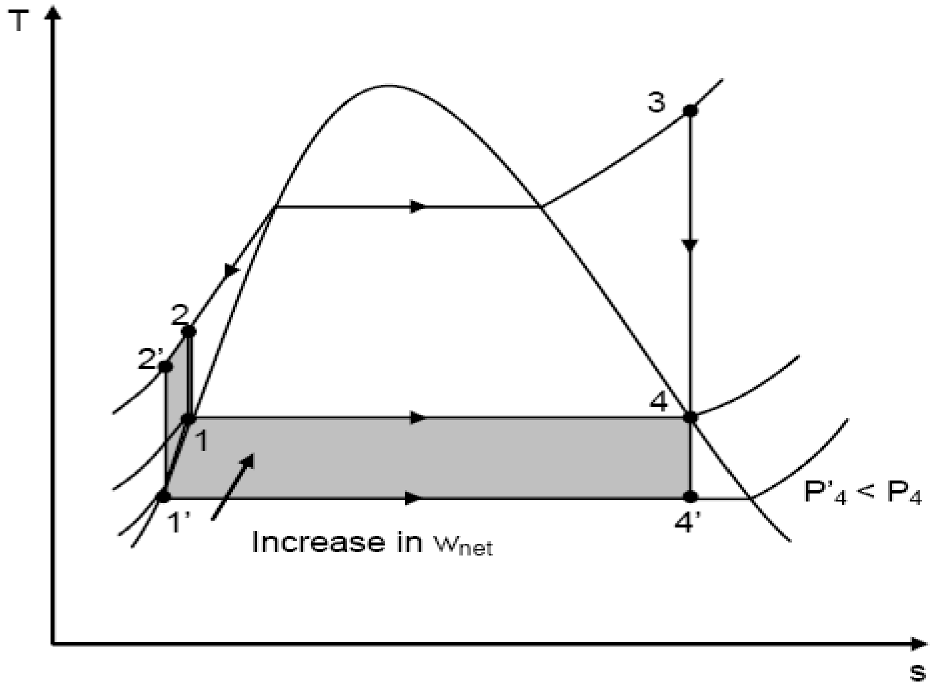

Fig.7. 3. Effect of lowering the condenser pressure on efficiency of Rankine cycle

7.3.4.2 Superheating the Steam to High Temperatures (Increases $T_{high,\,av}$)

The average temperature at which heat is added to the steam can be increased without increasing the boiler pressure by superheating the steam to high temperatures. The effect of superheating on the performance of vapor power cycle is illustrated on a T-*s* diagram as shown in Figure:

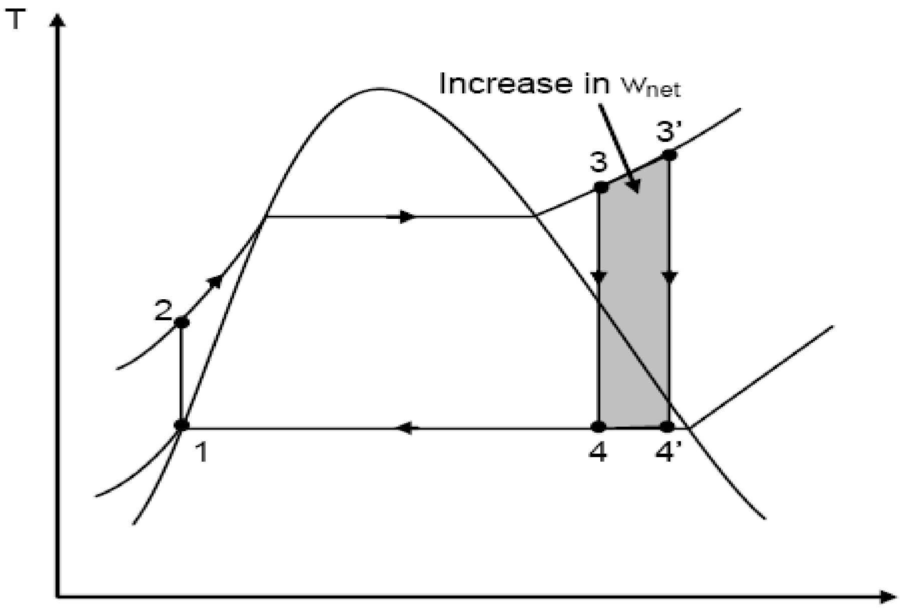

Fig.7. 4. Effect of superheating the steam to a higher temperature on efficiency of Rankine cycle

7.3.4.3 Increasing the Boiler Pressure (Increases $T_{high, av}$)

The average temperature during the heat addition process is to increase the operating pressure of the boiler, which automatically raises the temperature at which boiling take place. This, in turn, raises the average temperature at which heat is added to the steam and thus raises the thermal efficiency of the cycle. It is depicted below:

