DHABALESWAR INSTITUTE OF POLYTECHNIC

DEPARTMENT OF MECHANICAL ENGINEERING

LECTURE NOTES ON

POWER STATION ENGINEERING

(TH – 3)

SEM – 6^{TH}

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HOD. IN MECH. ENGINEERING

HYDEL POWER STATION/HYDRO ELECTRIC POWER PLANT

INTRODUCTION

Energy is a critical factor in developing countries for economic growth as well as for social development and human welfare.
Hydropower is a renewable source of energy, which is economical, non-polluting and environmentally benignamong all renewable sources of energy. For efficient operationof hydropower plants, in order to meet the electricity demand,the hydro energy is stored either in reservoirs for dam basedschemes or settling basins for run-of-river schemes. Thesereservoirs or settling basins are filled with sediments over aperiod of time. This problem must be taken care of by sedimentsettling systems in power plants. However, lot of unsettledsediment pass through the turbines every year and turbineparts are exposed to severe erosion. The erosion of hydroturbine components is a major problem for the efficientoperation of hydropower plants. These problems are moreprominent in power stations which are of run-of-river types.The problem is aggravated if the silt contains higherpercentage of quartz, which is extremely hard.

HYDRO POTENTIAL

India is endowed with economically exploitable and viable hydro potential assessed to be about 84,000 MW at 60% load factor. In addition, 6,780 MW in terms of installedcapacity from Small, Mini, and Micro Hydel schemes havebeen assessed. Also, 56 sites for pumped storage schemeswith an aggregate installed capacity of 94,000 MW havebeen identified. It is the most widely used form of renewableenergy. India is blessed with immense amount of hydro-electric potential and ranks 5th in terms of exploitable hydro- potential on global scenario.The present installed capacity as on September 30, 2013 isapproximately 39,788.40 MW which is 17.39% of totalelectricity generation in India. The public sector has a predominant share of 97% in this sector. National Hydroelectric Power Corporation (NHPC), Northeast Electric Power Company (NEEPCO), SatlujJalVidyut Nigam (SJVNL), THDC, NTPC-Hydro are a few public sector companies engaged in development of Hydroelectric Power in India. Bhakra Beas Management Board (BBMB), an illustrative state owned enterprise in north India has an installed capacity of 2.9 GW and generates 12,000-14,000 million units per year. The cost of generation of energy after four decades of operation is about 20 paise/kWh. [citation needed] BBMB is a major source of peaking power and black start to the northern grid in India. Large reservoirs provide operational flexibility. BBMB reservoirs annually supply water for irrigation to 12.5 million acres (51,000 km2; 19,500 sq mi) of agricultural land of partner states, enabling northern India in its green revolution.

HISTORY OF HYDROELECTRICITY

Archaeologists confirm that the history of the storage dam goes back to 5000 years to 3000 BC. Vitruvius was the first architect to explain a water wheel which could generate power. Then Barbegal from France in the 4th century AD worked on water wheels and generated a system of sixteen water wheels which followed the principle of kinetic energy into mechanical energy.

STRENGTHS OF HYDRO POWER

- Environmental friendly, clean renewable
- High degree of flexibility
- Part of multipurpose project with additional benefits.
- Pumped storage for optimal integrate operation of grid
- Least operational and maintenance cost
- Additional benefits of Flood control, Tourism, fishery.
- Well recognized for obtaining financial support.

WEAKNESS OF HYDRO POWER

- Mainly depends on rainfall/snowmelt.
- Run of river not for peaking
- High capital intensive.
- Remotely located
- Gestation period is very large.
- Relatively smaller units.
- Nonstandard occurrence.

OPPORTUNITIES OF HYDRO POWER

- Vast potential untapped
- Requirement for power peaking
- Greater concern towards increasing pollutions on land, water and in air causes leading inclination towards hydro
- Depletion of fossil fuels.

THREATS OF HYDRO POWER

- Ambitious plan for thermal/nuclear programme for power.
- Growing concern of environment.
- Prone to natural calamities.
- Submergence of land and displacement of population
- Apprehension on seismic disturbance
- Over emphasis of other renewable energy sources development.

WORKING PRINCIPLE OF HYDRO- ELECTRIC POWER PLANT

In hydroelectric power plants the potential energy of water due to its high location is converted into electrical energy. The total power generation capacity of the hydroelectric power plants depends on the head of water and volume of water flowing towards the water turbine. The water flowing in the river possesses two type of energy:

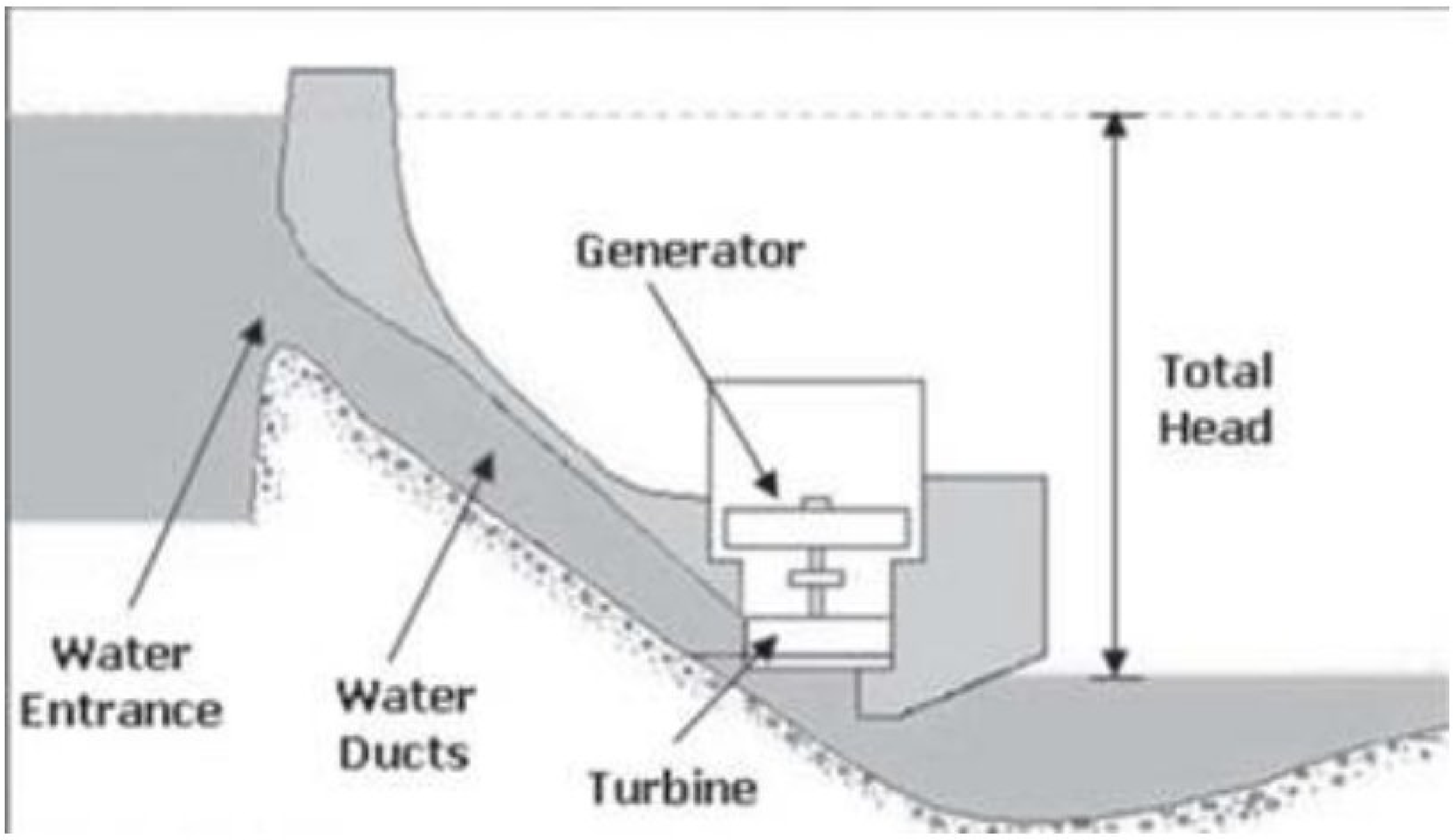
• The kinetic energy due to flow of water and • Potential energy due to the height of water.

In hydroelectric power and potential energy of water is utilized to generate electricity. The formula for total power that can be generated from water in hydroelectric power plant due to its height is given

P= q*h*g Where,

"p" is the power produced in "watt"

"Q" is the rate of flow of water which in cubic meter/second



"h"= height of water which is measured in "meter" It's also head of water. The difference between source of water (from where water is taken) and the water's outflow (where the water is used to generate electricity, it is the place near the turbines).

"g" is the gravity constant 9.81 m/second square.

The formula clearly shows that the total power that can be generated from the hydroelectric power plants depends on these factors.

a) The flow rate of water or volume of flow of water and
b) Height or head of water.
c) More the volume of water and
d) More the head of water more is the power produced in the hydroelectric power plant.

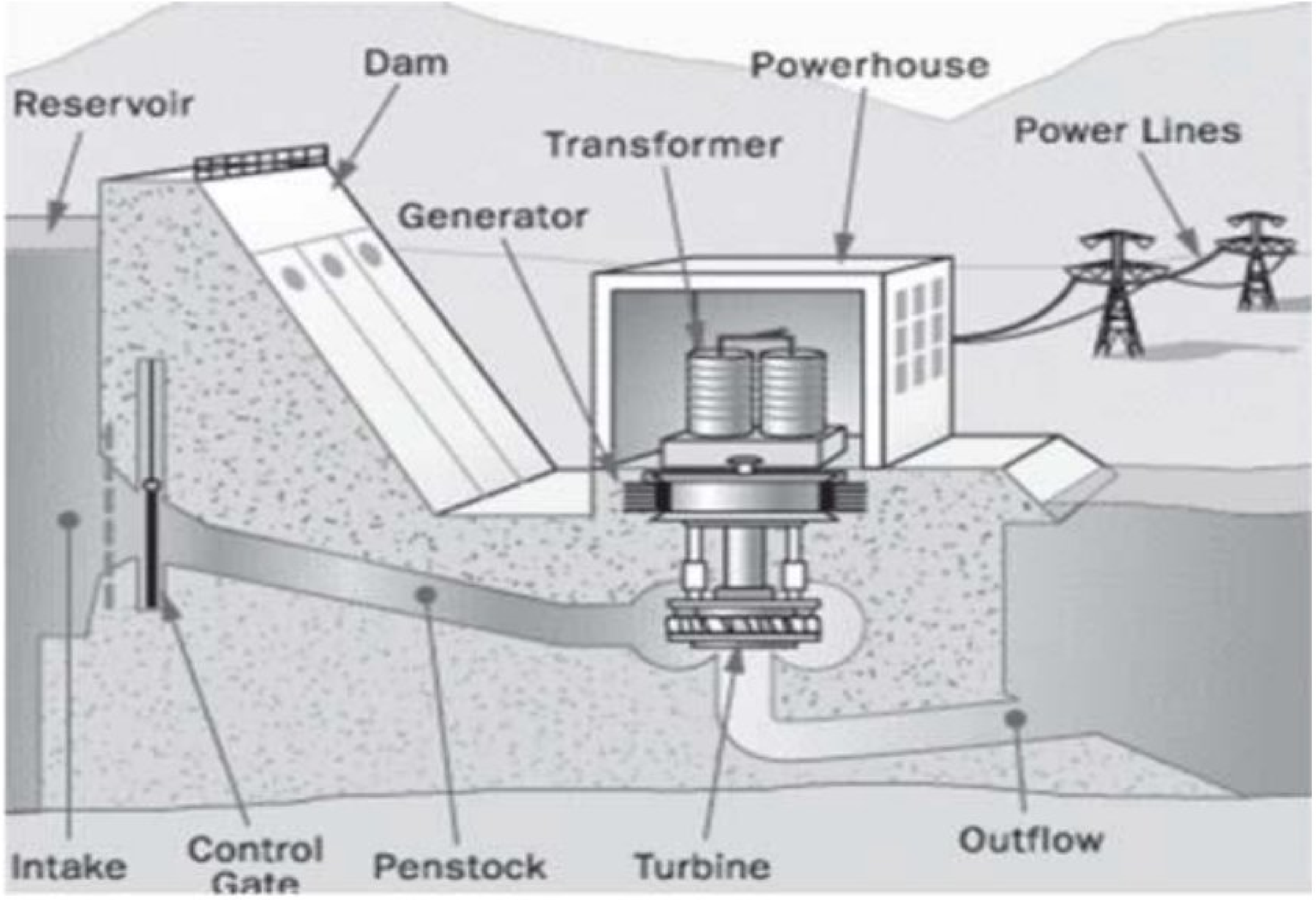
To obtain the high head of water the reservoir of water should as high as possible and power generation unit should be as low as possible. The maximum height of reservoir of water is fixed by natural factors like the height of river bed, the amount of water and other environmental factors. The location of the power generation unit can be adjusted as per the total amount of power that is to be generated. Usually the power generation unit is constructed at levels lower than ground level so as to get the maximum head of water.

The total flow rate of water can be adjusted through the pen stock as per the requirements. If more power is to be generated more water can be allowed to flow through it.

COMPONENTS OF HYDROELECTRIC POWER PLANTS

Hydroelectric power plant requires various components for generating electrical power. Some of the major components in hydroelectric power plants are: Reservoirs, Dam, Trash Rack, Fore bay, Surge Tank, Penstock, Spillway, Prime Mover and Generator, Draft Tube. The functions of all major components are discussed.

The basic requirement of a hydroelectric power station is a reservoir where large quantity of water is stored during rainy season and used during the dry season. The reservoir is built by constructing a dam across the river. The water from the reservoir is drawn by the fore bay through an open canal or tunnel. The water from the fore bay is supplied to the water prime mover through the penstock which is located at the much lower level than the height of the water in the reservoir. Thus potential energy of water stored in reservoir is converted into kinetic energy and made to rotate the turbine. Turbine shaft is connected to synchronous generator or alternator for generating electricity. This generated power is stepped up using step-up transformer and delivered to load centers or grid. The regulation of water flow to the turbine depending on the electrical load demand is carried out by the governor system.



Some of the components of hydroelectric power plants and their functions are given below:

WATER RESERVOIR

The function or purpose of reservoir is to store the water during rainy season and supply the same during dry season. This is in simple, water storage area. The water reservoir is the place behind the dam where water is stored. The water in the reservoir is located higher than the rest of the dam structure. The height of water in the reservoir decides how much potential energy the water possesses. The higher the height of water, the more its potential energy. The high position of water in the reservoir also enables it to move downwards effortlessly. The height of water in the reservoir is higher than the natural height of water flowing in the river, so it is considered to have an altered equilibrium.

This also helps to increase the overall potential energy of water, which helps ultimately produce more electricity in the power generation unit.

DAM

The function of dam is to increase the height of the water level (increase in the potential energy) behind it which ultimately increases the reservoir capacity. The dam also helps in increasing the working head of the power plant. Dams are generally built to provide necessary head to the power plant.

TRASH RACK

The water intake from the dam or from the fore bay is provided with trash rack. The main function of trash rack is to prevent the entry of any debris which may damage the wicket gates and turbine runners or choke-up the nozzles of impulse turbine. During winter season when water forms ice, to prevent the ice from clinging to the trash racks, they are often heated electrically. Sometimes air bubbling system is provided in the vicinity of the trash racks which bring warmer water to the surface of the trash racks.

FOREBAY

The function of fore bay is to act as regulating reservoir temporarily storing water when the load on the plant is reduced and to provide water for initial increment of an increasing load while water in the canal is being accelerated. In many cases, the canal itself is large enough to absorb the flow variations. In short, forebay is naturally provided for storage of water to absorb any flow variations if exist. This can be considered as naturally provided surge tank as it does the function of the surge tank. The fore bay is always provided with some type of outlet structure to direct water to penstock depending upon the local conditions.

SURGE TANK

The main function of surge tank is to reduce the water hammering effect. When there is a sudden increase of pressure in the penstock which can be due sudden decrease in the load demand on the generator. When there is sudden decrease in the load, the turbine gates admitting water to the turbine closes suddenly owing to the action of the governor. This sudden rise in the pressure in the penstock will cause the positive water hammering effect. This may lead to burst of the penstock because of high pressures.

When there is sudden increase in the load, governor valves opens and accepts more water to the turbine. This results in creation of vacuum in the penstock resulting into the negative water hammering effect. Therefore the penstock should have to withstand both positive water hammering effect created due to close of governor valve and negative water hammering effect due to opening of governor valve. In order to protect the penstock from these water hammering effects, surge tank is used in hydroelectric power station. A surge tank is introduced in the system between dam and the power house nearest. Surge tank is a tank provided to absorb any water surges caused in the penstock due to sudden loading and unloading of the generator.When the velocity of the water in the penstock decreases due to closing of turbine valves, the water level in the surge tank increases and fluctuating up and down till its motion is damped out by the friction. Similarly when the water accelerates in the penstock, water is provided by the surge tank for acceleration. Surge tank water level falls down and fluctuates up and down absorbing the surges.

INTAKE OR CONTROL GATES

These are the gates built on the inside of the dam. The water from reservoir is released and controlled through these gates. These are called inlet gates because water enters the power generation unit through these gates. When the control gates are opened the water flows due to gravity through the penstock and towards the turbines. The water flowing through the gates possesses potential as well as kinetic energy.

THE PENSTOCK

The penstock is the long pipe or the shaft that carries the water flowing from the reservoir towards the power generation unit, comprised of the turbines and generator. The water in the penstock possesses kinetic energy due to its motion and potential energy due to its height. The total amount of power generated in the hydroelectric power plant depends on the height of the water reservoir and the amount of water flowing through the penstock. The amount of water flowing through the penstock is controlled by the control gates.

SPILLWAY

The function of spillway is to provide safety of the dam. Spillway should have the capacity to discharge major floods without damage to the dam and at the same time keeps the reservoir levels below some predetermined maximum level.

POWER HOUSE

A power house consists of two main parts, a sub-structure to support the hydraulic and electrical equipment and a superstructure to house and protect this equipment.

The superstructure of most power plants is the buildings that house all the operating equipment. The generating unit and the exciter is located in the ground floor. The turbines which rotate on vertical axis are placed below the floor level while those rotating on a horizontal axis are placed on the ground floor alongside of the generator.

WATER TURBINES

Water flowing from the penstock is allowed to enter the power generation unit, which houses the turbine and the generator. When water falls on the blades of the turbine the kinetic and potential energy of water is converted into the rotational motion of the blades of the turbine. The rotating blades cause the shaft of the turbine to also rotate. The turbine shaft is enclosed inside the generator. In most hydroelectric power plants there is more than one power generation unit.

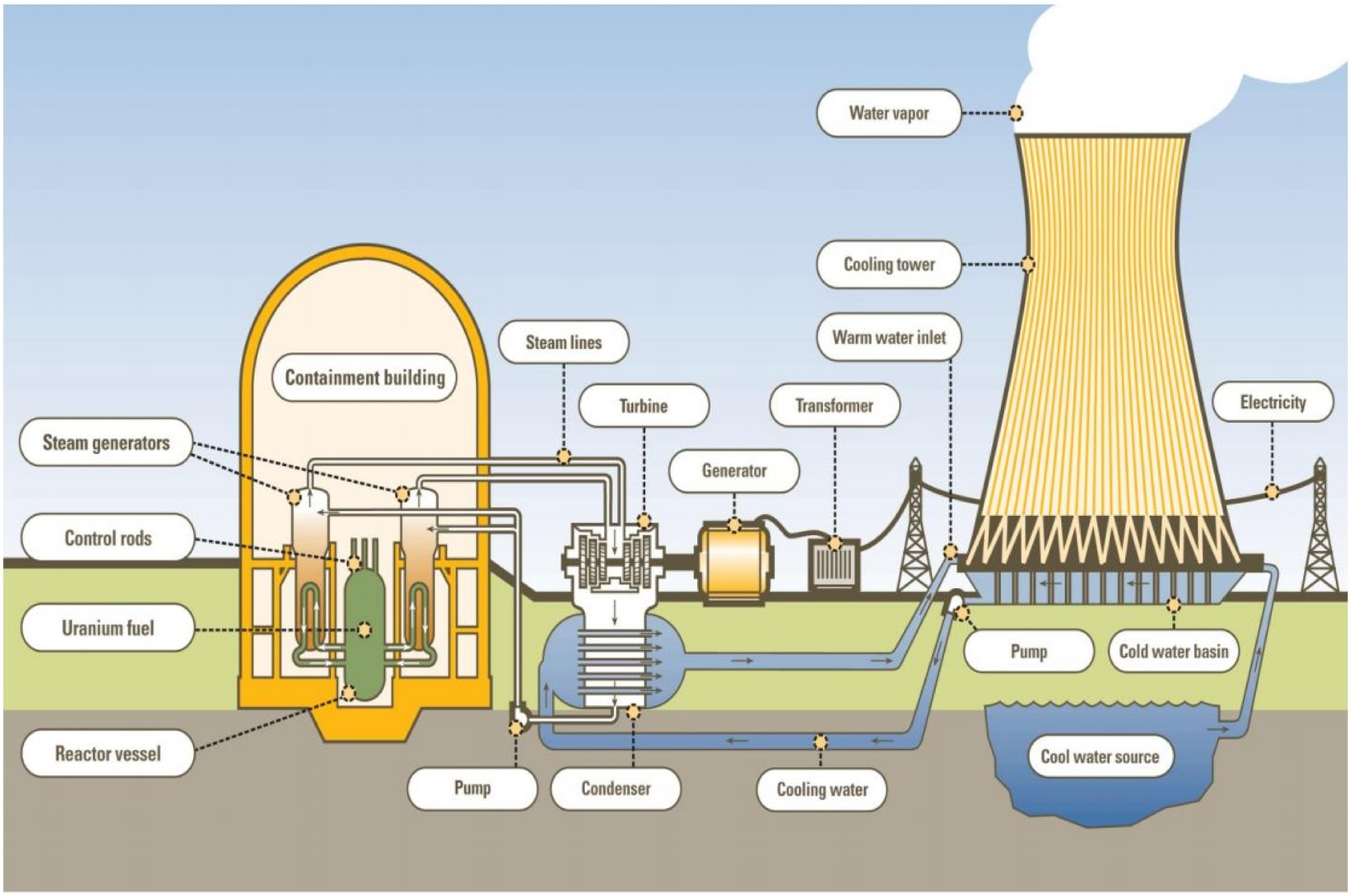
There is large difference in height between the level of turbine and level of water in the reservoir. This difference in height, also known as the head of water, decides the total amount of power that can be generated in the hydroelectric power plant.