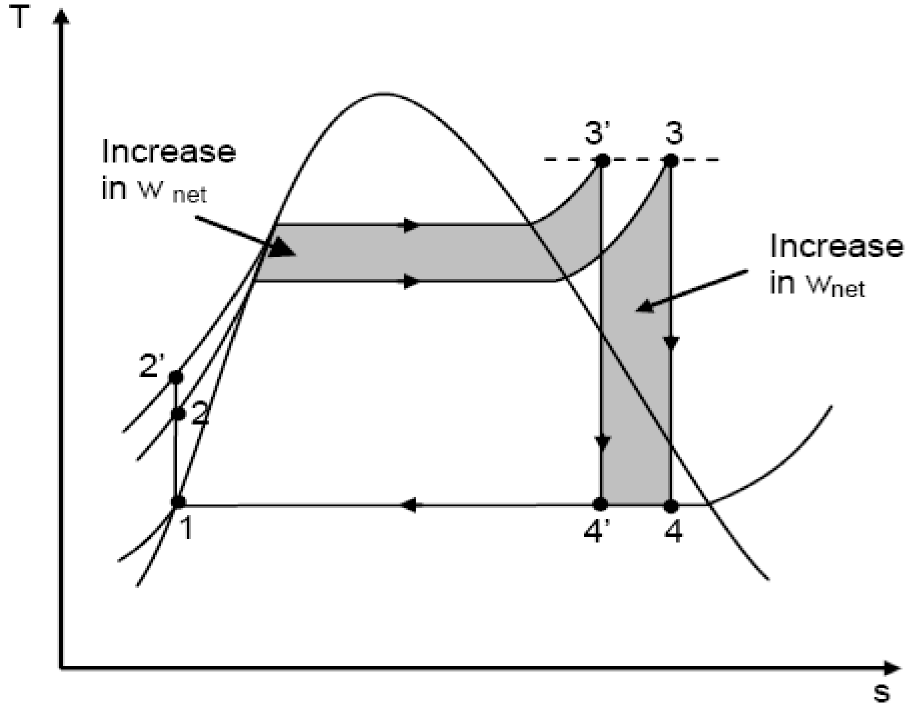

Fig.7. 5. Effect of increasing the boiler pressure on efficiency of Rankine cycle

7.4 Specifications

Work Output	Maximum 0.6 kW
Fuel	Kerosene Oil

7.5 Specimen Calculation

$\eta_t = W_{out} / m_f .CV$

m_f = mass flow rate of fuel consumed = $\rho_f V_f / t$

C V = 42700(kj/kg)

ρ_f = 820 kg/m^3

7.6 Observations

Table 7. 1. Effect of work output and fuel flowrate on thermal efficiency of steam power plant

No. of obs	**W_{out} (kW)**	**m_f (kg/s)**	**η_t (%)**
1			
2			
3			
4			

8. Experiment No – 8

8.1 Objective

To determine the efficiency of Gas Generator Set of UET Power House

8.2 Apparatus

Gas Generator Set of UET Power House

8.3 Theory

8.3.1 Natural gas engine

This engine is a spark ignition engine that uses natural gas as a fuel. It runs on the Otto cycle which is shown below:

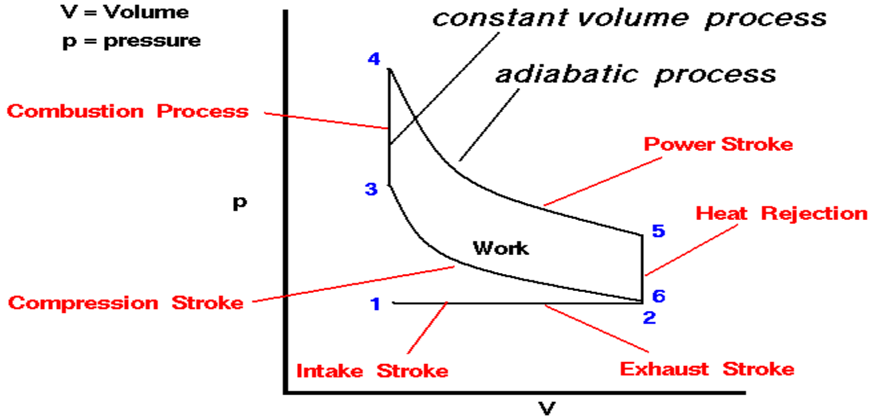

Fig.8. 1. P-v diagram of an Otto cycle

Here, the mixture of air and natural gas is first drawn in the cylinder and then compression occurs and at the end of compression, a spark ignites the fuel mixture. After this, the expansion process occurs and then burned gases are exhausted.