There are various types of water turbines such as Kaplan turbine, Francis turbine, Pelton wheels etc. The type of turbine used in the hydroelectric power plant depends on the height of the reservoir, quantity of water and the total power generation capacity.

QUESTIONS FOR PRACTICE

1. What do you mean by Hydro Power?
2. With a neat diagram explain the working principle of a Hydro Electric Power Plant.
3. What are the components of a Hydroelectric Power Plant? Explain each one of them.
4. What are the advantages and disadvantages of a Hydro Electric Power Plant?
5. What are the applications of a Hydro Electric Power Plant?

NUCLEAR POWER PLANT



INTRODUCTION OF THE TOPIC: NUCLEAR POWER PLANT:-

WHY? NUCLEAR POWER PLANT:

In previous chapters, we studied how electricity produced with the help of water & coal (known as Hydro & Thermal Power Plant). But, now a day's our population as well as industrial sector increases, it means that demand of electrical power increases day by day. To full fill this demand water & coal is of limited edition, so we required searching newly source of energy for production & fulfilment of electrical demand.

To overcome the above mentioned problem, nuclear energy is a best solution to produce huge amount of electrical energy. With the fission process, we have to produce this energy. This topic is similar to thermal
power plant, in thermal power, coal is used to produce heat energy on the other hand in nuclear heat energy is produced with fission process of uranium, thorium & plutonium.

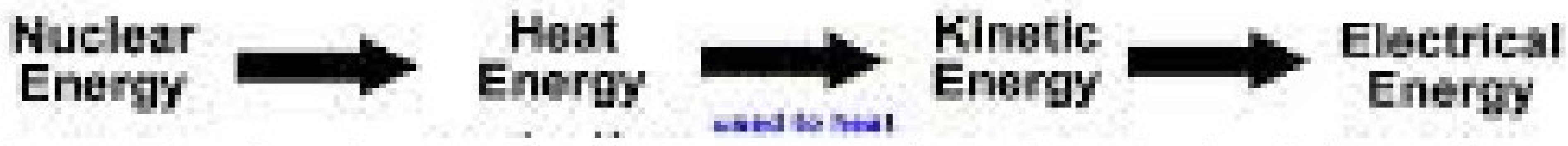
DEFINITION OF NUCLEAR POWER PLANT:

The Power Plant which uses nuclear energy of radioactive material (Uranium or Thorium) converted into Electrical Energy is known as Nuclear Power Plant.

BASIC PRINCIPAL OF NUCLEAR POWER PLANT:

Every power plant has its own basic principal, on the basis of this the plant works. The Basic Principal of Nuclear Power Plant is given below:

$$CE \leftrightarrow HE \leftrightarrow KE \leftrightarrow ME \leftrightarrow EE$$



As we know that, the freely moving neutrons bombarded with radioactive material (U235 or Th232) the heat energy produced, with the help of this heat energy & water a steam produced at high pressure & temperature. High pressure steam passes towards turbine where KE is converted to ME. We know that, turbine & generator are mechanically coupled through this combination an Electrical Energy is produced in Nuclear Power Plant.

LIST OF NUCLEAR POWER PLANT IN MAHARASHTRA & INDIA WITH THEIR INSTALLED CAPACITIES:

1. State the nuclear power plant in Maharashtra with their installed capacity?
2. State the nuclear power plant in India with their installed capacities?
3. List any FOUR nuclear power stations in India with their generating capacity?
4. List out any TWO nuclear power stations in India with Capacity.
5. State locations of any four nuclear power plants in India.

FACTORS GOVERNING SELECTION OF SITE FOR THE NUCLEAR POWER PLANT

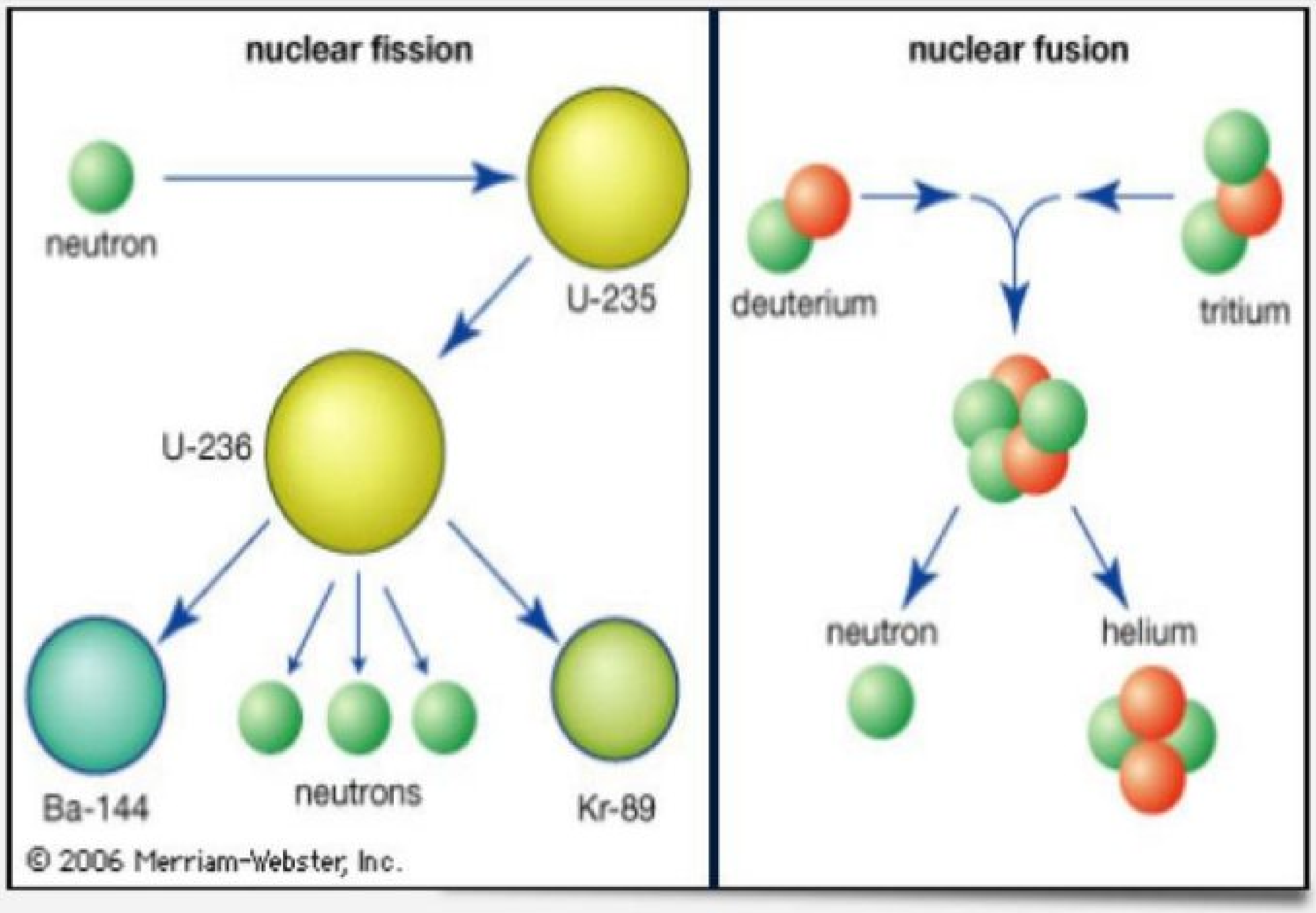
1. Availability of water:sufficient supply of neutral water is obvious for generating steam & cooling purposes in nuclear power station.
2. Disposal of Waste: The wastes of nuclear power station are radioactive and may cause severe health hazards. Because of this, special care to be taken during disposal of wastes of nuclear power plant. The wastes must be buried in sufficient deep from earth level or these must be disposed off in sea quite away from the sea share.
3. Distance from Populated Area: As there is always a probability of radioactivity, it is always preferable to locate a nuclear station sufficiently away from populated area.
4. Transportation Facilities: During commissioning period, heavy equipment to be erected, which to be transported from manufacturer site.So good railways and road ways availabilities are required.
5. Skilled Person Requirement: For availability of skilled manpower to run & handle the plant also good public transport should also be present at the site.

6. Near to Load Centre: As we know that generating stations are far away from thickly populated area, so to reduce the transmission & distribution losses the plant should located near to load centre.

7. Storage of Nuclear Material: the nuclear materials are radioactive, which are dangerous to health to overcome this drawback a separate arrangement provided for storage of material.

8. Geographical Condition: the radioactive material are very dangerous to human health & all living organisms, if due to earthquake chances occurs to blast the reactors to avoided this the area should be free from earthquake.

NUCLEAR FISSION VS. NUCLEAR FUSION



Top: Uranium-235 combines with a neutron to form an unstable intermediate, which quickly splits into barium-144 and krypton-89 plus three neutrons in the process of nuclear fission. Bottom: Deuterium and tritium combine by nuclear fusion to form helium plus a neutron.

NUCLEAR FISSION VS NUCLEAR FUSION

Nuclear fusion and **nuclear fission** are two different types of energy-releasing reactions in which energy is released from high-powered atomic bonds between the particles within the nucleus. The main difference between these two processes is that **fission is the splitting of an atom into two or more smaller ones** while **fusion is the fusing of two or more smaller atoms into a larger one**.

	Nuclear Fission	Nuclear Fusion
Definition:	Fission is the splitting of a large atom into two or more smaller ones.	Fusion is the fusing of two or more lighter atoms into a larger one.
Natural occurrence of the process:	Fission reaction does not normally occur in nature.	Fusion occurs in stars, such as the sun.
Byproducts of the reaction:	Fission produces many highly radioactive particles.	Few radioactive particles are produced by fusion reaction, but if a fission "trigger" is used, radioactive particles will result from that.
Conditions:	Critical mass of the substance and high-speed neutrons are required.	High density, high temperature environment is required.
Energy Requirement:	Takes little energy to split two atoms in a fission reaction.	Extremely high energy is required to bring two or more protons close enough that nuclear forces overcome their electrostatic repulsion.
Energy Released:	The energy released by fission is a million times greater than that released in chemical reactions; but lower than the energy released by nuclear fusion.	The energy released by fusion is three to four times greater than the energy released by fission.
Nuclear weapon:	One class of nuclear weapon is a fission bomb, also known as an atomic bomb or atom bomb.	One class of nuclear weapon is the hydrogen bomb, which uses a fission reaction to "trigger" a fusion reaction.

NUCLEAR FUELS:

Q.1) what are the different fuels used in nuclear power plant? Write in short?
Q.2) state any two fuels used in nuclear power plant?

In Nuclear Power Plant for the Production of heat energy Uranium, thorium & plutonium fuels are used.

A. URANIUM & ITS PROPERTIES:

Atomic Number: 92
Melting Point: 1408 K (1135°C or 2075°F)
Boiling Point: 4404 K (4131°C or 7468°F)
Uranium is a very important element because it provides us with nuclear fuel used to generate electricity in nuclear power stations. Naturally occurring uranium consists of 99% uranium-238 and 1% uranium-235. Uranium-235 is the only naturally occurring fissionable fuel (a fuel that can sustain a chain reaction).

B. NATURAL URANIUM: it consists of 0.714% of & 99.28% .
C. ENRICHED URANIUM: The Process used to increase the percentage of 235-U is known as enrichment. This will help us to maintain chain reaction. Normally it contains higher percentages (3 to 4%) of 235-U.

PLUTONIUM: Due to the absorption of neutrons without fusion in & the plutonium is formed. Atomic Number: 94,Melting point: 641 °C, Boiling point: 3232 °C

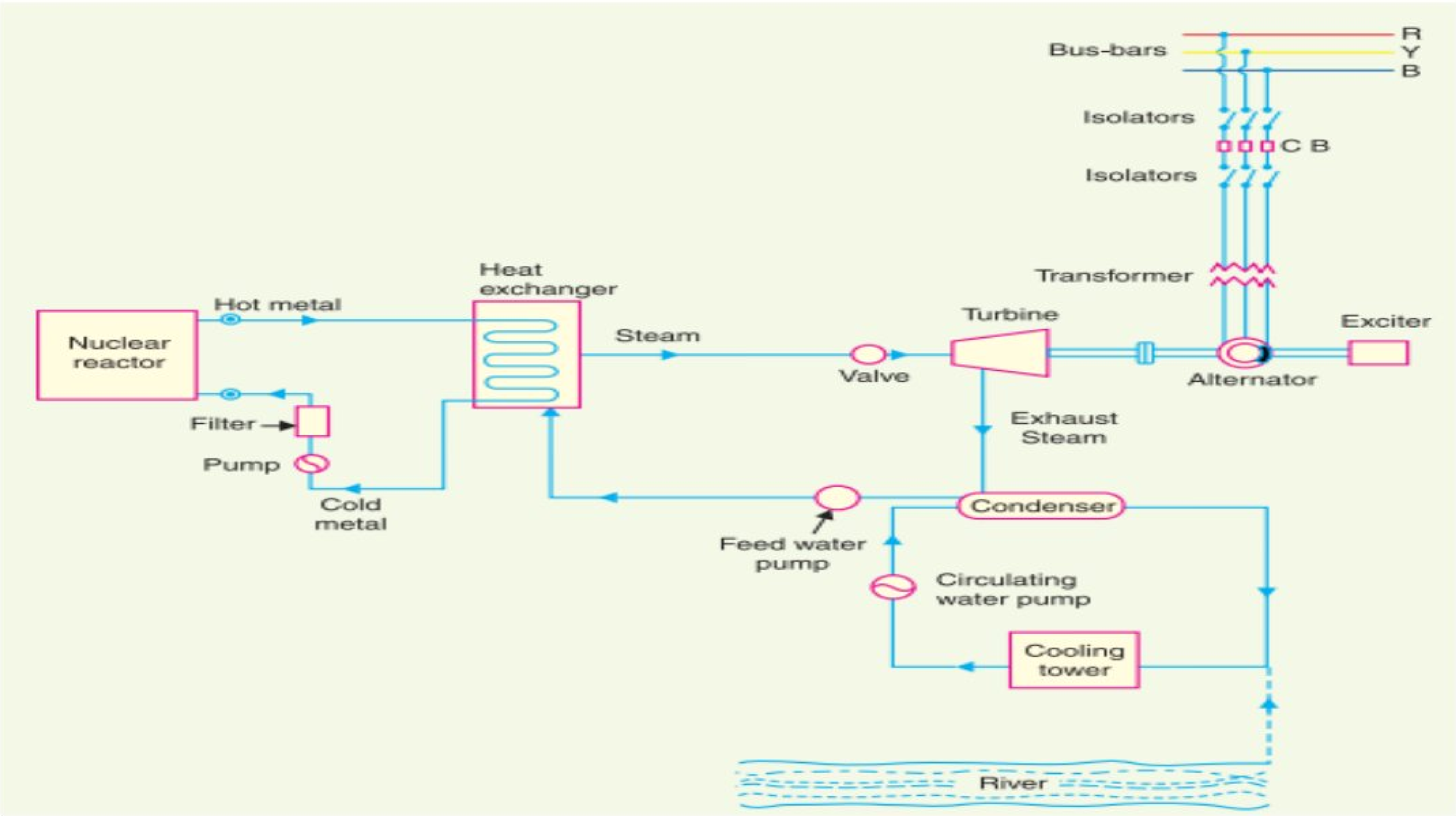
D. URANIUM OXIDE:it is also formed due to enrichment process, but it is in brittle & produced in the form of powder.

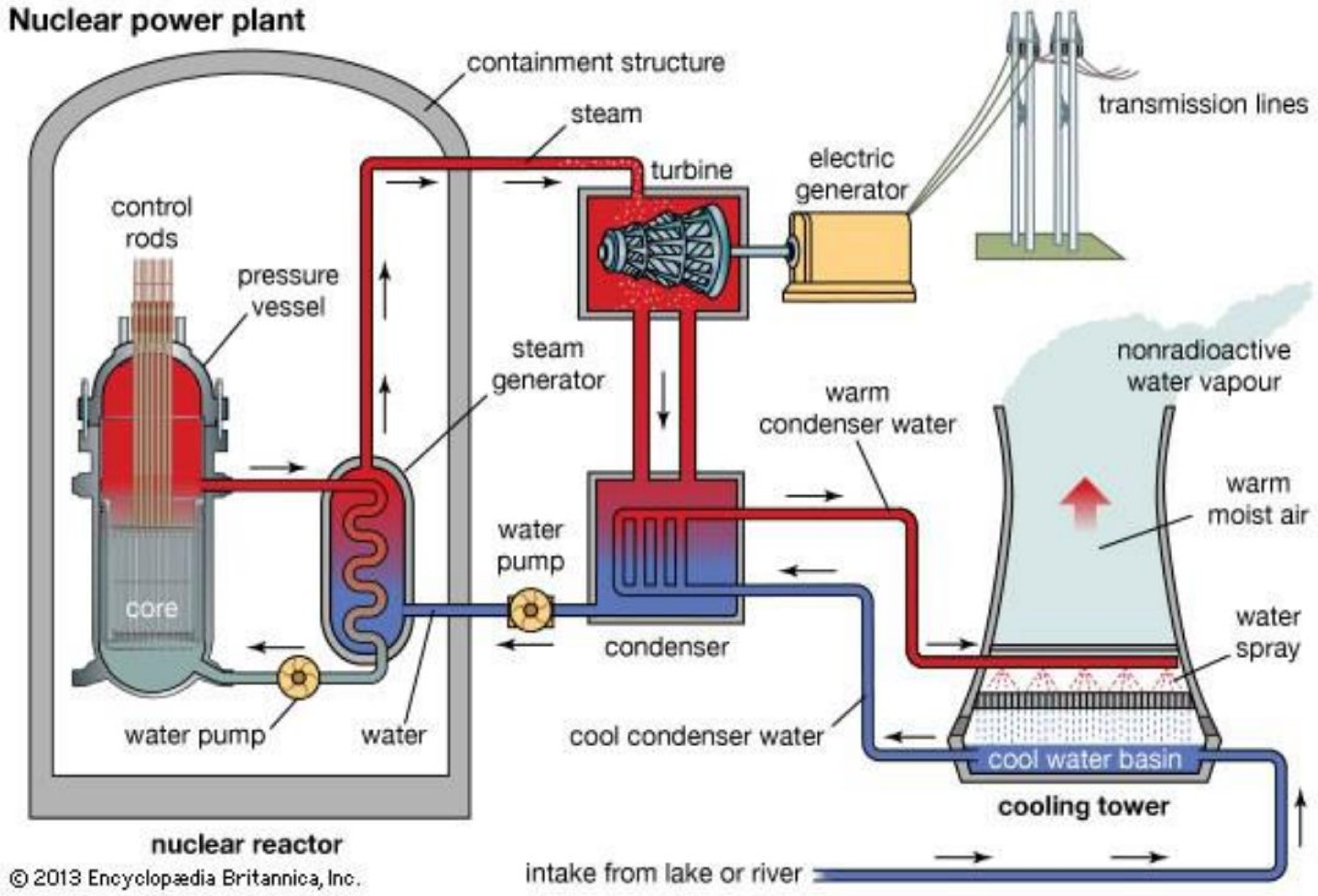
E. URANIUM CARBIDE: this material is not economical in use, but it has very good properties to use as nuclear fuel.

F. THORIUM & ITS PROPERTIES:

Atomic Number: 90
Melting Point: 1750 0c
Boiling Point: 4790 0c
A weakly radioactive, silvery metal. Before it uses of Thorium first up all converted into Thorium is weakly radioactive: all its known isotopes are unstable, with the six naturally occurring ones (thorium-227, 228, 230, 231, 232, and 234). India and China are in the process of developing nuclear power plants with thorium reactors, but this is still a very new technology. Thorium has higher cost that's why it is not popular.