The diagram of Cummins gas generator is shown below:

Fig.8. 2. A natural gas engine with generator

8.3.2 Turbocharger

A turbocharger, is a turbine-driven forced induction device that increases an internal combustion engine's efficiency and power output by forcing extra compressed air into the combustion chamber. This improvement over a naturally aspirated engine's power output is due to the fact that the compressor can force more air—and proportionately more fuel—into the combustion chamber than atmospheric pressure alone.

It is shown below:

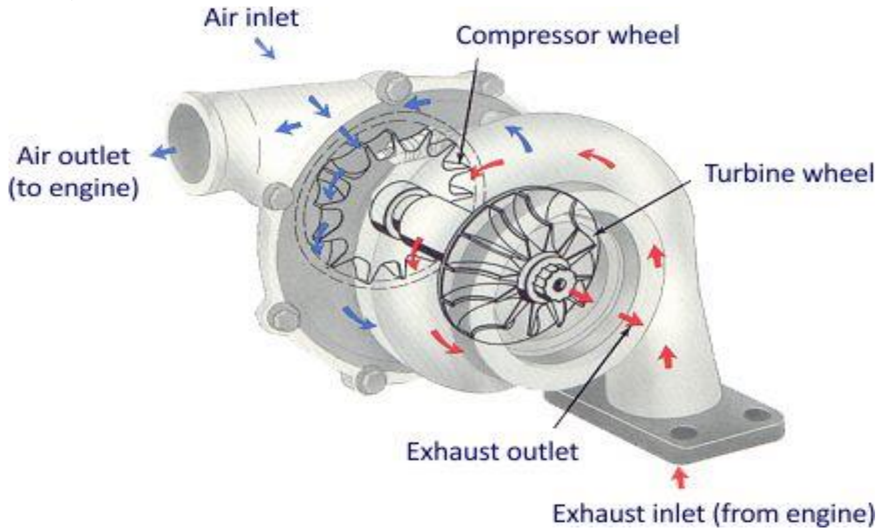

Fig.8. 3. Schematic diagram of a turbocharger

8.3.3 Aftercooler

An intercooler is a mechanical device used to cool a gas after compression process, Compression process increases the internal energy of the gas which in turn raises its temperature and reduces the density. In other words intercooler is a device used in compression process, typically a heat exchanger that removes waste heat in a gas compressor. In this natural gas engine, the temperature of the compressed fuel mixture raises to 100°C and it becomes less dense and to increase density of this mixture we cool the mixture with an aftercooler. Its schematic diagram is shown below:

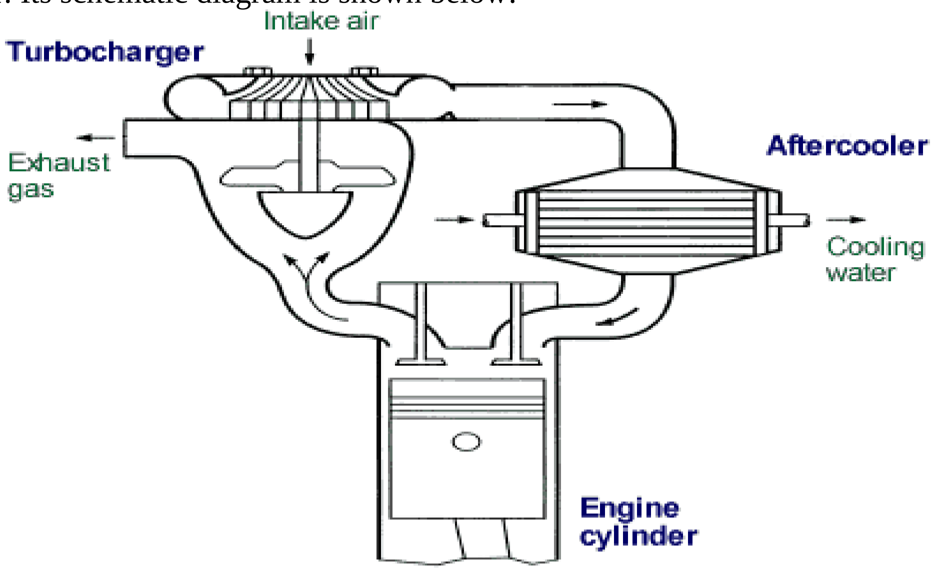

Fig.8. 4. Schematic diagram of an aftercooler attached with intake manifold

8.3.4 Firing order of the engine

The firing order is the sequence of power delivery of each cylinder in a multi-cylinder reciprocating engine. This is achieved by sparking of the **spark** plugs in an engine in the correct order. A sample is shown below:

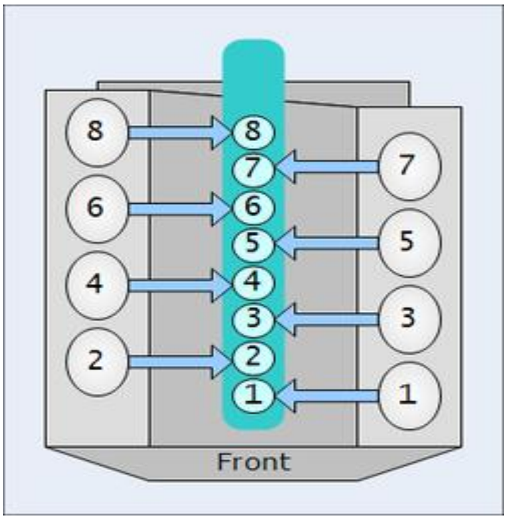

Fig.8. 5. Firing order of the engine

8.3.5 Heat exchangers

These are used to remove heat from the coolant passing through engine block as well as the from the coolant passing through aftercooler.
In this gas engine, plate type heat exchangers are used in two stages i.e., high and low temperature. The cooling water carries heat to cooling towers and then heat is removed by evaporative cooling.
Plate type heat exchanger is shown below:

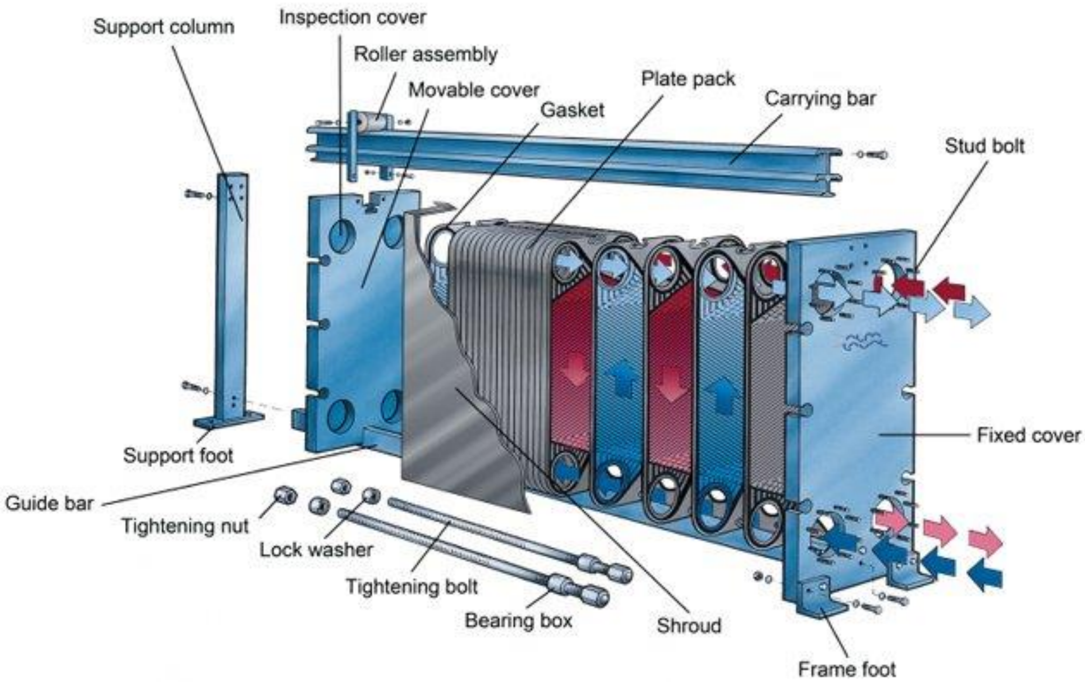

Fig.8. 6. Schematic of a plate type heat exchanger

8.4 Specifications

8.4.1 Engine specifications

Design: 4 cycle, V-block, turbocharged low temperature after-cooled
Bore: 159 mm (6.25 in.)
Stroke: 190 mm (7.48 in.)
Displacement: 60.3 liters (3685 in^3)
Cylinder block: Cast iron, V16
Battery charging alternator: None
Starting voltage: 24 volts negative ground
Fuel system: Lean burn
Ignition system: Individual coil on plug
Air cleaner type: Dry replaceable element
Lube oil filter type(s): Full flow and bypass filters
Breather: Breather filter

8.4.2 Alternator specifications

Total capacity: 3.4 MW
Design: Brushless, 4 pole, revolving field
Stator: 2/3 pitch
Rotor: Two bearing
Insulation system: Class F and H see ADS (Alternator Data Sheet) for details
Standard temperature rise: 105 °C (221 °F) Continuous @ 40 °C (104 °F) ambient
Exciter type: Permanent Magnet Generator (PMG)
Phase rotation: A (U), B (V), C (W)
Alternator cooling: Direct drive centrifugal blower fan
AC waveform: Total Harmonic Distortion (THDV) < 5% no load to full linear load, < 3% for any single harmonic
Telephone Influence Factor (TIF): < 50 per NEMA MG1-22.43
Telephone Harmonic Factor (THF): < 3