SCHEMATIC ARRANGEMENT OF NUCLEAR POWER PLANT





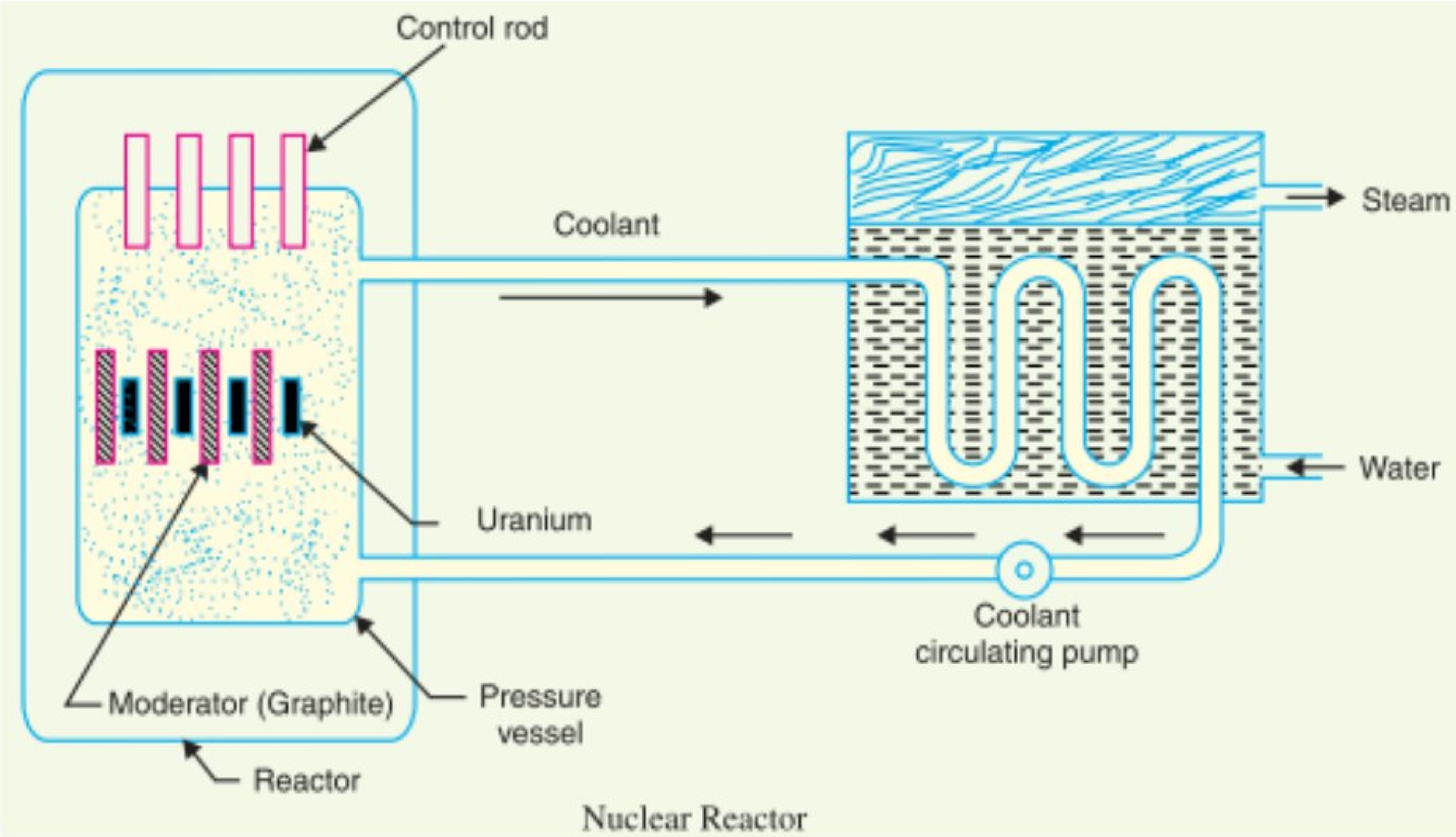
1. **Explain working of nuclear power plant with block diagram?**
2. **Draw the schematic arrangement of the typical nuclear power plant and state the function of reflector?**

The above figure shows, the schematic arrangement of nuclear power plant. Every nuclear power plant consists of following main parts, which are mentioned below:

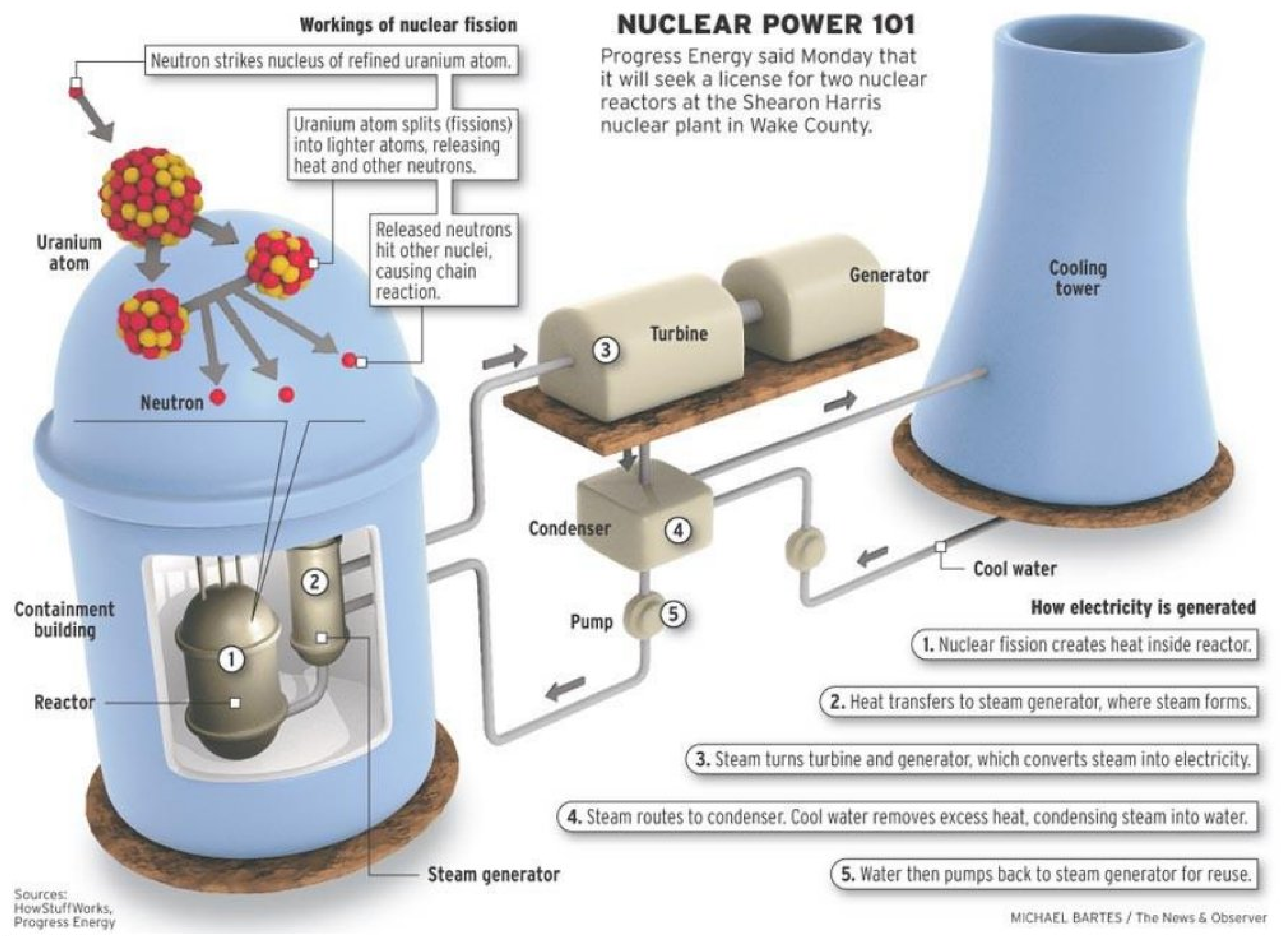
1. Nuclear Reactor
2. Heat Exchanger
3. Steam Turbine
4. Condenser & Cooling Tower
5. Feed Water Heater

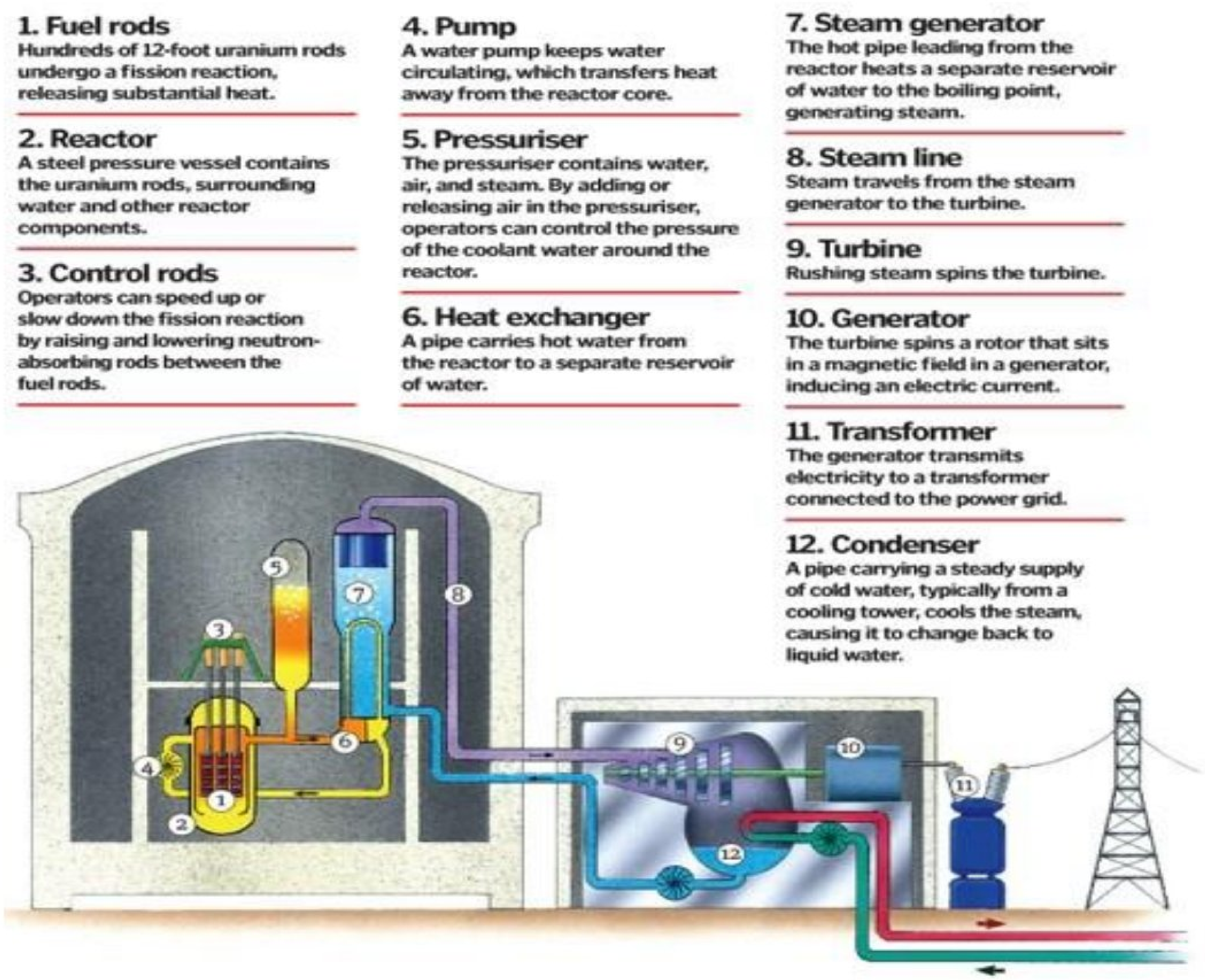
The nuclear reactor function is to produce heat at high temperature. For producing heat the reactor uses, nuclear fuel these are uranium or thorium etc. when the slowly moving neutrons hits the nuclear fuel it produces heat. This heat passes to the heat exchanger; other input to this heat exchanger is heated water. The water is heated with the help of feed water heater. The main function of heat exchanger is to produce steam at high pressure. This high pressure steam passes to the steam turbine. When this steam flow towards turbine it starts rotating, the turbine & alternator are coupled mechanically. Simultaneously alternator starts rotating and the electrical power produced. The exhaust hot steam is passes to the condenser, where it is condensed by using cooling tower, and it is again passing to the heat exchanger through feed water heater. This process is continued.

MAIN PARTS OF REACTORS AND THEIR FUNCTION:



Nuclear Reactor





MAIN PARTS & ITS EXPLANATION OF NUCLEAR REACTOR:

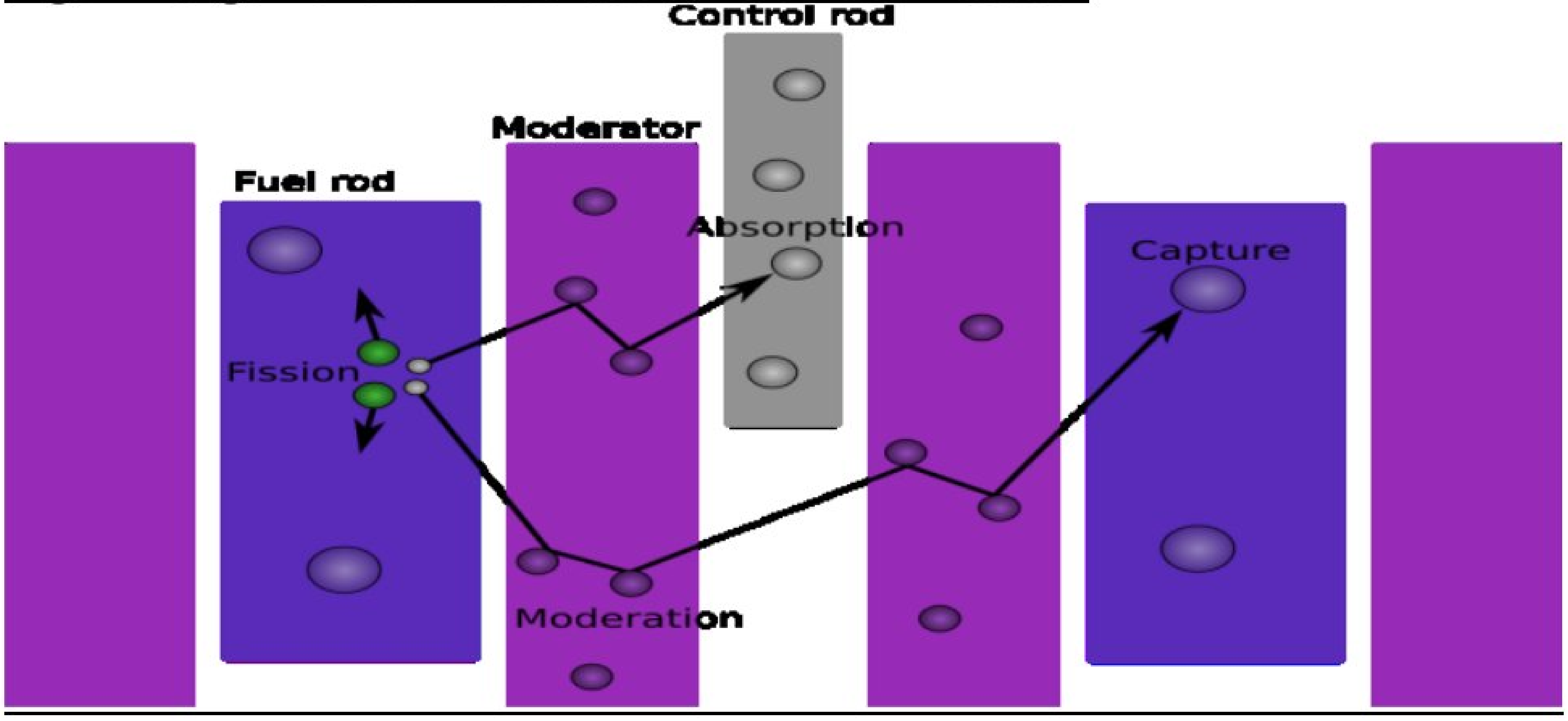
1. Nuclear Fuels.
2. Moderator.
3. Control rods.
4. Reflectors
5. Shielding
6. Reactor vessel
7. Heat Exchanger
8. Coolant
9. Turbine, 10. Condenser, 11. Cooling Tower,12. Water Treatment Chamber.

1. Nuclear Fuel:

In Nuclear Power Plant the fuels used are, or or . Out of the three fuel any one of the fuel used in nuclear power plant. The fuel is required in nuclear power plant to produce a huge amount of heat energy. The fuel are inserted in fuel rod, these fuel rods are bombarded with slow moving neutrons. Separate provision provided for bombarded or hits the neutron to the fuel rod, this device is known as neutron bombardment device.

2. Moderator:

Fig: Arrangement of Moderator in Nuclear Reactor



Q.1) Give four properties of a good moderator for nuclear reaction control?

In nuclear power plant, moderator is a device, of rod shaped. Moderator is placed near the nuclear fuel rod. The main function of moderator in nuclear power plant is reduce the speed of neutrons *(neutron at slower speed is required to produce fission)* & increases the fission processes. Moderator rod is made up of graphite or heavy water or beryllium material.

3. Control Rods:

In nuclear power plant, the control rods are placed in between nuclear fuel rod, moderator and then control rod. These control rods are operated either automatically or manually.(To start or stop the chain reaction). In nuclear power plant the main function of control rod is to control the chain reaction. If the control rod is inserted then it absorbs the freely moving neutrons & stop the chain reaction, if it is no inserted chain reaction is in process, means chain reaction continued. The steady rate or to stop the chain reaction is maintained through control rods. The control rods are made up of cadmium, boron (alloyed with steel or aluminium).

Q.1) Explain the purpose of shielding & reflector in nuclear power plant?
Q.2) State the purpose of reflector in nuclear power plant?

4. Reflector:

Before shielding, the reflector is placed. The reflector is used to surround the reactor core. The reflector will also help to bounce the escaping neutrons back to the reactor core & it conserve the nuclear fuel.

5.Shielding:

Shielding is the also important part of nuclear power plant, shielding is in other words protecting. In nuclear reactor, first one is nuclear fuel rod then moderator, control rod & reflector. Through this shielding is provided. When the chain reaction starts, heat energy start to produce. During this period lots of radiation or rays are produced, these are very harmful; to avoid this shielding is provided in reactor.

6. Reactor vessel:

After shielding the next layer is a reactor vessel. This vessel encloses reactor core, reflector, shielding. It is used to protect complete nuclear reactor. Few holes are provided in the top portion of reactor vessel to insert control rods & at lower side of this vessel fuel & moderator assembly are placed.

7. Heat Exchanger:

The main function of heat exchanger in nuclear power plant is the boiled the cold water and produces steam at high temperature & pressure.
Heat exchanger is used in nuclear power plant, to exchange the heat i.e. it consists of one input to feed the cold water & output to flow of hot steam. The heat exchanger receives the heat from reactor, this heat is continuously circulated through pipe, before it is re-entered to the reactor it is filter. By using this heat a heat exchanger boils the cold water produces steam at high temperature & Pressure. Further this steam passes to the steam turbine for generation of electrical power.

8. Coolant:

Q.1) Write the function of coolant in nuclear power plant?

The coolant becomes a cold metal. In coolant the gases are used like carbon dioxide, air, hydrogen etc. the heats from the heat exchanger are re-circulated to the reactor through pump after filtration. During filtrations the unwanted impurities in the coolant are removed.

9. Turbine:

We know that, the turbine is a mechanical device and it is mechanically coupled with alternator. In case of nuclear power plant turbine receives steam from heat exchange at high pressure, and it rotates at high speed then alternator also rotates, this way electrical power produced. The exhaust steam from turbine passes to condenser for further use.

10. Condenser:

The condenser receives an exhaust hot steam from turbine; with the help of water it is cooled. Water taken from available water sources e.g. river and is filtered in water treatment plant. This water is re-circulated to heat exchanger through feed water heater & Pump.

11. Cooling Tower:

The cooling towers are used to convert the hot water or steam exhausted from turbine into normal water. That is, its temperature decreases at normal temperature.

12. Water treatment chamber:

The water treatment chamber provides filter water to the cooling tower, condenser through available water source. It also reduces unwanted impurities in the stored water.

Types of Nuclear Reactor:

The nuclear reactors are classified into four types. These are mentioned below:

1. Pressurised Water Reactor (PWR).
2. Boiling Water Reactor (BWR).
3. Advanced Gas Cooled Reactor (AGCR).
4. Fast Breeder Reactor (FBR).

1. Pressurised Water Reactor (PWR).

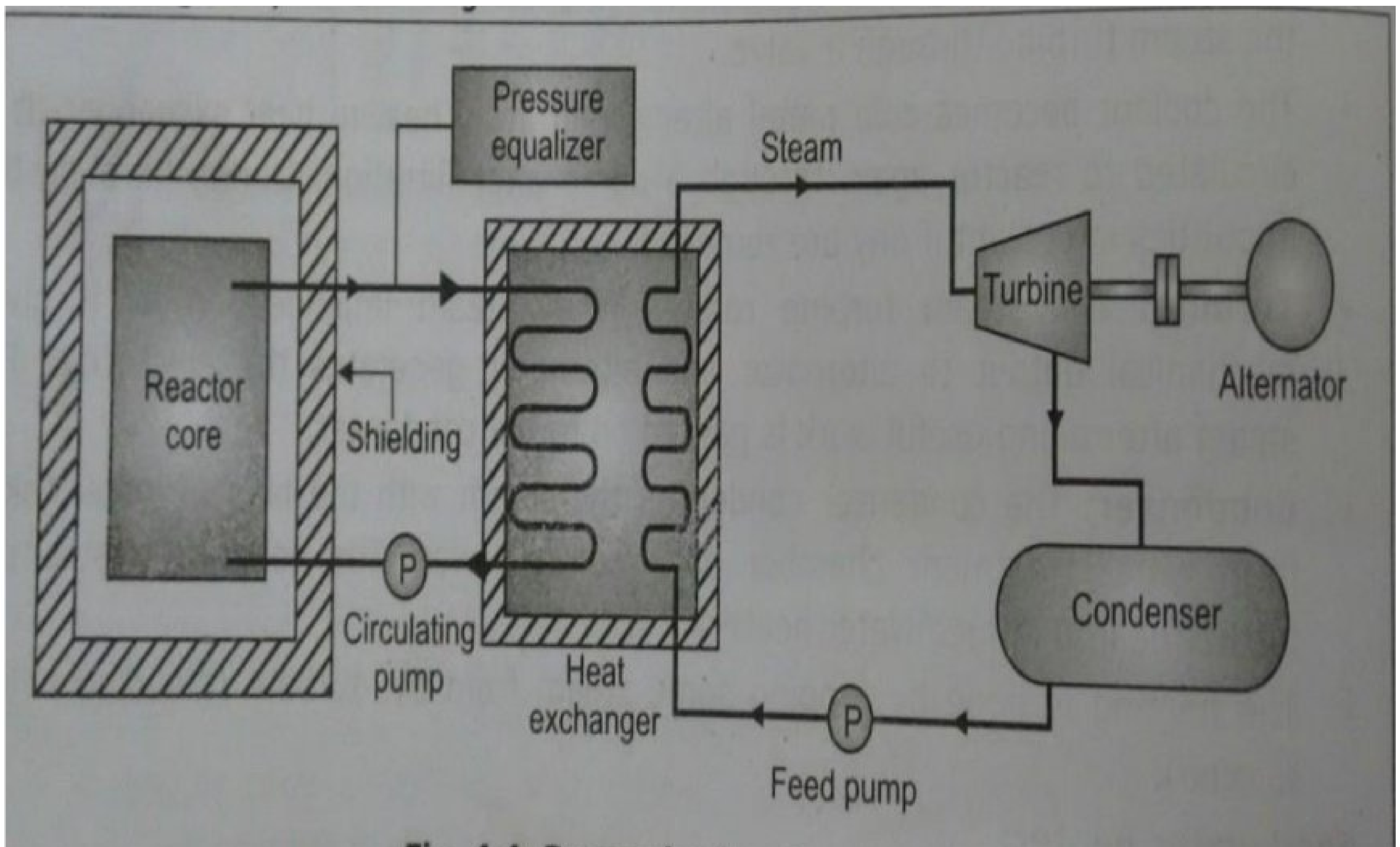
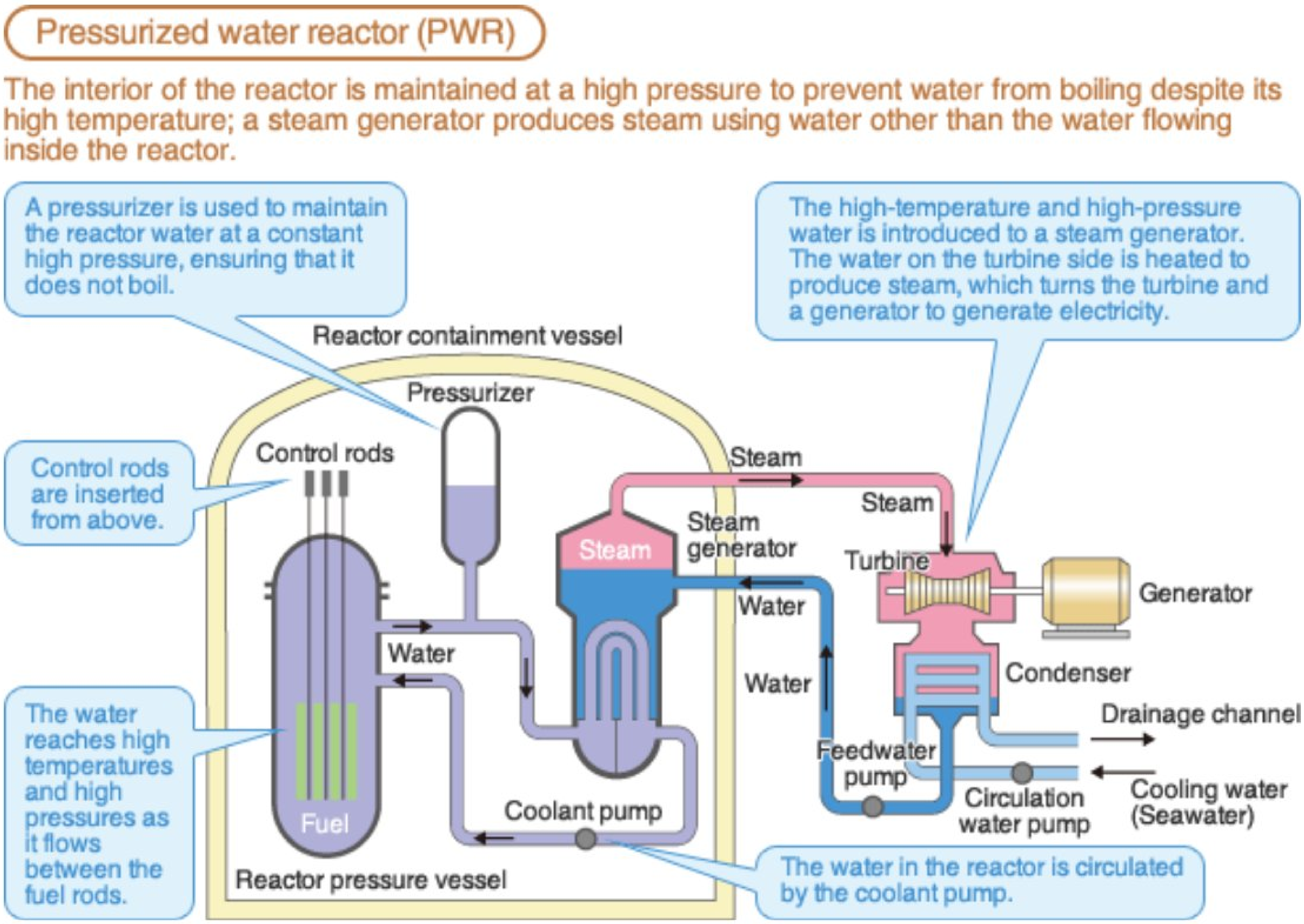


Fig. 4.4: Pressurised water reactor



Q.1) Explain working of pressurised water nuclear reactor?

Ans-In PWR the enriched uranium fuel is used. When the chain reaction starts the reactor core produces heat energy at high temperature. This produced heat energy passes to the heat exchanger. We have passed the hot metal to the heat exchanger, this metal is also radioactive, and that's why heat exchanger also requires shielding. The pressure equalizer uses to maintain the pressure of hot metal. In heat exchanger, other side tubes of water are inserted; this will help us to boil the water & Produces steam at high pressure. This steam passes to the steam turbine for the generation of electrical energy with the help of alternator. After that the exhausted steam passes to the condenser this process is continued.

2. **Boiling Water Reactor (BWR)**

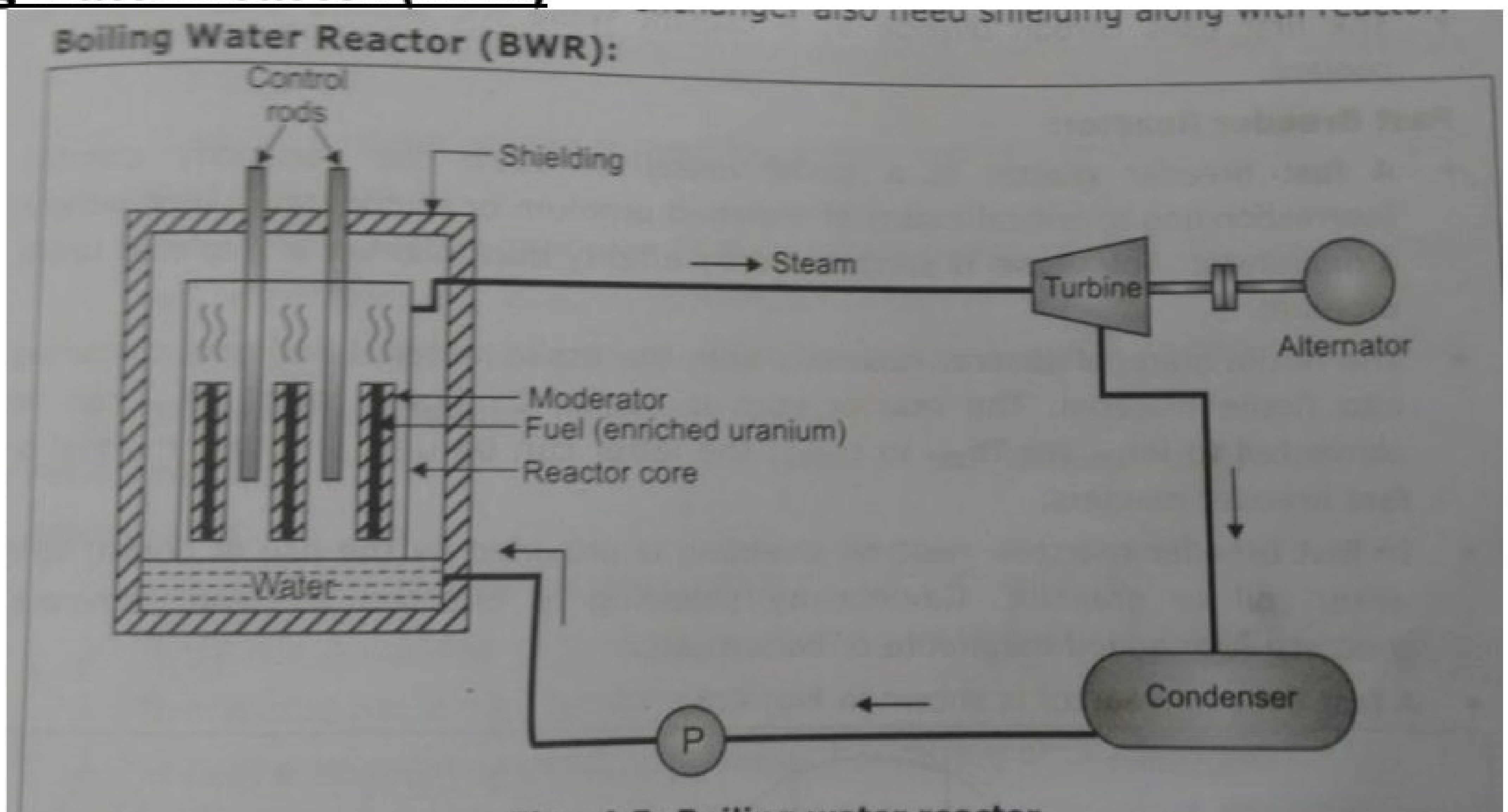
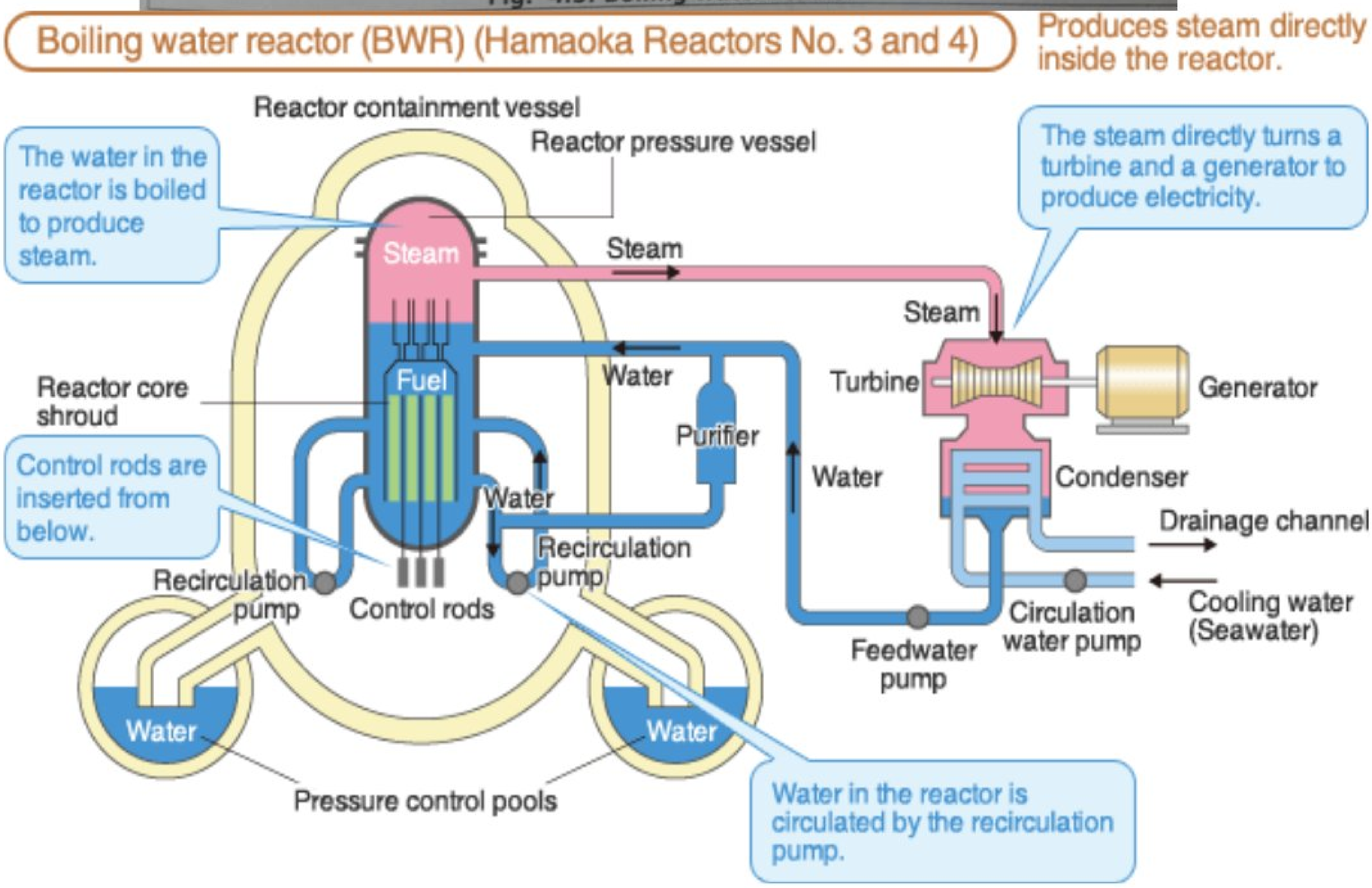


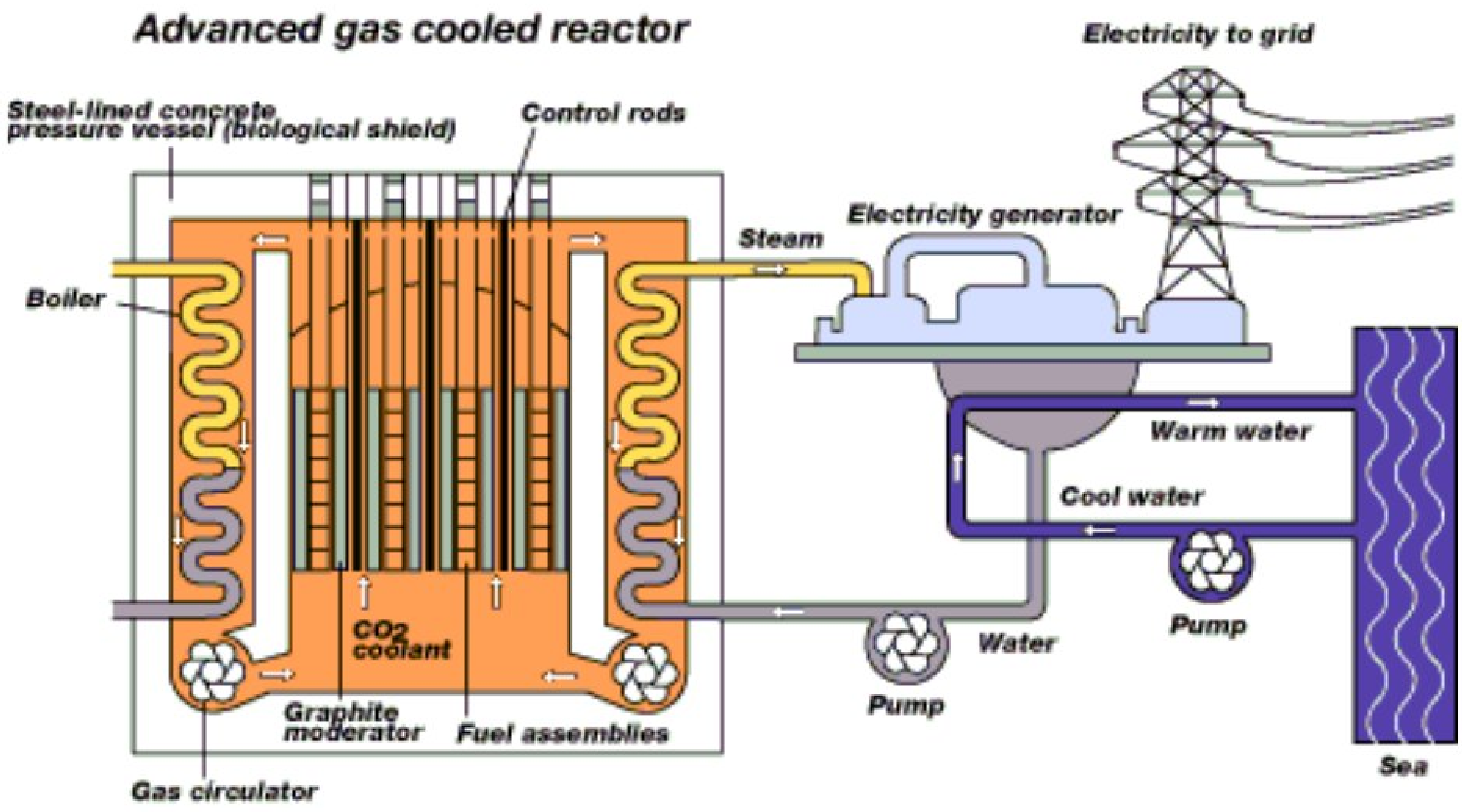
Fig. 4.5: Boiling water reactor



Q.1) Explain working of boiler water nuclear reactor?

Ans-In BWR, the enriched uranium fuel is used in reactor. In this type of reactor water is directly passes to the bottom of reactor core. When the chain reaction starts, the reactor core produces a heat energy, which is help full to boiled the water & produced steam at high temperature & Pressure. This steam passes to the turbine, through turbine-alternator combination electrical power produced. The exhausted steam from the steam turbine passes to the condenser. Where it is condensed, and again passes to the reactor core through pump.

3. Advanced Gas Cooled Reactor



Q.1) Witha neat diagram, explain the main features of advanced gas cooled reactor?

Ans- As its name indicates, it is advanced for the PWR & BWR. For the above mentioned two reactors, we used water for the production of steam. But in case of advanced gas cooled reactor gas is used. This gas is passes to the heat exchanger, the heat exchanger receives heat from reactor core, where its temperature increases, and then it runs the turbine in this way electrical power is produced.

A gas is of inferior quality to water so far as heat transfer properties are concerned, because of its poor heat transfer qualities; it required large quantity of gas for circulation. In advanced gas cooled reactor either carbon dioxide or helium is used as a coolant.

4. Fast Breeder Reactor:

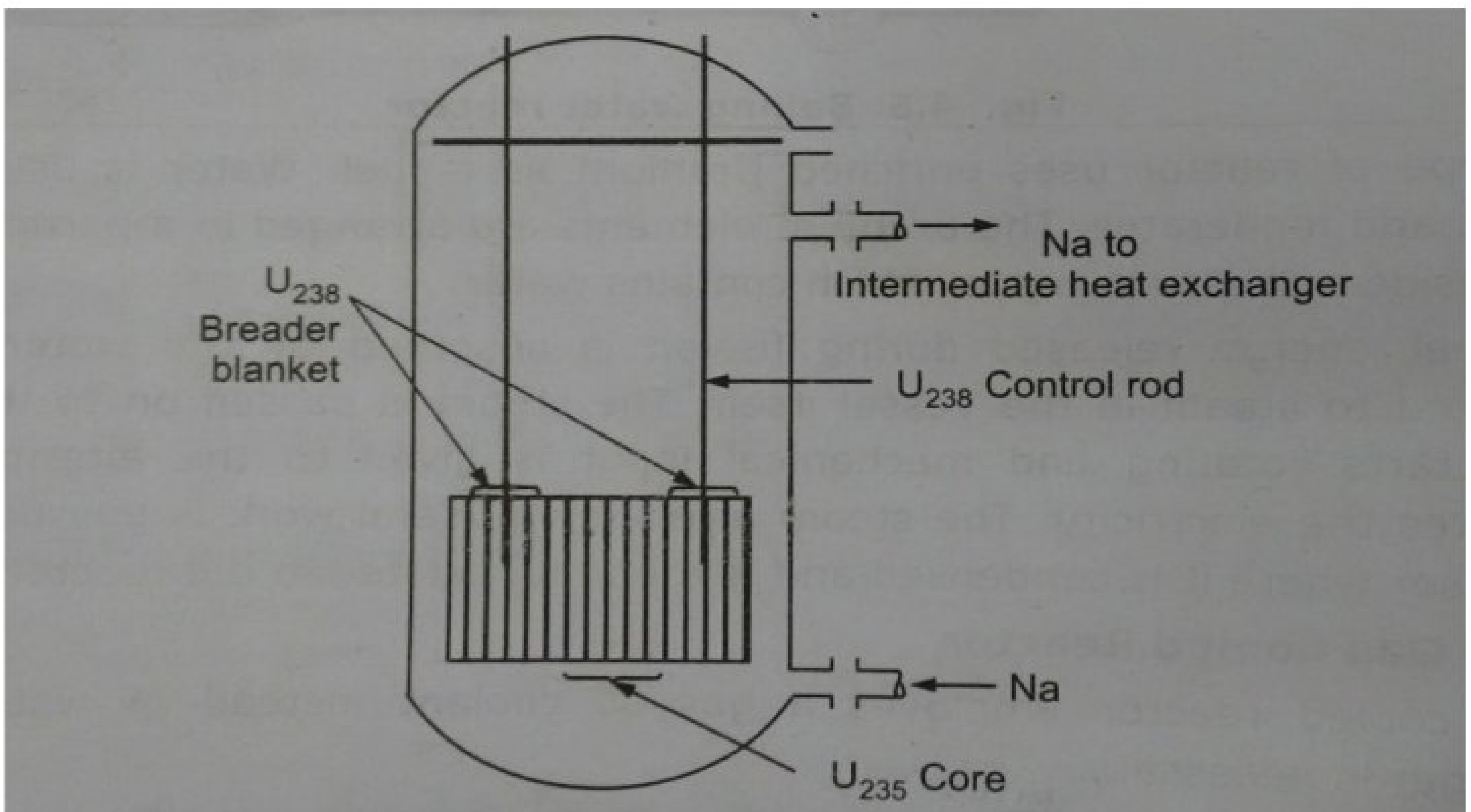


Fig. 4.6: Fast breeder reactor

In fast breeder reactor the fuel used are either enriched uranium or plutonium. Without using moderator the fuels are kept in fuel blanket. The closed vessel is surrounded by a fairly thick blanket. The shielding is also provided with boron material. The core of reactor is cooled by liquid metal.