8.5 Specimen Calculation

m_f = mass flow rate of fuel consumed = $\rho_f V_f / t = 0.029$ kg/s

$\eta_t = W_{out} / m_f.CV = 430 \text{ W} / (0.029*50000) = 0.296$

8.6 Observations

C V = 50000 kJ/kg
ρ_f = 0.717 kg/m^3

Table 8. 1. Effect of fuel flowrate and work output on efficiency of gas generator set

No. of obs.	**W_{out} /s (W)**	**m_f (kg/s)**	**η_t (%)**
1			

2			
3			
4			

9. Experiment No – 9

9.1 Objective

To determine the efficiency of Diesel Generator Set of UET Power House

9.2 Apparatus

Diesel Generator Set of UET Power House

9.3 Theory

9.3.1 Diesel engine

The Diesel engine (also known as a compression-ignition or CI engine), named after Rudolf Diesel, is an internal combustion engine in which ignition of the fuel, which is injected into the combustion chamber, is caused by the elevated temperature of the air in the cylinder due to the mechanical compression (adiabatic compression).
Diesel engines work by compressing only the air. This increases the air temperature inside the cylinder to such a high degree that atomized Diesel fuel injected into the combustion chamber ignites spontaneously. With the fuel being injected into the air just before combustion, the dispersion of the fuel is uneven; this is called a heterogenous air-fuel mixture. The process of mixing air and fuel happens almost entirely during combustion, the oxygen diffuses into the flame, which means that the Diesel engine operates with a diffusion flame. The torque a Diesel engine produces is controlled by manipulating the air ratio; this means, that instead of throttling the intake air, the Diesel engine relies on altering the amount of fuel that is injected, and the air ratio is usually high.
The Diesel engine has the **highest thermal efficiency (engine efficiency) of any practical internal or external combustion engine due to its very high expansion ratio** and inherent lean burn which enables heat dissipation by the excess air.
It runs on diesel cycle as shown:

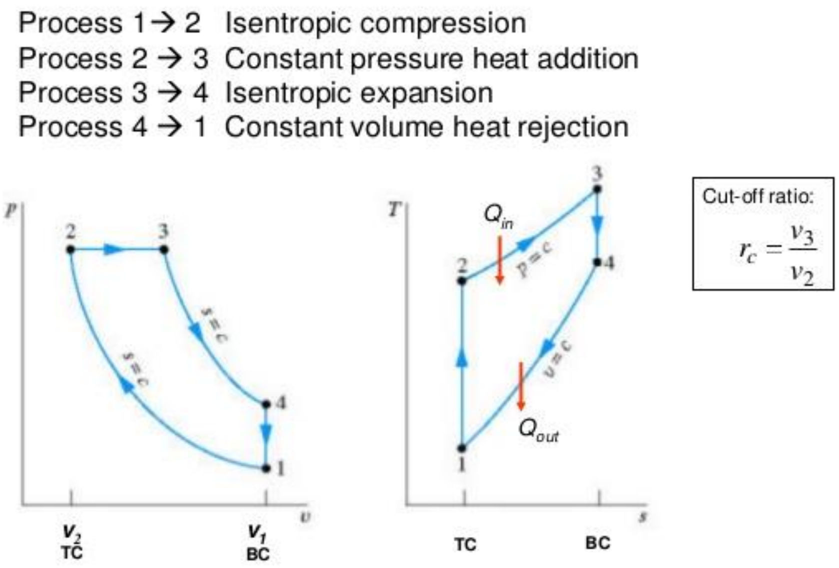

Fig.9. 1. P-v and t-s diagram of diesel cycle

Diagram of the diesel generator is given below:

Fig.9. 2. Diesel generator set

9.3.2 Turbocharger

A turbocharger, is a turbine-driven forced induction device that increases an internal combustion engine's efficiency and power output by forcing extra compressed air into the combustion chamber. This improvement over a naturally aspirated engine's power output is due to the fact that the compressor can force more air—and proportionately more fuel—into the combustion chamber than atmospheric pressure alone.
It is shown below:

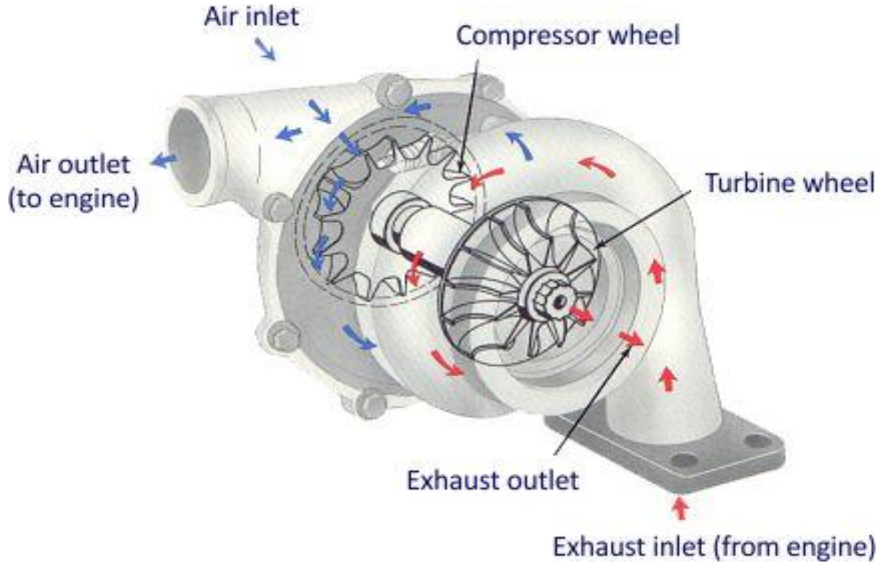

Fig.9. 3. Schematic diagram of a turbocharger

9.3.3 Engine cooling system

Internal combustion engine cooling uses either air or liquid to remove the waste heat from an internal combustion engine. For small or special purpose engines, cooling using air from the atmosphere makes for a lightweight and relatively simple system. Watercraft can use water

directly from the surrounding environment to cool their engines. For water-cooled engines on aircraft and surface vehicles, waste heat is transferred from a closed loop of water pumped through the engine to the surrounding atmosphere by a radiator.
Engine cooling system is shown below:

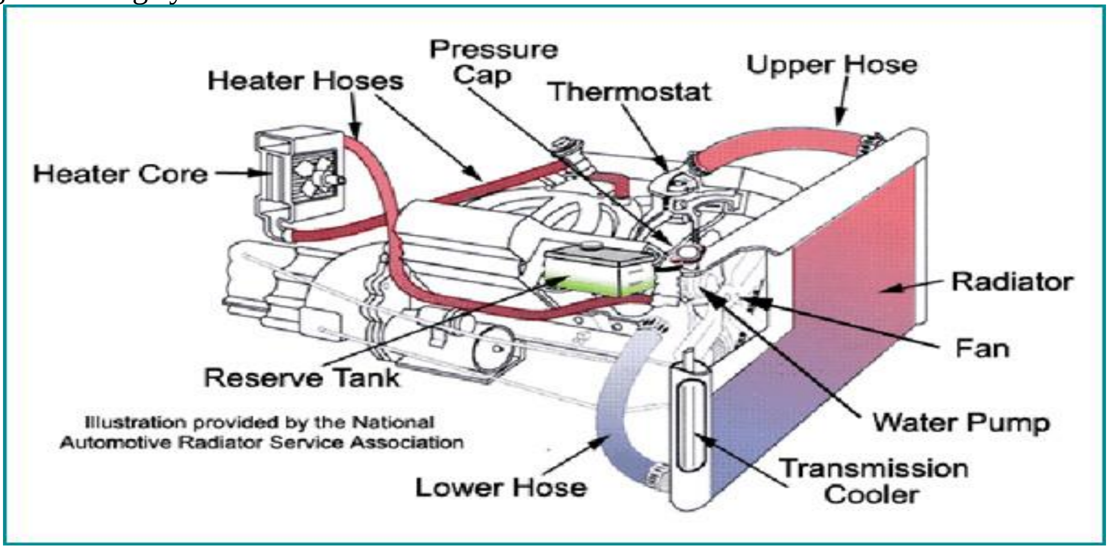

Fig.9. 4. Schematic of engine cooling system

9.3.4 Diesel fuel injection system

Fuel injection is the introduction of fuel in an internal combustion engine, most commonly automotive engines, by the means of an injector.
All diesel engines use fuel injection by design.
Its schematic is shown below:

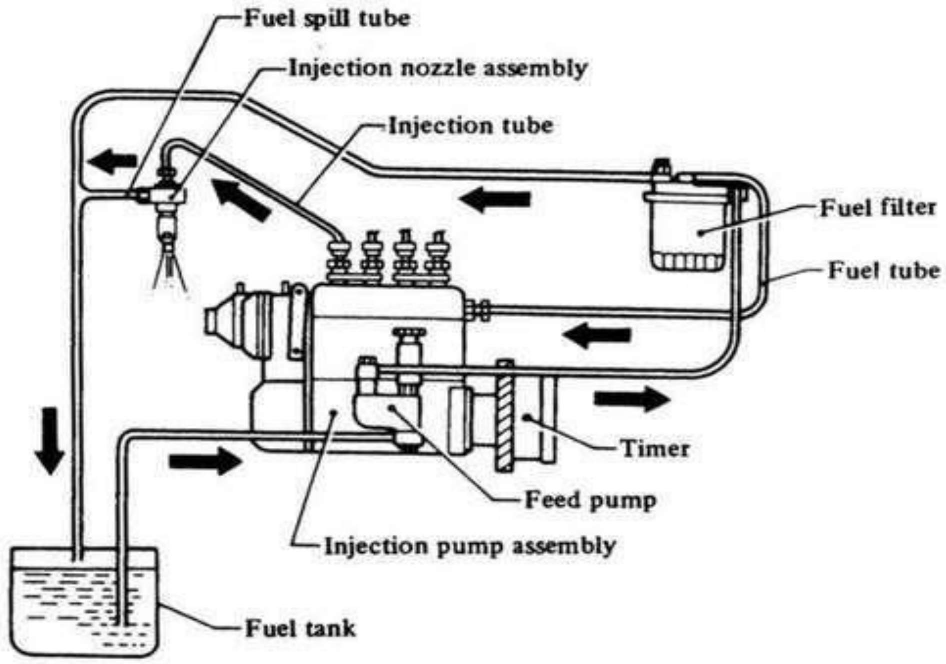

Fig.9. 5. Schematic of diesel engine fuel injection system

9.4 Specifications

Fuel: Diesel

Power output: 440kW

Displacement: 15000cc

Aspiration: Turbocharged

Compression ratio: 17:1

Bore: 137mm

Stroke: 169 mm

Radiator: Air cooled

9.5 Specimen Calculation

m_f = mass flow rate of fuel consumed = $\rho_f V_f / t$ =0.01 kg/s

$\eta_t = W_{out} / m_f .CV$ = 393/0.01*45500 = 86.4 %

9.6 Observations

C V **= 45500 kJ/kg**

ρ_f = **830kg/m^3**

Table 9. 1. Effect of fuel flowrate and work output on thermal efficiency of diesel generator set

No. of obs.	**W_{out}/s (kW)**	**m_f (kg/s)**	**η_t (%)**
1			
2			
3			
4			

10. Experiment No –10

10.1 Objective

To determine the Thermal Efficiency and Water Efficiency of Cooling Towers at UET Power House

10.2 Apparatus

Cooling Towers at UET Power House

10.3 Theory

10.3.1 Cooling tower

A cooling tower extracts heat from water by evaporation. In an evaporative cooling tower, a small portion of the water being cooled is allowed to evaporate into a moving air stream to provide significant cooling to the rest of that water stream.

10.3.2 Working of Cooling towers

When water is reused in the process, it is pumped to the top of the cooling tower and will then flow down through plastic or wood shells, much like a honeycomb. The water will emit heat as it is downward flowing which mixes with the above air flow, which in turn cools the water. Part of this water will also evaporate, causing it to lose even more heat.

10.3.3 Types of cooling towers

10.3.3.1 Natural draft

Natural draft towers are typically about 120 m high, depending on the differential pressure between the cold outside air and the hot humid air on the inside of the tower as the driving force. No fans are used.

10.3.3.2 Mechanical Draft

Mechanical draft towers uses fans (one or more) through the tower. They are two different classes:

(a) Forced draft cooling towers

(b) Induced draft cooling towers

10.3.3.3 Forced Draft

The forced draft tower has the fan, basin, and piping located within the tower structure. In this model, the fan is located at the base. There are no louvered exterior walls. Instead, the structural steel or wood framing is covered with paneling made of aluminum, galvanized steel, or asbestos cement boards.

It is shown below:

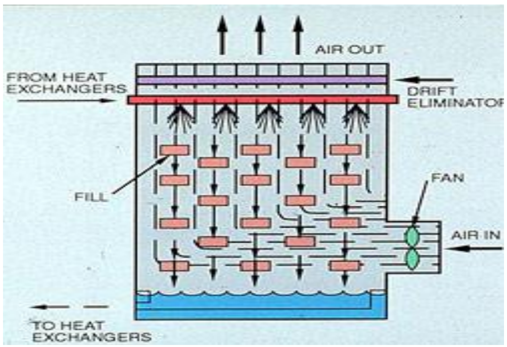

Fig.10. 1. Forced draft cooling tower

10.3.3.4 Induced Draft

The induced draft tower shown in the following picture has one or more fans, located at the top of the tower, that draw air upwards against the downward flow of water passing around the wooden decking or packing. Since the airflow is counter to the water flow, the coolest water at the bottom is in contact with the driest air while the warmest water at the top is in contact with the moist air, resulting in increased heat transfer efficiency.