CONTROL OF NUCLEAR REACTOR:

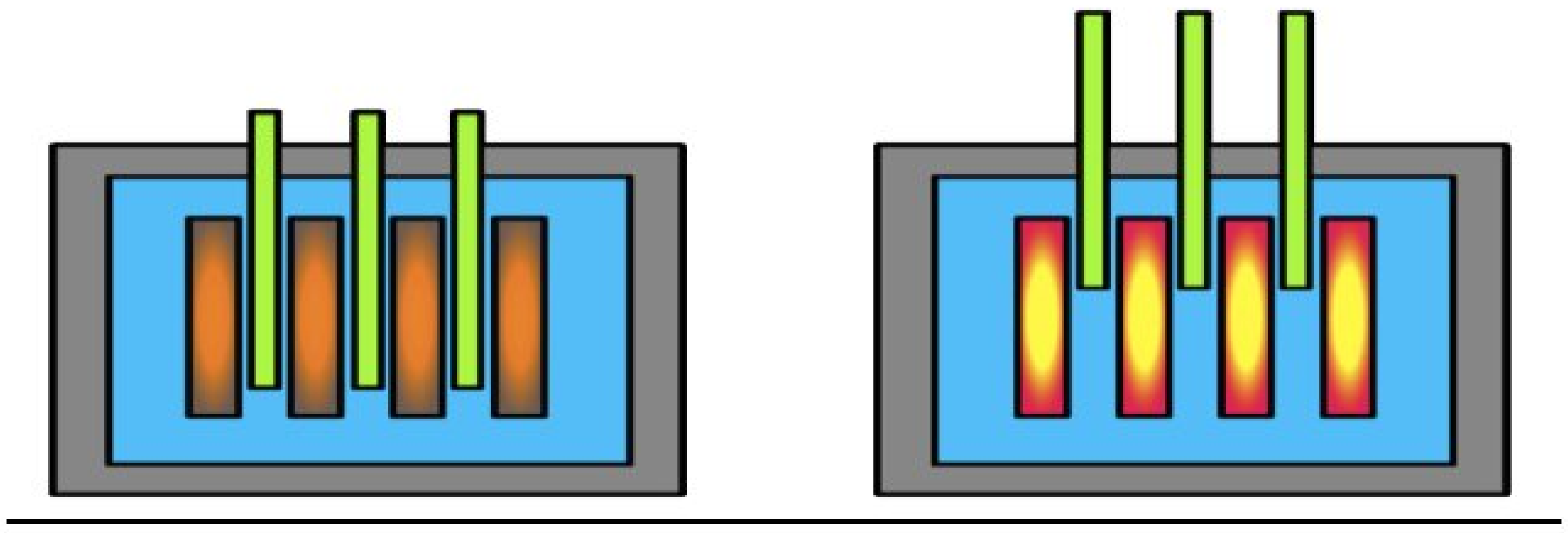
Q.1) How are nuclear reactor controlled? Explain two different methods in brief?

As we already studied that, why the control rods are used in the nuclear reactor? In this point we have to study how the nuclear reactors are controlled.

The nuclear reactors are controlled in two ways:

1. By using control rods.
2. Control through flow of coolant.

1. By using control rods:



Q.1) Explain how nuclear reactor is controller using control rods?

Q.2) Explain the role of control rod in nuclear reactor. State any two materials for control rod.

We know that, in nuclear reactor uranium or thorium or plutonium materials are used for generation of heat energy. If a slowly moving neutron hits or bombarded with this heavy nucleus of nuclear fuel then the chain reaction starts. Once the chain reaction starts then it is continued. By using control rods, we have to maintain its rate of flow of neutron or its speed, if the control rod is not used in the nuclear reactor this process is very dangerous to control. In other words this process is works like atomic bomb. To avoid this control rods are used in nuclear reactor. The main function of control rod in nuclear reactor is to absorb the freely moving neutrons. To absorb these freely moving neutrons from nuclear reactor the control rods are made up of either boron or cadmium. The diameter of control rod is 8cm. its height is just more than nuclear reactor. The control rods operated either automatically or manually. If it is operated automatically then sensors are used, these sensors give signals to the control rods. The rods are operated in up & down direction, if it in up then more heat generated & if it is down then it control the reaction i.e. rate of heat generated is minimum.

2. Control through flow of coolant:

We know that, the heat is generated in nuclear reactor. This heat is passes to the heat exchanger for the conversion of boiled water into steam. So the coolant is used in the nuclear reactor to remove the heat generated. As the operating temperature of nuclear reactor fluid coolant is used of higher thermal conductivity. There are different methods of nuclear reactor cooling:

1. Annular ducts surrounding and coolant is passed is passed through them.
2. Completely immerse the reactor fuel element in coolant bath.
3. A fluid mixture of fuel & moderator is circulated through the reactor.

Nuclear Waste Management:

Q.1) Explain how nuclear waste is disposed?
Q.2) State the types of radioactive waste generated in a nuclear power station. Explain the method employed for their disposal?
Q.3) how will you dispose nuclear waste? Explain the method for solid, liquid & gaseous waste?

In Second World War, we know that the real condition of Japanese city like Hiroshima & Nagasaki. For consider this example, you know the idea of the: radioactivity material or how it is dangerous. The same material we have to use in nuclear reactor, every part of nuclear fuel cycle produces radioactive waste. These wastes are very dangerous to human health & it handling very carefully. For e.g. how much electricity generated through nuclear power plant out of that 5% is cost of wastage. Based on this means the level of radioactivity material or radiations, nuclear waste management is classified into three types:
Classification of nuclear (Radioactive) Wastage:

1. Low Level Waste (LLW)
2. Intermediate Level Waste (ILW)
3. High Level Wastage (HLW)

1. LLW (Low Level Waste):

In case of low level waste, the (% Content of Radioactivity) radioactive level is very less. Normally, this type of waste comes from industries, hospitals, small nuclear plant. At the time of handling & transport the low level waste, it does not require shielding. The low level waste buried in land with suitable depth at the time of disposal.

2. ILW (Intermediate Level Waste):

The percentage of radioactivity is higher as compared with low level waste. At the time of handling & transportation shielding is required because, the produce radioactive are very difficult. It means that it's affected to human health. At the time of ILW disposal first up all it is placed in concrete container, after that it is well sealed. Finally the ILW is buried in underground facility.

3. HLW (High Level Waste):

As compared with LLW & ILW, the HLW is very dangerous to handling as well as it is directly affected to human health. Most of accidents in nuclear power plants are occurred due to this HLW. At the time of handling it requires shielding as well as cooling. The HLW mainly comes from reprocessing of nuclear fuel in the reactor. The HLW is obtained in liquid form & the heat % is very high. There are three ways to dispose the HLW.

i. **With the help of Storage Tank:**

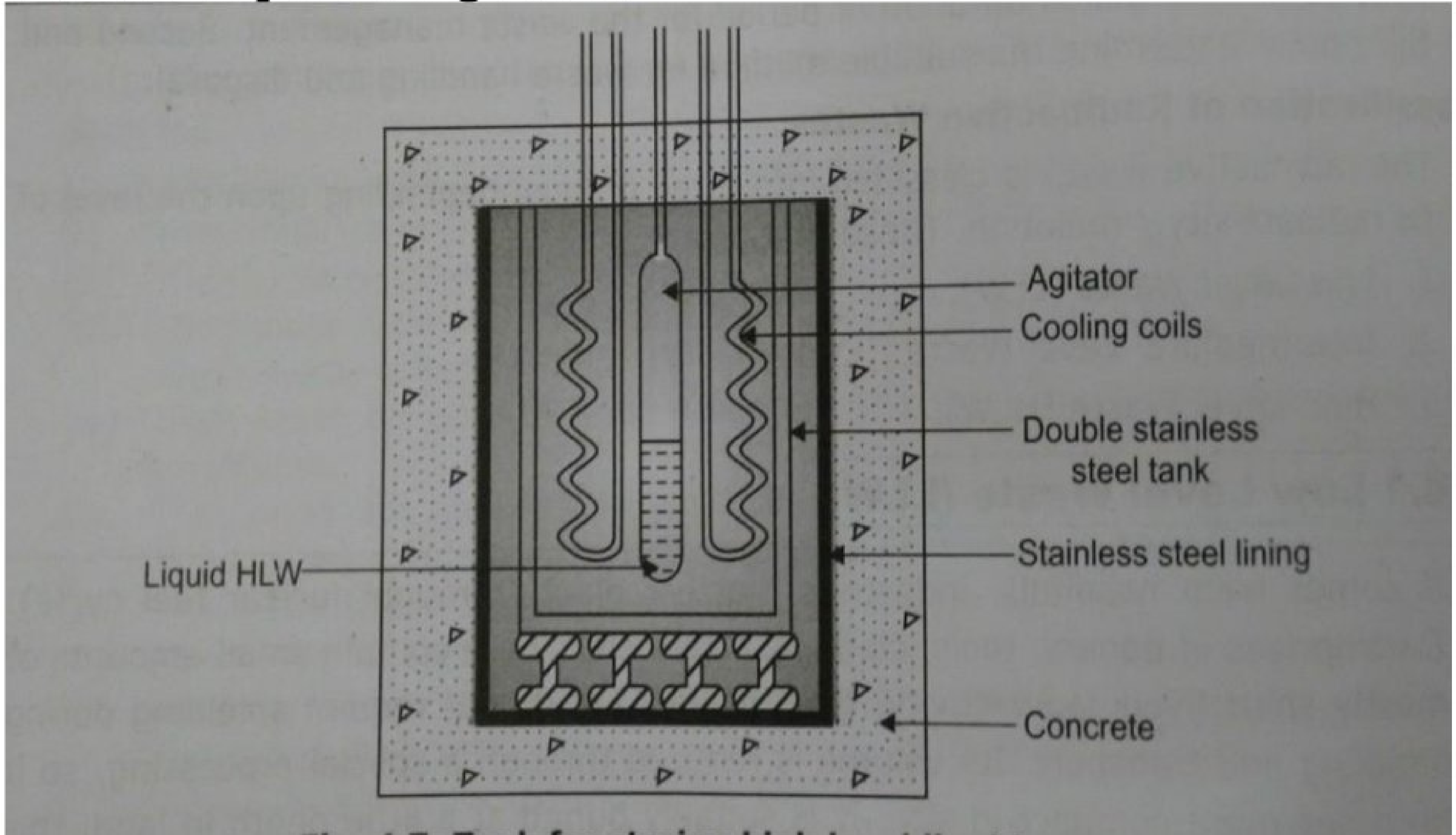


Fig. 4.7: Tank for storing high level liquid waste

The agitator is placed, which is rotating type. In that agitator the high temperature liquid waste is kept. Due to its continuous rotation, & outer cooling, it will help to its high temperature is converter into its normal value. For the protection & leak proof purpose the closed vessel surrounded by stainless steel tank & concrete layer. Whenever the tank is full, it will be well sealed & buried underground.

ii. **Disposal through Deep Well Injection:**

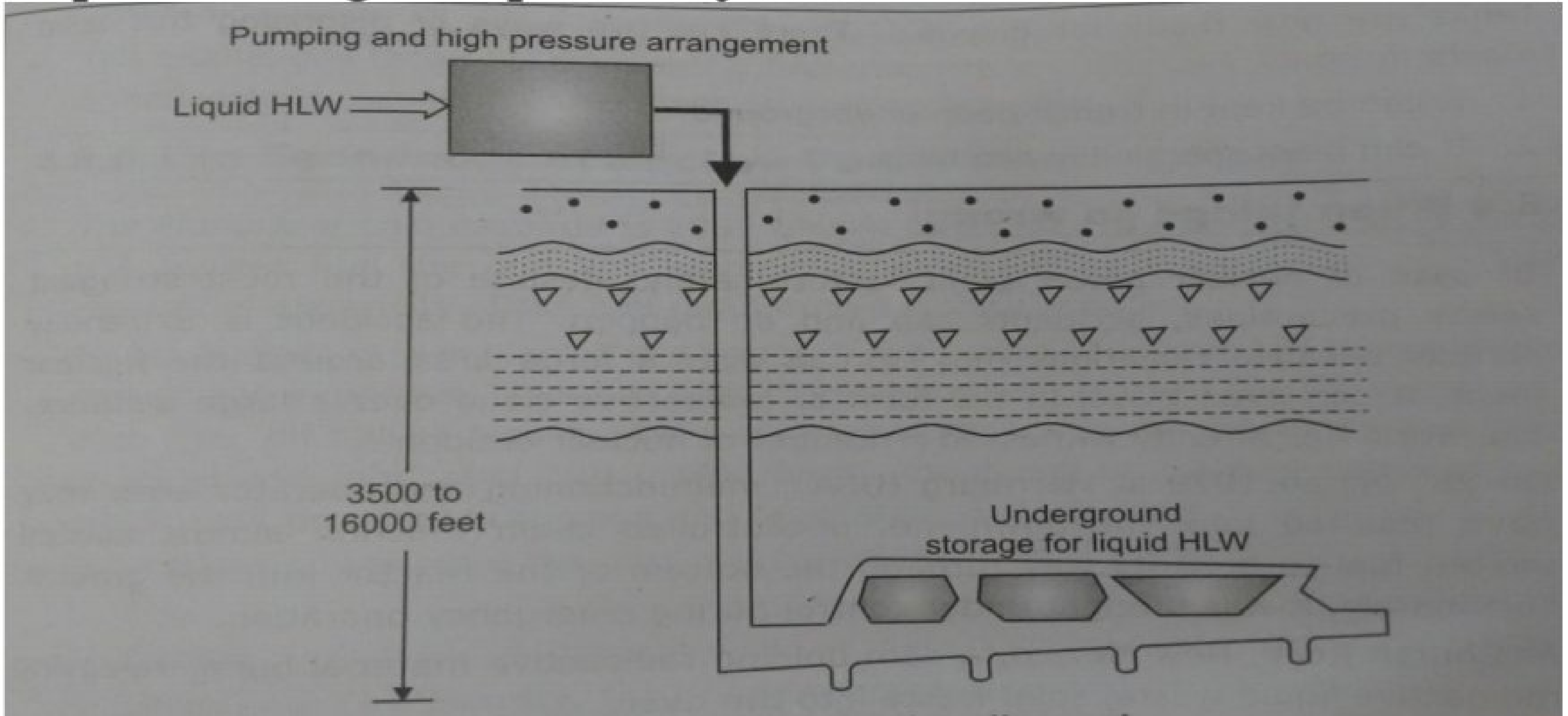


Fig. 4.8: Deep well injection disposal

In this method, first up all the high temperature liquid HLW is kept in storage tank. Then with the help of pumps these liquid HLW is sent to ground at high pressure. Its depth is normally 3500 to 16000 feet.

iii. Vitrification Process:

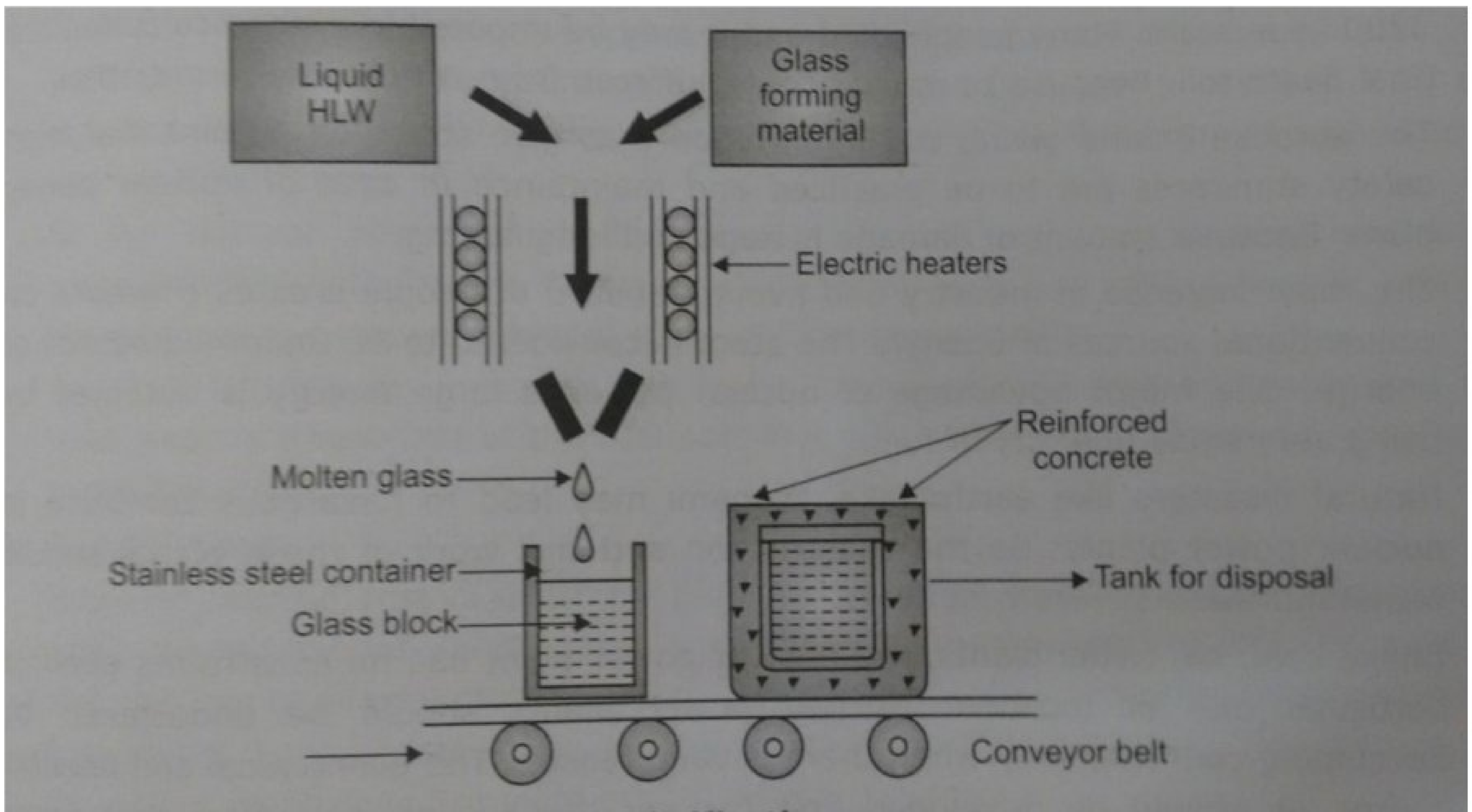


Fig. 4.9: Vitrification process

We know that, the HLW is liquid form & it is difficult to handling and disposal. To overcome this drawback in vitrification process first up all it is converted into solid form (the liquid form of HLW is converted into solid form is known as vitrification). Whenever the liquid HLW is kept with steel container, it is mixed with glass forming material through heating process. Due to this a solid glass is formed which is put in steel container, after that it is surrounded by reinforced concrete. These tanks are now ready for disposal.

There are two ways of disposing these solid waste tanks:

1. It can be kept in trench deep underground.
2. It can be suspended in sea beads.

Advantages of Nuclear Power Station:

1. A nuclear power station occupies much smaller space compared to other conventional power station of same capacity.
2. This station does not require plenty of water; hence it is not essential to construct plant near natural source of water.
3. This also does not required huge quantity of fuel; for e.g. 1 kg of uranium produces a heat which is equivalent to 4300 tonnes of coal.
4. It is possible to locate the plant near to load center
5. If bulk power is produced it is economical.
6. Clean operation, no ash is produced.
7. Area required is very less.
8. Independent of geographical conditions.
9. Saving of natural resources such as coal, oil, gas etc.

Disadvantages of Nuclear Power Plant

1. The fuel is not easily available and it is very costly.
2. Initial cost for constructing nuclear power station is quite high.
3. Erection and commissioning of this plant is much complicated.
4. The fission by products is radioactive in nature, and it may cause high radioactive pollution.
5. The maintenance cost is higher and the man power required to run a nuclear power plant is quite higher since specialty trained people are required.
6. Sudden fluctuation of load cannot be met up efficiently by nuclear plant.
7. It is very big problem for disposal of this by products. It can only be disposed deep inside ground or in a sea away from sea share.
8. Enrichment technology is essential for fuel processing & fabrication.
9. Maintenance cost is very high.
10. Waste disposal is problematic.
11. For variable load it is not suitable.
12. Construction is complicated.

QUESTION FOR PRACTICE

1. Write down the advantages and disadvantages of Nuclear Power Plant.
2. Discuss about the type of Nuclear Wastes &What are the processes for the disposal of such Wastes? Explain.
3. With a neat sketches Describe the working procedure of PWR & BWR?
4. What are the components of a Nuclear Power Plant? Explain each one of them.
5. What do you mean by Nuclear Fission & Nuclear Fusion reactions?
6. Explain the working of a Nuclear Power Plant with Block diagram?
7. What are the governing conditions for setting up of a Nuclear Power Plant?

DIESEL ENGINE POWER PLANT

INTRODUCTION

A generating station in which diesel engine is used as the prime mover for the generation of electrical energy is known as **diesel power station**.

In a diesel power station, diesel engine is used as the prime mover. The diesel burns inside the engine and the products of this combustion act as the working fluid to produce mechanical energy. The diesel engine drives alternator which converts mechanical energy into electrical energy. As the generation cost is considerable due to high price of diesel, therefore, such power stations are only used to produce small power. Although steam power stations and hydro-electric plants are invariably used to generatebulk power at cheaper costs, yet diesel power stations are finding favour at places where demand of power is less, sufficient quantity of coal and water is not available and the transportation facilities are inadequate. This plants are also standby sets for continuity of supply to important points such as hospitals, radio stations, cinema houses and telephone exchanges.

ADVANTAGES

(a) The design and layout of the plant are quite simple.
(b) It occupies less space as the number and size of the auxiliaries is small.
(c) It can be located at any place.
(d) It can be started quickly and it can pickup load in a short time.
(e) There are no standby losses.
(f) It requires less quantity of water for cooling.
(g) The overall cost is much less than that of steam power station of same capacity.
(h) The thermal efficiency of the plant is higher than that of a steam power station.
(i) It requires less operating staff.

DISADVANTAGES

(a) The plant has high running charges as the fuel (diesel) used is costly.
(b) The plant doesn't work satisfactorily under overload conditions for a longer period.
(c) The plant can only generate small power.
(d) The cost of lubrication is generally high.
(e) The maintenances charges are generally high.

OBJECTIVES

After studying this unit, you should be able to

a. Understand about diesel engine power plant,
b. Explain fuel injection system and its functions, and
c. Describe various injection schemes.

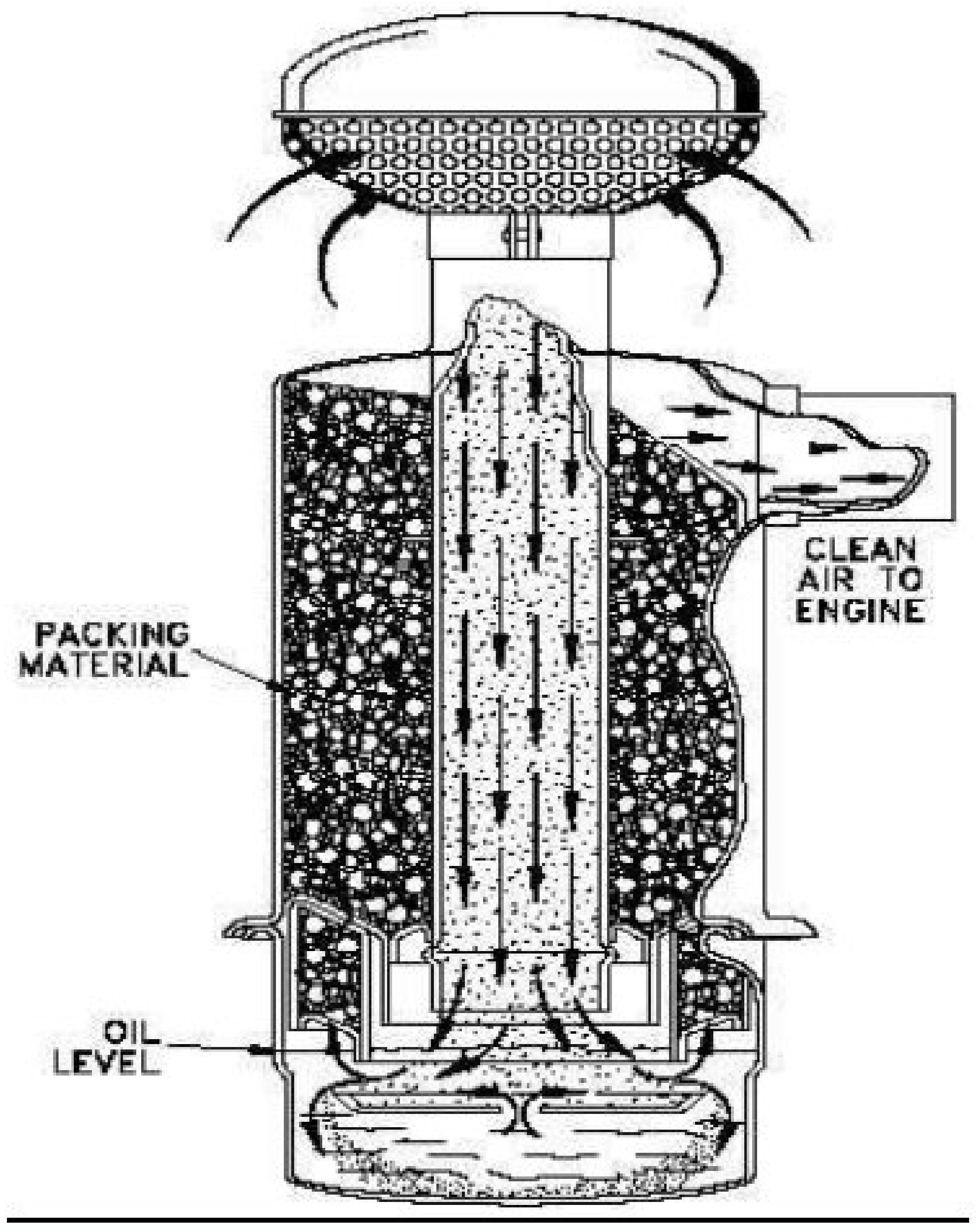
ESSENTIAL ELEMENTS OF DIESEL POWER PLANT

Fuel Supply System

It consists of storage tank, strainers, fuel transfer pump and all day fuel tank. The fuel oil is supplied at the plant site by rail or road. The oil is stored in the storage tank. From the storage tank, oil is pumped to smaller all day tank at daily or short intervals. From this tank, fuel oil is passed through strainers to remove suspended impurities. The clean oil is injected into the engine by fuel injection pump.

Air Intake System

This system supplies necessary air to the engine for fuel combustion. It consists of pipes for the supply of fresh air to the engine manifold. Filters are provided to remove dust particles from air which may act as abrasive in the engine cylinder.
Because a diesel engine requires close tolerances to achieve its compression ratio, and because most diesel engines are either turbocharged or supercharged, the air entering the engine must be clean, free of debris, and as cool as possible. Also, to improve a turbocharged or supercharged engine's efficiency, the compressed air must be cooled after being compressed. The air intake system is designed to perform these tasks. Air intake systems are usually one of two types, wet or dry. In a wet filter intake system, as shown in the Figure 4.1, the air is sucked or bubbled through a housing that holds a bath of oil such that the dirt in the air is removed by the oil in the filter. The air then flows through a screen-type material to ensure any entrained oil is removed from the air. In a dry filter system, paper, cloth, or a metal screen material is used to catch and trap dirt before it enters the engine. In addition to cleaning the air, the intake system is usually designed to intake fresh air from as far away from the engine as practicable, usually just outside of the engine's building or enclosure. This provides the engine with a supply of air that has not been heated by the engine's own waste heat. The reason for ensuring that an engine's air supply is as cool as possible is that cool air is denser than hot air. This means that, per unit volume, cool air has more oxygen than hot air.
Thus, cool air provides more oxygen per cylinder charge than less dense, hot air.
More oxygen means a more efficient fuel burn and more power.



After being filtered, the air is routed by the intake system into the engine's intake manifold or air box. The manifold or air box is the component that directs the fresh air to each of the engine's intake valves or ports. If the engine is turbocharged or supercharged, the fresh air will be compressed with a blower and possibly cooled before entering the intake manifold or air box. The intake system also serves to reduce the air flow noise.

Exhaust System

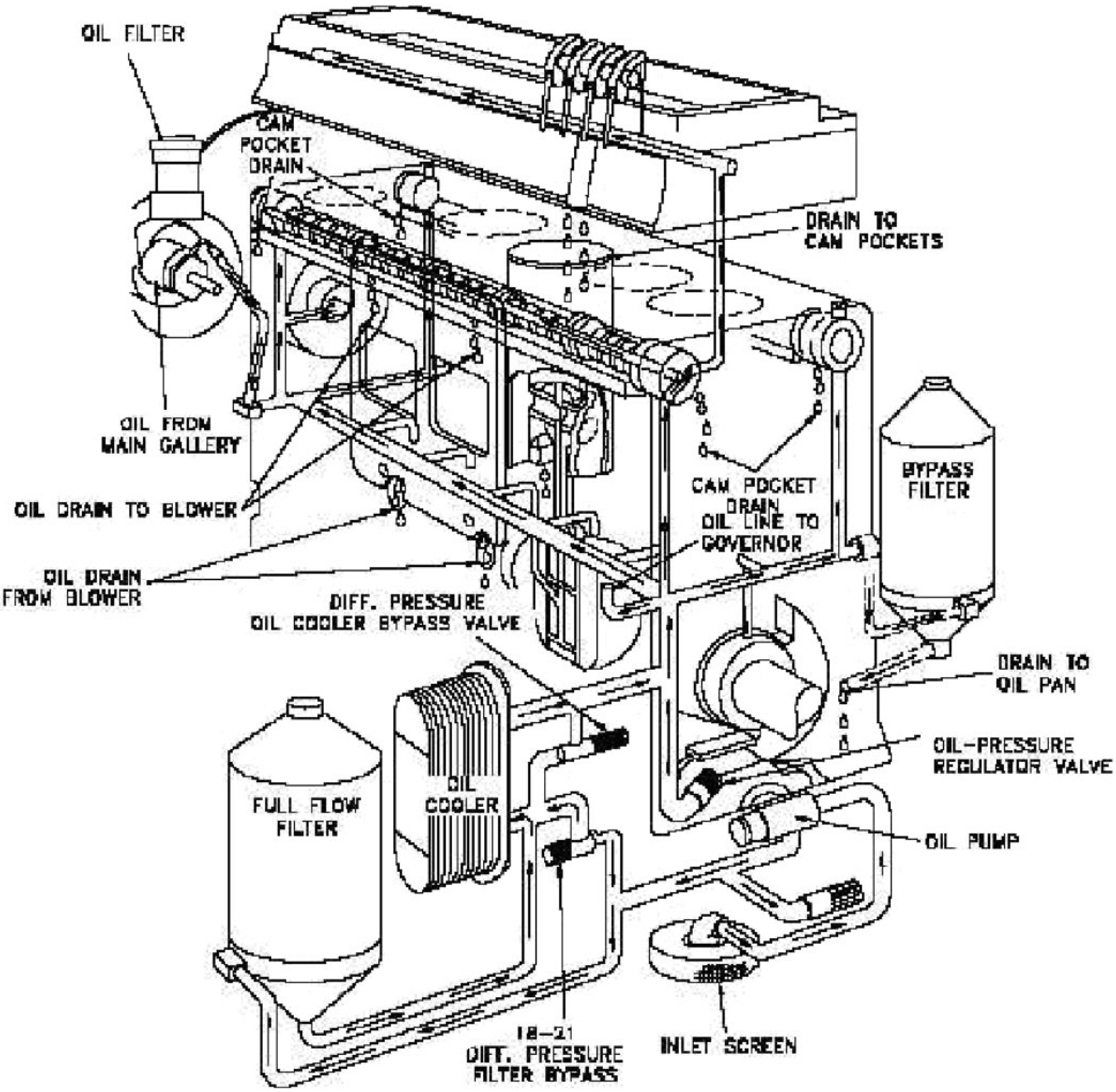
This system leads the engine exhaust gas outside the building and discharges it into atmosphere. A silencer is usually incorporated in the system to reduce the noise level. The exhaust system of a diesel engine performs three functions. First, the exhaust system routes the spent combustion gasses away from the engine, where they are diluted by the atmosphere. This keeps the area around the engine habitable. Second, the exhaust system confines and routes the gases to the turbocharger, if used. Third, the exhaust system allows mufflers to be used to reduce the engine noise.

Cooling System

The heat released by the burning of fuel in the engine cylinder is partially converted into work. The remainder part of the heat passes through the cylinder wall, piston, rings etc. and may cause damage to system. In order to keep the temperature of the engine parts within the safe operating limits, cooling is provided. The cooling system consists of a water source, pump and cooling towers. The pump circulates water through cylinder and head jacket. The water takes away heat form the engine and it becomes hot. The hot water is cooled by cooling towers and re circulated for cooling.

Lubricating System

The system minimises the wear of rubbing surfaces of the engine. It comprises of lubricating oil tank, pump, filter and oil cooler. The lubrication oil is drawn from the lubricating oil tank by the pump and is passed through filter to remove impurities .The clean lubrication oil is delivered to the points which require lubrication. The oil coolers incorporated in the system keep the temperature of the oil low.An internal combustion engine would not run for even a few minutes if themoving parts were allowed to make metal-to-metal contact. The heat generated due to the tremendous amounts of friction would melt the metals, leading to the destruction of the engine. To prevent this, all moving parts ride on a thin film of oil that is pumped between all the moving parts of the engine. The oil serves two purposes. One purpose is to lubricate the bearing surfaces. The other purpose is to cool the bearings by absorbing the friction- generated heat. The flow of oil to the moving parts is accomplished by the engine's internal lubricating system.Oil is accumulated and stored in the engine's oil pan where one or more oil pumpstake suction and pump the oil through one or more oil filters as shown in the figure. The filters clean the oil and remove any metal that the oil has picked up due to wear. The cleaned oil then flows up into the engine's oil galleries. A pressure relief valve(s) maintains oil pressure in the galleries and returns oil to the oil pan upon high pressure. The oil galleries distribute the oil to all the bearingsurfaces in the engine. Once the oil has cooled and lubricated the bearing surfaces, it flows out of the bearing and gravity-flows back into the oil pan. In medium to large diesel engines, the oil is also cooled before being distributed into the block. This is accomplished by either internal or external oil cooler. The lubrication system also supplies oil to the engine's governor.



Engine Starting System

This is an arrangement to rotate the engine initially, while starting, until firing starts and the unit runs with its own power. Small sets are started manually by handles but for larger units, compressed air is used for starting. In the latter case, air at high pressure is admitted to a few of the cylinders, making them to act as reciprocating air motors to turn over the engine shaft. The fuel is admitted to the remaining cylinders which makes the engine to start under its own power.

Starting Circuits

Diesel engines have as many different types of starting circuits as there are types, sizes, and manufacturers of diesel engines. Commonly, they can be started by air motors, electric motors, hydraulic motors, and manually. Thestart circuit can be a simple manual start pushbutton, or a complex auto-start circuit. But in almost all cases the following events must occur for the starting engine to start.

A) The start signal is sent to the starting motor. The air, electric, or hydraulic motor, will engage the engine's flywheel.

B) The starting motor will crank the engine. The starting motor will spin the engine at a high enough rpm to allow the engine's compression to ignite the fuel and start the engine running.

C) The engine will then accelerate to idle speed. When the starter motor is overdriven by the running motor it will disengage the flywheel.

Because a diesel engine relies on compression heat to ignite the fuel, a coldengine can rob enough heat from the gasses that the compressed air falls below the ignition temperature of the fuel. To help overcome this condition, some engines (usually small to medium sized engines) have glow plugs. Glow plugs are located in the cylinder head of the combustion chamber and use electricity to heat up the electrode at the top of the glow plug. The heat added by the glow plug is sufficient to help ignite the fuel in the cold engine. Once the engine is running, the glow plugs are turned off and the heat of combustion is sufficient to heat the block and keep the engine running. Larger engines usually heat the block and/or have powerful starting motors that are able to spin the engine long enough to allow the compression heat to fire the engine. Some large engines use air start manifolds that inject compressed air into the cylinders which rotates the engine during the start sequence.

FUEL INJECTION SYSTEM

Fuel injection is a system for mixing fuel with air in an internal combustion engine. Afuel injection system is designed and calibrated specifically for the type of fuel it will handle. Most fuel injection systems are for diesel applications. With the advent of electronic fuel injection (EFI), the diesel gasoline hardware has become similar. EFI's programmable firmware has permitted common hardware to be used with different fuels. Carburettors were the predominant method used to meter fuel before the widespread use of fuel injection. A variety of injection systems have existed since the earliest usage of the internal combustion engine. The primary difference between carburetors and fuel injection is that fuel injection atomizes the fuel by forcibly pumping it through a small nozzle under high pressure, while a carburettor relies on low pressure created by intake air rushing through it to add the fuel to the air stream. The fuel injector is only a nozzle and a valve: the power to inject the fuel comes from a pump or a pressure container farther back in the fuel supply.

Objectives

The functional objectives for fuel injection systems can vary. All share the central task of supplying fuel to the combustion process, but it is a design decision how a particular system will be optimized. There are several competing objectives such as :

a. power output,
b. fuel efficiency,
c. emissions performance,
d. reliability,
e. smooth operation,
f. initial cost,
g. maintenance cost,
h. diagnostic capability, and
i. Range of environmental operation.

Certain combinations of these goals are conflicting, and it is impractical for a single engine control system to fully optimize all criteria simultaneously. In practice, automotive engineers strive to best satisfy a customer's needs competitively. The modern digital electronic fuel injection system is far more capable at optimizing these competing objectives consistently than a carburettor.
Carburettors have the potential to atomize fuel better.

Benefits

Operational benefits include smoother and more dependable engine response during quick throttle transitions, easier and more dependable engine starting, better operation at extremely high or low ambient temperatures, increased maintenance intervals, and increased fuel efficiency. On a more basic level, fuel injection does away with the choke which on carburettor-equipped systems must be operated when starting the engine from cold and then adjusted as the engine warms up. An engine’s air/fuel ratio must be precisely controlled under all operating conditions to achieve the desired engine performance, emissions, and fuel economy. Modern electronic fuel-injection systems meter fuel very accurately, and use closed loop fuel-injection quantity-control based on a variety of feedback signals from an oxygen sensor, a mass airflow (MAF) or manifold absolute pressure (MAP) sensor, a throttle position (TPS), and at least one sensor on the crankshaft and camshaft to monitor the engine's rotational position. Fuel injection systems can react rapidly to changing inputs and control the amount of fuel injected to match the engine's dynamic needs across a wide range of operating conditions such as engine load, ambient air temperature, engine temperature, fuel octane level, and atmospheric pressure.

A multipoint fuel injection system generally delivers a more accurate and equal mass of fuel to each cylinder, thus improving the cylinder-to-cylinder distribution.

Exhaust emissions are cleaner because the more precise and accurate fuel metering reduces the concentration of toxic combustion by products leaving the engine, and because exhaust cleanup devices such as the catalytic converter can be optimized to operate more efficiently since the exhaust is of consistent and predictable composition.

Fuel injection generally increases engine fuel efficiency. With the improved cylinder-to-cylinder fuel distribution, less fuel is needed for the same power output. When cylinder-to-cylinder distribution is less than ideal, as is always the case to some degree with a carburettor or throttle body fuel injection, some cylinders receive excess fuel as a side effect of ensuring that all cylinders receive sufficient fuel. Power output is asymmetrical with respect to air/fuel ratio; burning extra fuel in the rich cylinders does not reduce power nearly as quickly as burning too little fuel in the lean cylinders. However, rich-running cylinders are undesirable from the standpoint of exhaust emissions, fuel efficiency, engine wear, and engine oil contamination. Deviations from perfect air/fuel distribution, however subtle, affect the emissions, by not letting the combustion events at the chemically ideal (stoichiometric) air/fuel ratio. Grosser distribution problems eventually begin to reduce efficiency, and the grossest distribution issues finally affect power. Increasingly poorer air/fuel distribution affects emissions, efficiency, and power, in that order. By optimizing the homogeneity of cylinder-to-cylinder mixture distribution, all the cylinders approach their maximum power potential and the engine's overall power output improves.

A fuel-injected engine often produces more power than an equivalent carburetted engine. Fuel injection alone does not necessarily increase an engine's maximumpotential output. Increased airflow is needed to burn more fuel, which in turnreleases more energy and produces more power. The combustion process convertsthe fuel's chemical energy into heat energy, whether the fuel is supplied by fuelinjectors or a carburettor. However, airflow is often improved with fuel injection,the components of which allow more design freedom to improve the air's path intothe engine. In contrast, a carburettor's mounting options are limited because it islarger, it must be carefully oriented with respect to gravity, and it must beequidistant from each of the engine's cylinders to the maximum practicable degree.

These design constraints generally compromise airflow into the engine. Furthermore, a carburettor relies on a restrictive venturi to create a local air pressure difference, which forces the fuel into the air stream. The flow loss caused by the venturi, however, is small compared to other flow losses in the induction system. In a well-designed carburettor induction system, the venturi is not a significant airflow restriction.