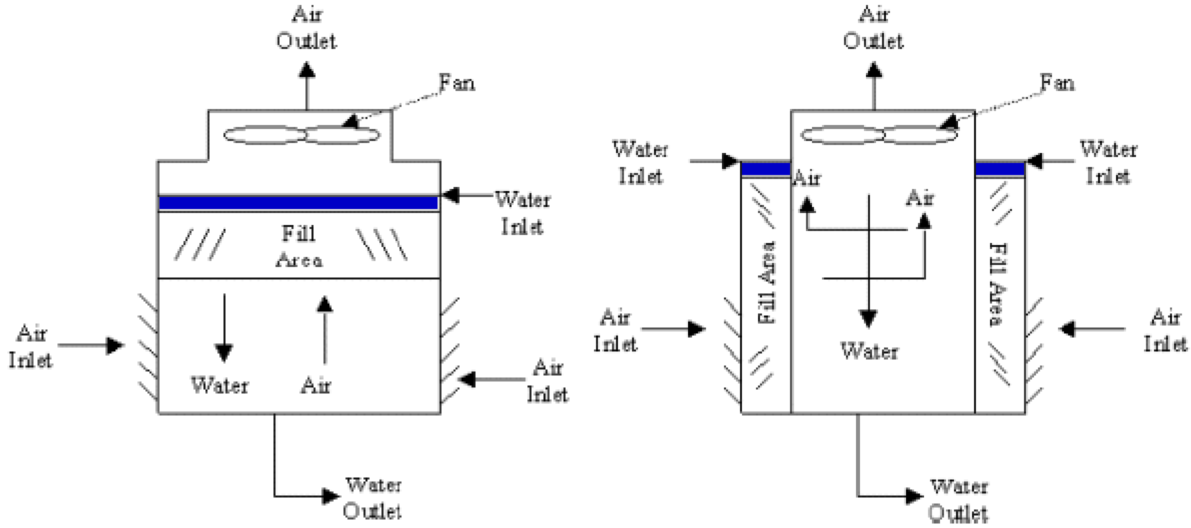

Fig.10. 2. Induced draft cooling tower

10.3.3.5 Hybrid Draft

They are equipped with mechanical draft fans to augment airflow. Consequently, they are also referred to as fan-assisted natural draft towers. The intent of their design is to minimize the power required for the air movement, but to do so with the least possible stack cost impact. Properly designed fans may need to be operated only during periods of high ambient and peak loads.

It is shown below:

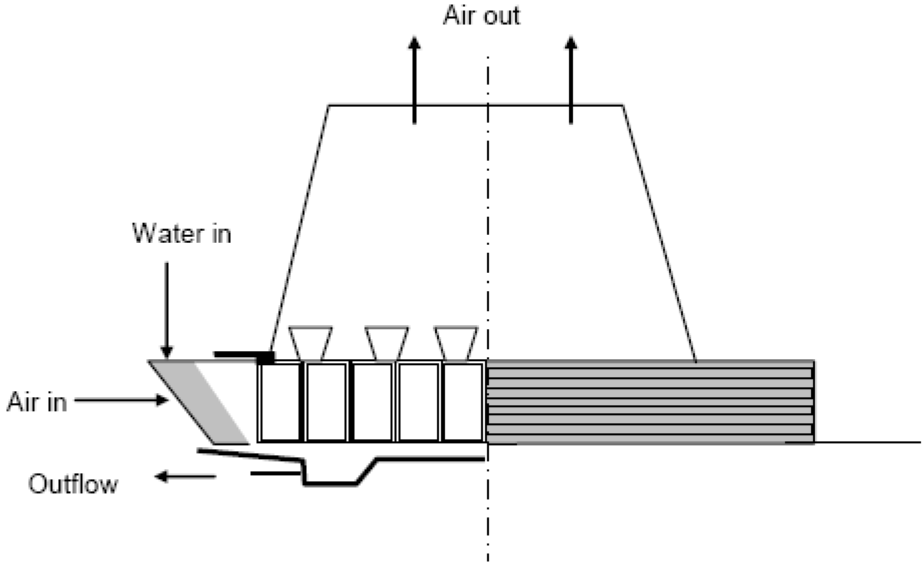

Fig.10. 3. Cooling tower with hybrid draft

10.4 Specimen Calculation

Water Efficiency = Desired losses / Total Losses =
Water Efficiency = Water evaporated / make-up water

10.5 Theoretical Cooling

Cooling Tower Inlet Temperature – Wet Bulb Temperature = CWR – WBT = 40°C

10.6 Actual cooling

Cooling Tower Inlet Temperature – Cooling Tower Outlet Temperature= CWR – CWS =

34°C

Thermal Efficiency =Actual cooling / theoretical cooling x 100

= (CWR-WBT) / (CWR – CWS) x 100 = 34/40 = 0.85*100= 85%

10.7 Observations

Table 10. 1. Effect of different temperatures on thermal efficiency of cooling tower

No. of obs	CWR(°C)	WBT(°C)	CWS(°C)	Actual Cooling (°C)	Theoretical Cooling (°C)	Thermal Efficiency (%)
1						
2						
3						
4						