Basic Function

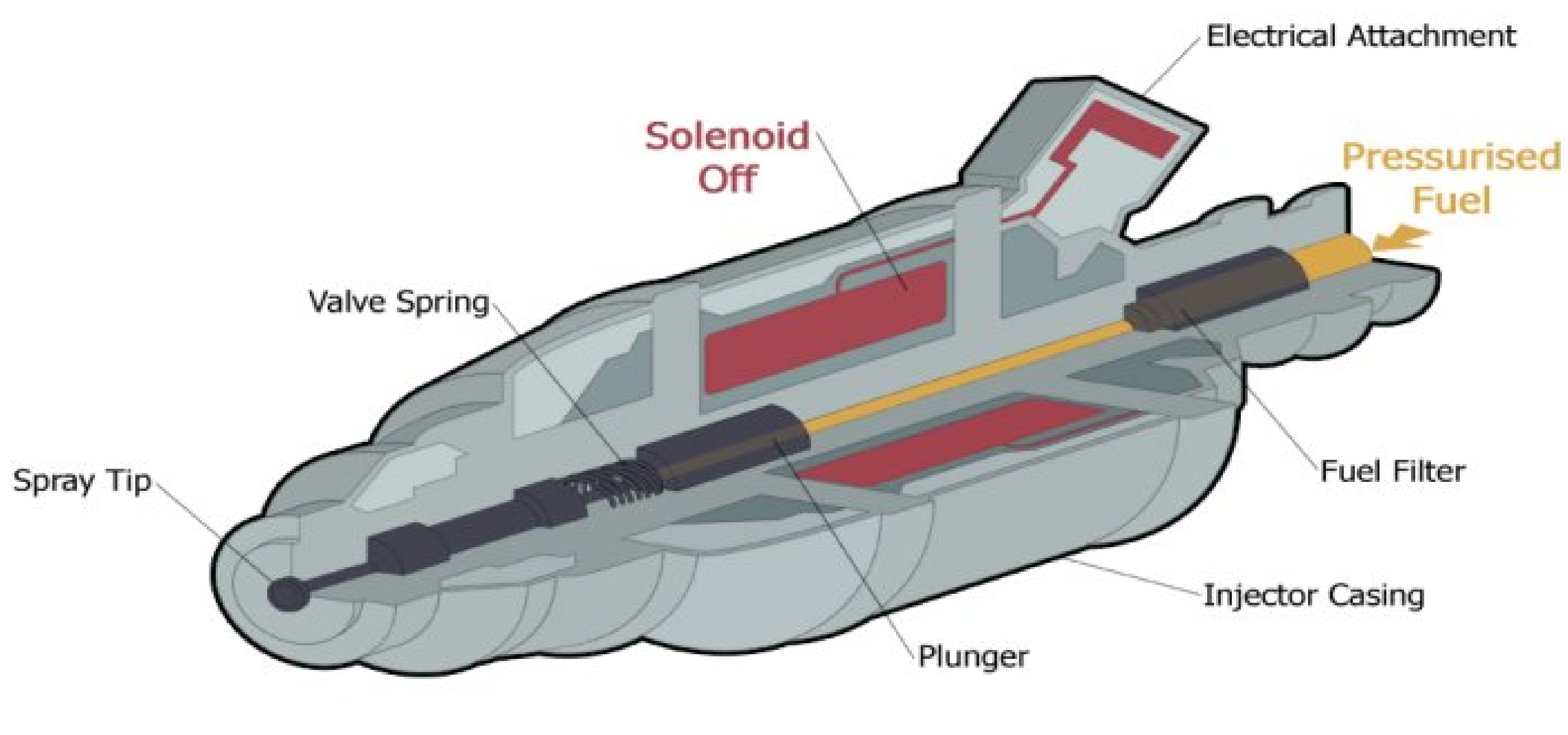
The process of determining the necessary amount of fuel, and its delivery into the engine, are known as fuel metering. Early injection systems used mechanical methods to meter fuel (non electronic or mechanical fuel injection). Modern systems are nearly all electronic, and use an electronic solenoid (the injector) to inject the fuel. An electronic engine control unit calculates the mass of fuel to inject. Modern fuel injection schemes follow much the same setup. There is a mass airflow sensor or manifold absolute pressure sensor at the intake, typically mounted either in the air tube feeding from the air filter box to the throttle body, or mounted directly to the throttle body itself. The mass airflow sensor does exactly what its name implies; it senses the mass of the air that flows past it, giving the computer an accurate idea of how much air is entering the engine. The next component in line is the Throttle Body. The throttle body has a throttle position sensor mounted onto it, typically on the butterfly valve of the throttle body. The throttle position sensor (TPS) reports to the computer the position of the throttle butterfly valve, which is used to calculate the load upon the engine. The fuel system consists of a fuel pump (typically mounted in-tank), a fuel pressure regulator, fuel lines (composed of either high strength plastic, metal, or reinforced rubber), a fuel rail that the injectors connect to, and the fuel injector(s). There a coolant temperature sensor that reports the engine temperature, which the engine uses to calculate the proper fuel ratio required. In sequential fuel injection systems there is a camshaft position sensor to determine which fuel injector to fire. The fuel injector acts as the fuel-dispensing nozzle. It injects liquid fuel directly into the engine's air stream. In almost all cases this requires an external pump. The pump and injector are only two of several components in a complete fuel injection system. An EFI system requires several peripheral components in addition to the injector(s), in order to duplicate all the functions of a carburettor. A point worth noting during times of fuel metering repair is that early EFI systems are prone to diagnostic ambiguity. A single carburettor replacement can accomplish what might require numerous repair attempts to identify which one of the several EFI system components is malfunctioning. Newer EFI systems can be very easy to diagnose due to the increased ability to monitor the realtimedata streams from the individual sensors.

Typical EFI Components

a. Animated cut through diagram of a typical fuel injector
b. Injectors
c. Fuel Pump
d. Fuel Pressure Regulator
e. ECM – Engine Control Module; includes a digital computer and circuitry to communicate with sensors and control outputs
f. Wiring Harness
g. Various Sensors (Some of the sensors required are listed here)
h. Crank/Cam Position (Hall effect sensor)
i. Airflow (MAF sensor)
j. Exhaust Gas Oxygen (Oxygen sensor, EGO sensor, UEGO sensor).

Functional Description

Central to an EFI system is a computer called the Engine Control Unit (ECU), which monitors engine operating parameters via various sensors. The ECU interprets these parameters in order to calculate the appropriate amount of fuel to be injected, among other tasks, and controls engine operation by manipulating fuel and/or air flow as well as other variables. The optimum amount of injected fuel depends on conditions such as engine and ambient temperatures, engine speed and workload, and exhaust gas composition. The electronic fuel injector is normally closed, and opens to inject pressurized fuel as long as electricity is applied to the injector's solenoid coil. The duration of this operation, called the pulse width, is proportional to the amount of fuel desired. The electric pulse may be applied in closely-controlled sequence with the valve events on each individual cylinder (in a sequential fuel injection system), or in groups of less than the total number of injectors (in a batch fire system). Since the nature of fuel injection dispenses fuel in discrete amounts, and since the nature of the 4-stroke-cycle engine has discrete induction (air-intake) events, the ECU calculates fuel in discrete amounts. In a sequential system, the injected fuel mass is tailored for each individual induction event. Every induction event, of every cylinder, of the entire engine, is a separate fuel mass calculation, and each injector receives a unique pulse width based on that cylinder's fuel requirements. It is necessary to know the mass of air the engine "breathes" during each induction event. This is proportional to the intake manifold's air pressure/temperature, which is proportional to throttle position. The amount of air inducted in each intake event is known as "air-charge", and this can be determined using several methods. The three elemental ingredients for combustion are fuel, air and ignition. However, complete combustion can only occur if the air and fuel is present in the exact stoichiometric ratio, which allows all the carbon and hydrogen from the fuel to combinewith all the oxygen in the air, with no undesirable polluting leftovers. Oxygen sensors monitor the amount of oxygen in the exhaust, and the ECU uses this information toadjust the air-to-fuel ratio in real-time. To achieve stoichiometry, the air mass flow into the engine is measured and multiplied by the stoichiometric air/fuel ratio. The required fuel mass that must be injected into the engine is then translated to the required pulse width for the fuel injector. Deviations from stoichiometry are required during non-standard operating conditions such as heavy load, or cold operation. In early fuel injection systems this was accomplished with a thermo time switch. Pulse width is inversely related to pressure difference across the injector inlet and outlet. For example, if the fuel line pressure increases (injector inlet), or the manifold pressure decreases (injector outlet), a smaller pulse width will admit the same fuel. Fuel injectors are available in various sizes and spray characteristics as well. Compensation for these and many other factors are programmed into the ECU's software.



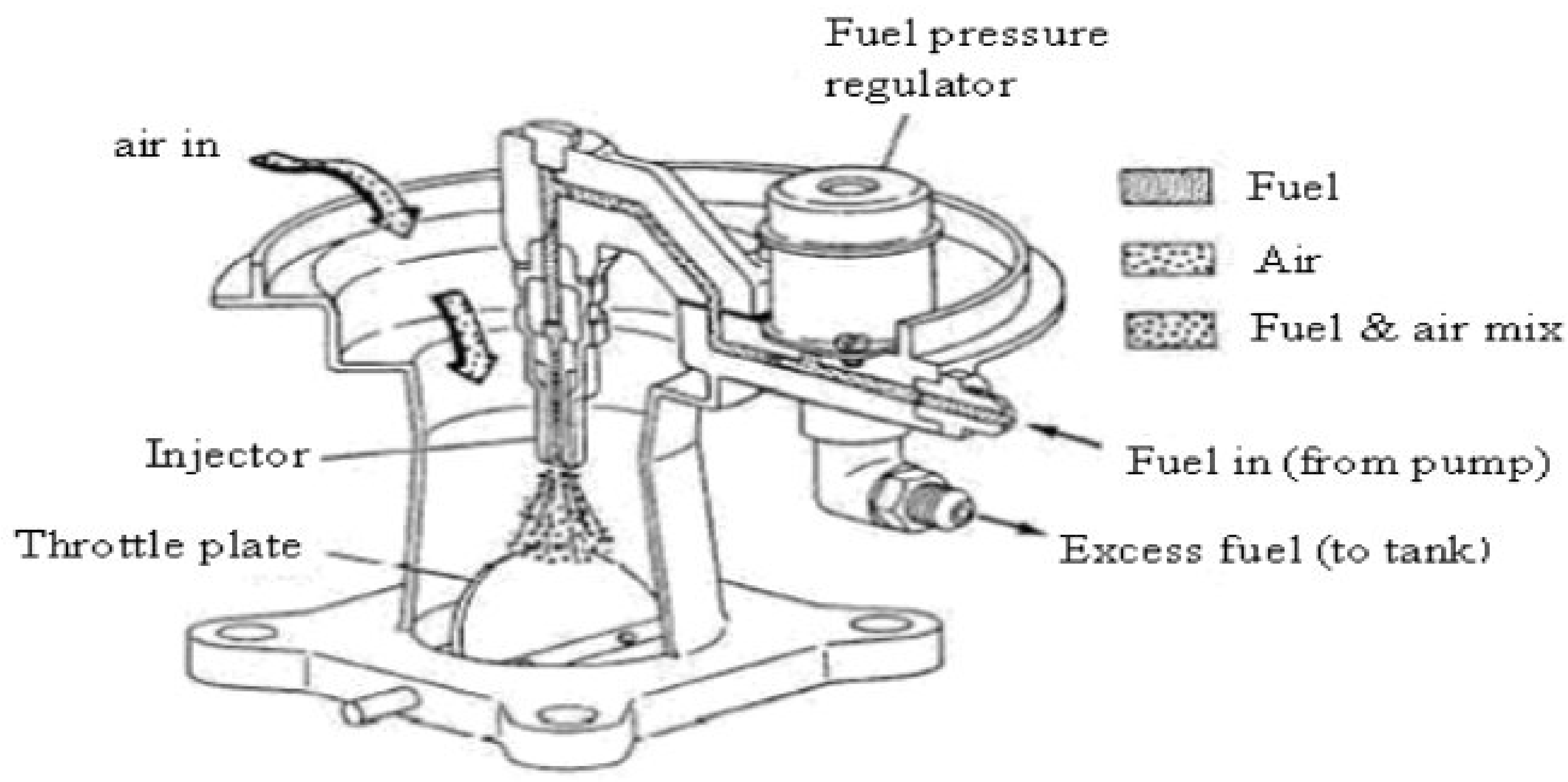
VARIOUS INJECTION SCHEMES

Throttle Body Injection Systems

Throttle body injection is a form of continuous injection-one or two injectors delivering fuel to the engine from one central point in the intake manifold. Though throttle body injection does not provide the precise fuel distribution of the direct port injection, it is cheaper to produce and to provide a degree of precision fuel metering. The throttle body injection unit is usually an integral one and contains all of the major system components. The unit mounts on the intake manifold in the same manner as a carburettor. Airflow sensors and electronic computers usually are mounted in the air cleaner body.

Throttle Body Injection Unit

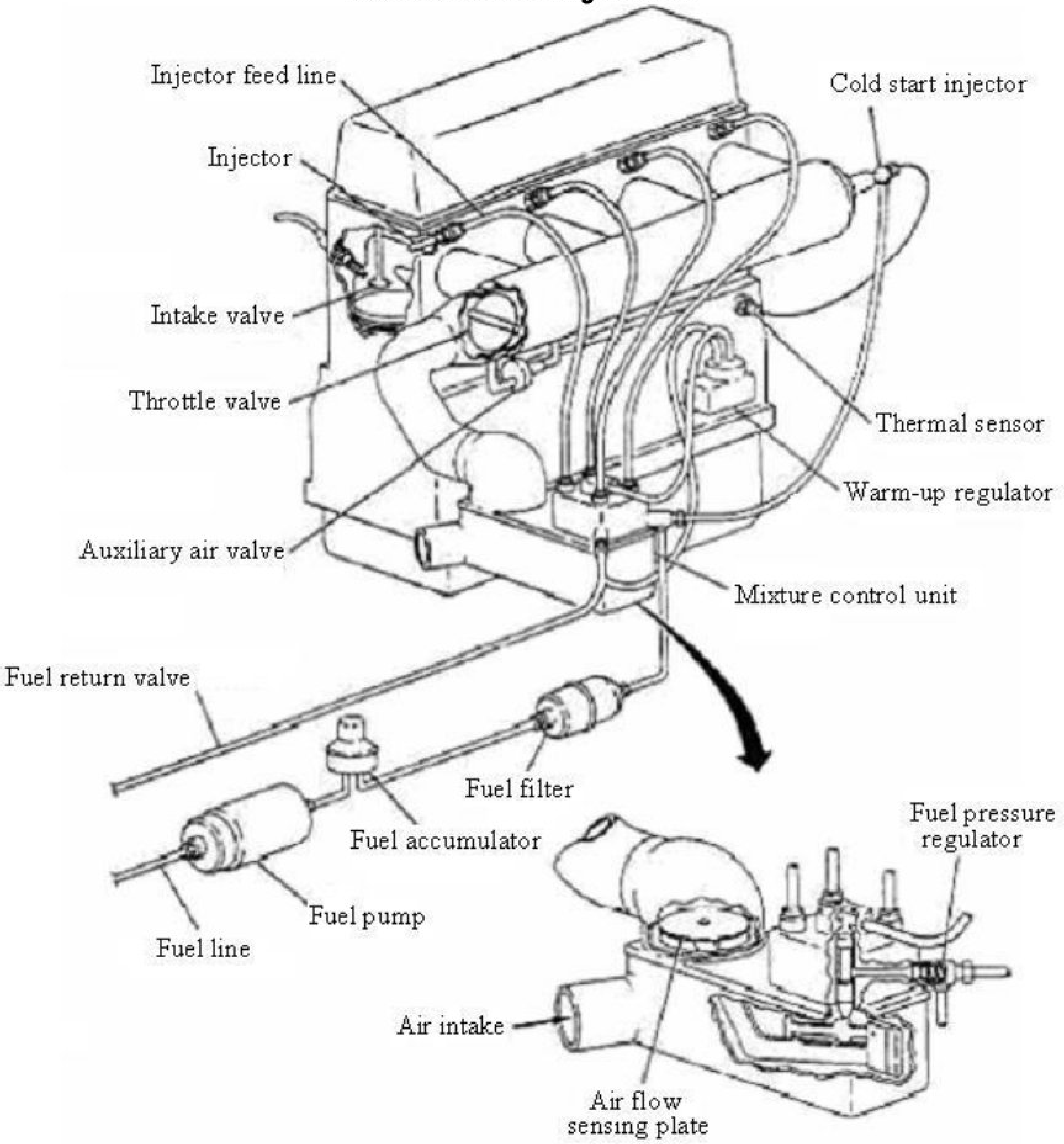
Throttle Body Injection



Continuous Fuel Injection Systems

Continuous fuel injection systems provide a continuous spray of fuel from each injector at a point before the intake valve. Timed injection systems, though a necessity on diesel engines, cost more than continuous systems. They are used on gasoline engines only when more precise fuel metering is desired. In the continuous system, fuel is delivered to the mixture control unit by the fuel pump.

Continuous Injection



The fuel pressure regulator maintains fuel line pressure by sending excess fuel back to the gas tank. The mixture control unit regulates the amount of fuel that is sent to the injectors, based on the amount of airflow through the intake and the engine temperature. The mixture control unit on mechanical systems is operated by the airflow sensing plate and the warm-up regulator. This information on an electronic system is fed into a computer that regulates the fuel injection rate. The accelerator pedal regulates the rate of airflow through the intake by opening and closing the throttle valve. A cold-start injector is installed in the intake to provide a richer mixture during engine start-up and warm-up. It is actuated by electric current from the thermal sensor whenever the temperature of the coolant is below a certain level. The cold-start injector works in conjunction with the auxiliary air valve. Its function is to speed up the engine idle during warm-up. It is also actuated by the thermal sensor.

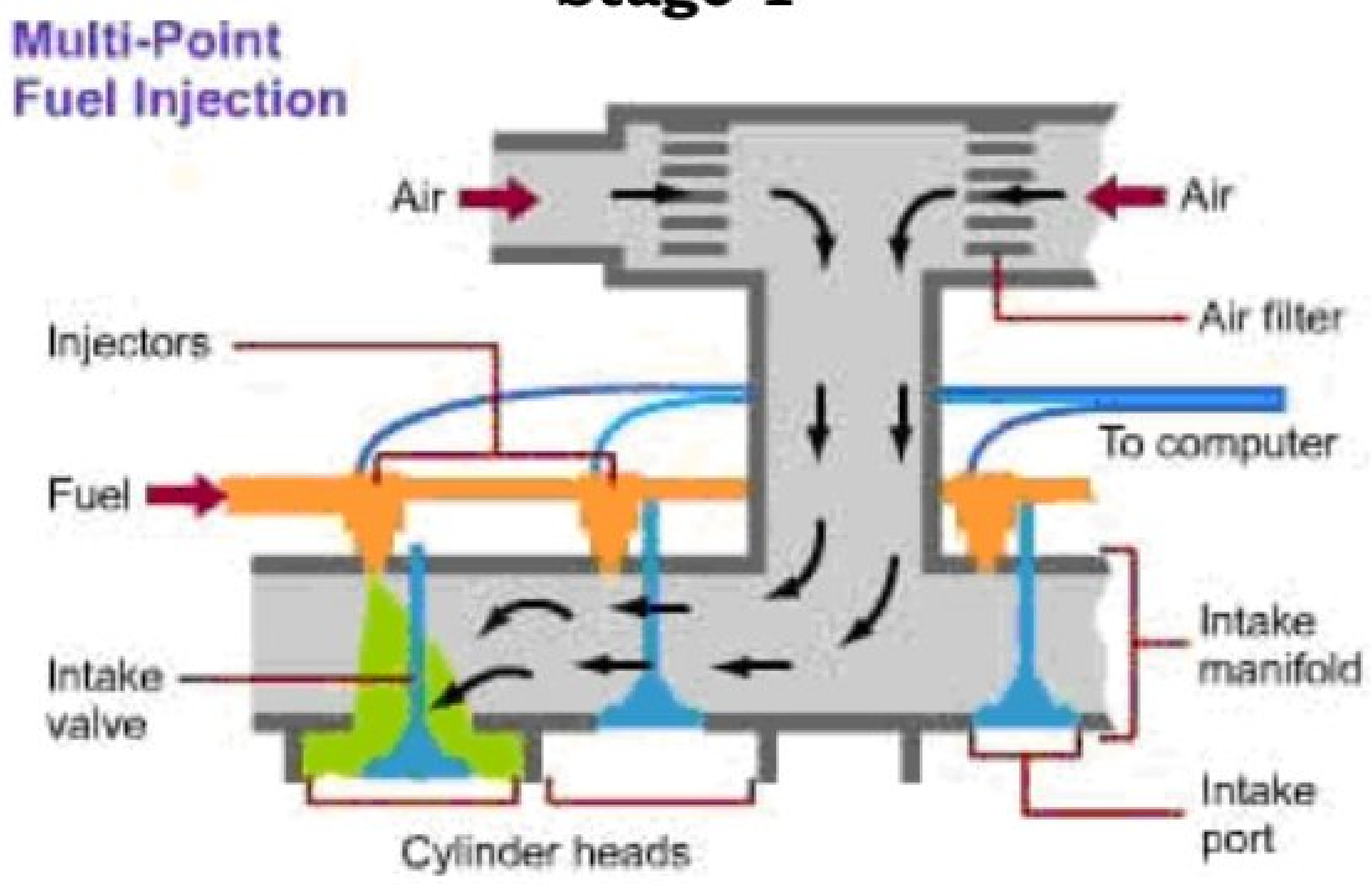
Central Port Injection (CPI)

It uses tubes with poppet valves from a central injector to spray fuel at each intake port rather than the central throttle-body. The 2 variants were CPFI from 1992 to 1995 and CSFI from 1996 and on. CPFI is a *batch-fire* system, in which fuel is injected to all ports simultaneously. The 1996 and later CSFI system sprays fuel *sequentially*.

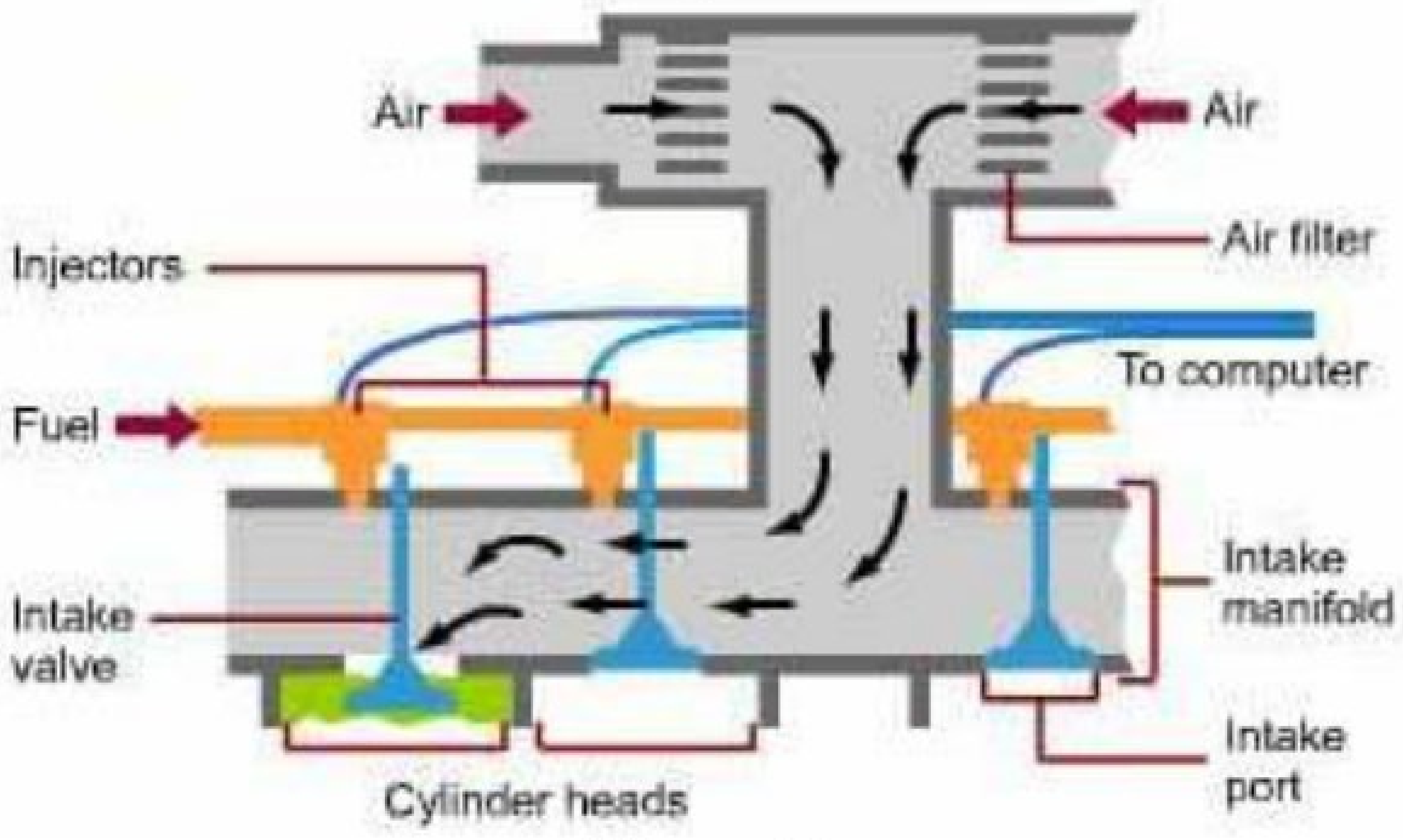
Multi-point Fuel Injection

Multi-point fuel injection injects fuel into the intake port just upstream of the cylinder's intake valve, rather than at a central point within an intake manifold, referred to as SPFI, or single point fuel injection. MPFI (or just MPI) systems can be sequential, in which injection is timed to coincide with each cylinder's intake stroke, batched, in which fuel is injected to the cylinders in groups, without precise synchronization to any particular cylinder's intake stroke, or simultaneous, in which fuel is injected at the same time to all the cylinders.

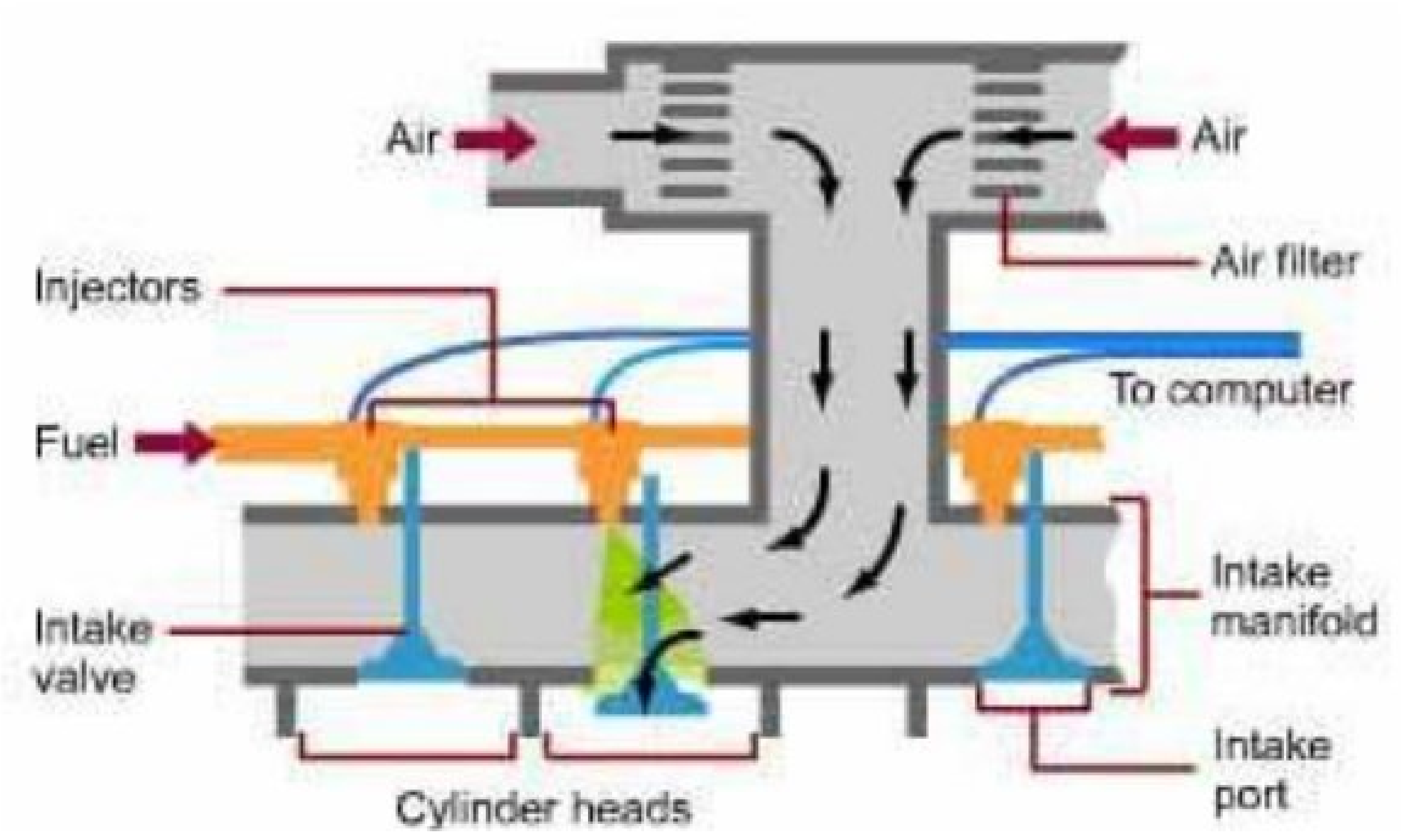
Stage 1



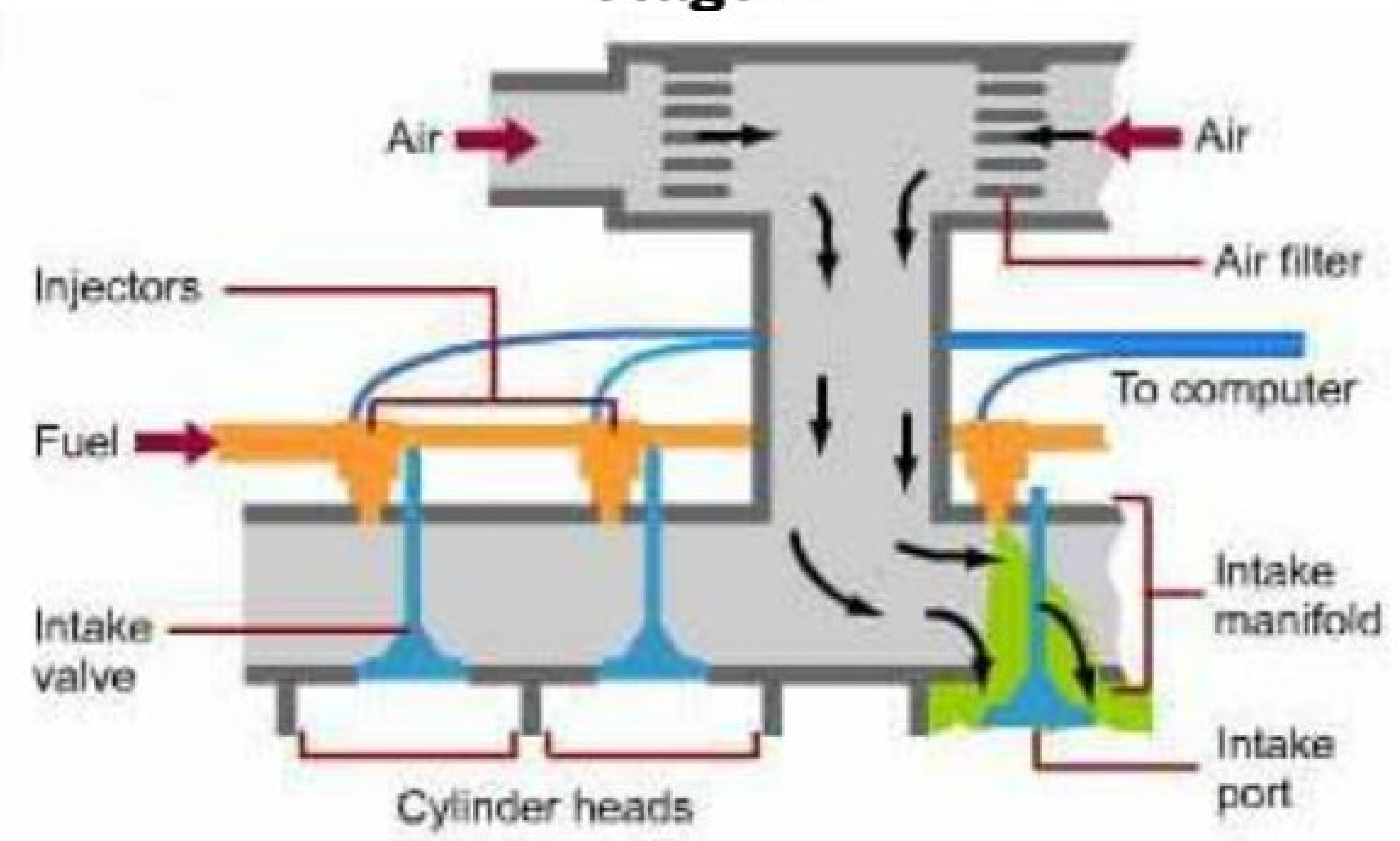
Stage 2



Stage 3



Stage 4



Direct Injection

Many diesel engines feature direct injection (DI). The injection nozzle is placed inside the combustion chamber and the piston incorporates a depression (often toroidal) where initial combustion takes place. Direct injection diesel engines are generally more efficient and cleaner than indirect injection engines. By virtue of better dispersion and homogeneity of the directly injected fuel, the cylinder and piston are cooled, thereby permitting higher compression ratios and more aggressive ignition timing, with resultant enhanced output. More precise management of the fuel injection event also enables better control of emissions. Finally, the homogeneity of the fuel mixture allows for leaner air/fuel ratios, which together with more precise ignition timing can improve fuel economy. Along with this, the engine can operate with stratified mixtures and hence avoid throttling losses at low and part load. Some direct-injection systems incorporate piezo electronic injectors. With their extremely fast response time, multiple injection events can occur during each power stroke of the engine. Direct fuel injection costs more than indirect injection systems; the injectors are exposed to more heat and pressure, so more costly materials and higher-precision electronic management systems are required.

Performance Testing of Diesel Engine Power Plant

The performance of the diesel engine focuses on the power and efficiency. The engine varies with parameters of the engine like piston speed, air-fuel ratio, compression ratio inlet air-pressure and temperature. The two usual conditions under which I.C. engines are operated are :

(a) constant speed with variable load, and
(b) variable speed with variable load.

The first situation is found in a.c. generator drives and the second one in automobiles, railway engines and tractors etc. A series of tests are carried out on the engine to determine its performance characteristics, such as : indicated power (I.P.), Brake power (B.P.), Frictional Power (F.P.), Mechanical efficiency (ηm), thermal efficiency, fuel consumption and also specific fuel consumption etc. The measurement of these quantities is discussed below.

Indicated Mean Effective Pressure (IMRP)

In order to determine the power developed by the engine, the indicator diagram of engine should be available. From the area of indicator diagram it is possible to find an average gas pressure which, while acting on piston throughout one stroke, would account for the network done. This pressure is called indicated mean effective pressure (IMEP).

Indicated Horse Power (IHP)

The indicated horse power (IHP) of the engine can be calculated as follows :

$$IHP = PmLANn/4500 * K$$

Pm = IMEP, kg/cm2,
L = Length of stroke, metres,
A = Piston areas, cm2,
N = Speed, RPM,
n = Number of cylinders, and
k = 1 for two stroke engine
= 2 for four stroke engine.

Brake Horse Power (BHP)

Brake horse power is defined as the net power available at the crankshaft. It is found by measuring the output torque with a dynamometer.

$$BHP = 2\pi NT/4500$$

T = Torque, kg.m.

Frictional Horse Power (FHP)

The difference of IHP and BHP is called FHP. It is utilized in overcoming frictional resistance of rotating and sliding parts of the engine.

$$FHP = IHP - BHP$$

Indicated Thermal Efficiency (ηi)

It is defined as the ratio of indicated work to thermal input.

$$\eta i = IHP*4500/(W*Cv*J)$$

W = Weight of fuel supplied, kg per minute,
Cv= Calorific value of fuel oil, kcal/kg, and
J = Joules equivalent = 427

Brake Thermal Efficiency (Overall Efficiency)

$$\eta b = IHP*4500/(W*Cv*J)$$

It is defined as the ratio of brake output to thermal input.

Mechanical Efficiency (ηm)

It is defined as the ratio of BHP to IHP. Therefore,

$$\eta m=BHP/IHP$$

VAPOUR POWER CYCLES

Vapor Power Cycles

We know that the Carnot cycle is most efficient cycle operating between two specified temperature limits. However; the Carnot cycle is not a suitable model for steam power cycle since:

- The turbine has to handle steam with low quality which will cause erosion and wear in turbine blades.
- It is impractical to design a compressor that handles two phase.
- It is difficult to control the condensation process that precisely as to end up with the desired at point 4.

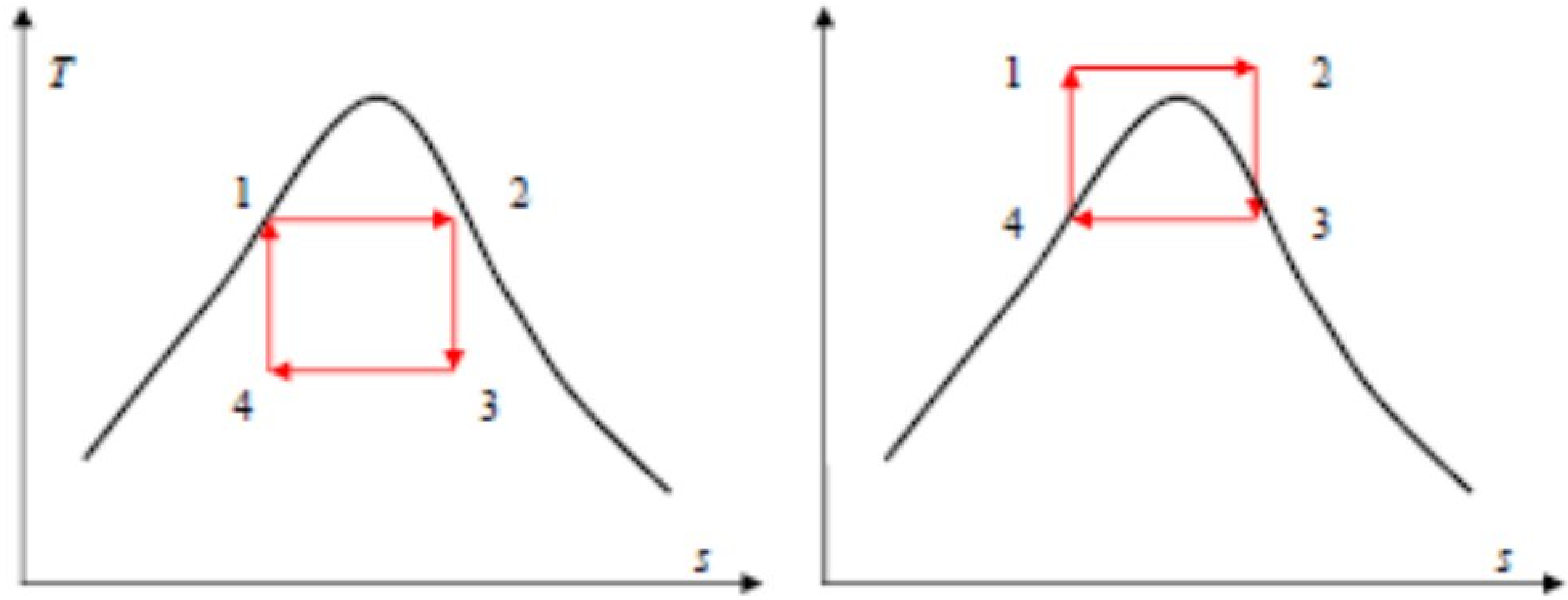


Fig. 1: *T-s* diagram for two Carnot vapor cycle.

Other issues include: isentropic compression to extremely high pressure and isothermal heat transfer at variable pressures. Thus, the Carnot cycle cannot be approximated in actual devices and is not a realistic model for vapor power cycles.

Ideal Rankine Cycle

The Rankine cycle is the ideal cycle for vapor power plants; it includes the following four reversible processes:

1-2:	Isentropic compression	Water enters the pump as state 1 as saturated liquid and is compressed isentropically to the operating pressure of the boiler.
2-3:	Const P heat addition	Saturated water enters the boiler and leaves it as superheated vapor at state 3
3-4:	Isentropic expansion	Superheated vapor expands isentropically in turbine and produces work.
4-1:	Const P heat rejection	High quality steam is condensed in the condenser

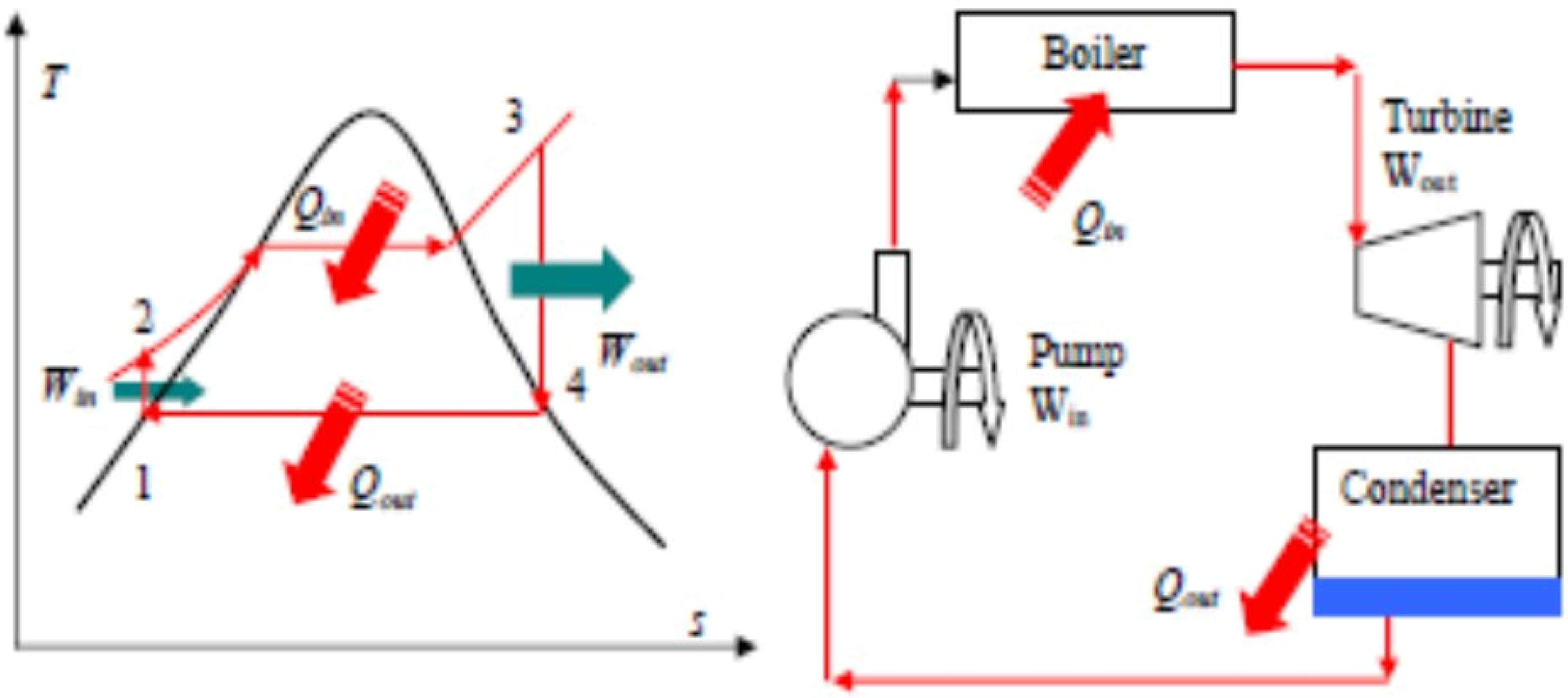


Fig. 2: The ideal Rankine cycle.

Energy Analysis for the Cycle

All four components of the Rankine cycle are steady-state steady-flow devices. The potential and kinetic energy effects can be neglected. The first law per unit mass of steam can be written as:

Pump	$q = 0$	$w_{pump,in} = h_2 - h_1$
Boiler	$w = 0$	$q_{in} = h_3 - h_2$
Turbine	$q = 0$	$w_{turbine,out} = h_3 - h_4$
Condenser	$w = 0$	$q_{out} = h_4 - h_1$

The thermal efficiency of the cycle is determined from:

$$\eta_{th} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

where

$$w_{net} = q_{in} - q_{out} = w_{turbine,out} - w_{pump,in}$$

If we consider the fluid to be incompressible, the work input to the pump will be:

$$(h_2 - h_1) = v(P_2 - P_1)$$

where $h_1 = h_{f@P1}$ & $v = v_1 = v_{f@P1}$

Deviation of Actual Vapor Power Cycle from Ideal Cycle

As a result of irreversibilities in various components such as fluid friction and heat loss to the surroundings, the actual cycle deviates from the ideal Rankine cycle. The deviations of actual pumps and turbines from the isentropic ones can be accounted for by utilizing isentropic efficiencies defined as:

$$\eta_P = \frac{w_s}{w_a} = \frac{h_{2s} - h_1}{h_{2a} - h_1} \qquad \eta_T = \frac{w_a}{w_s} = \frac{h_3 - h_{4a}}{h_3 - h_{4s}}$$

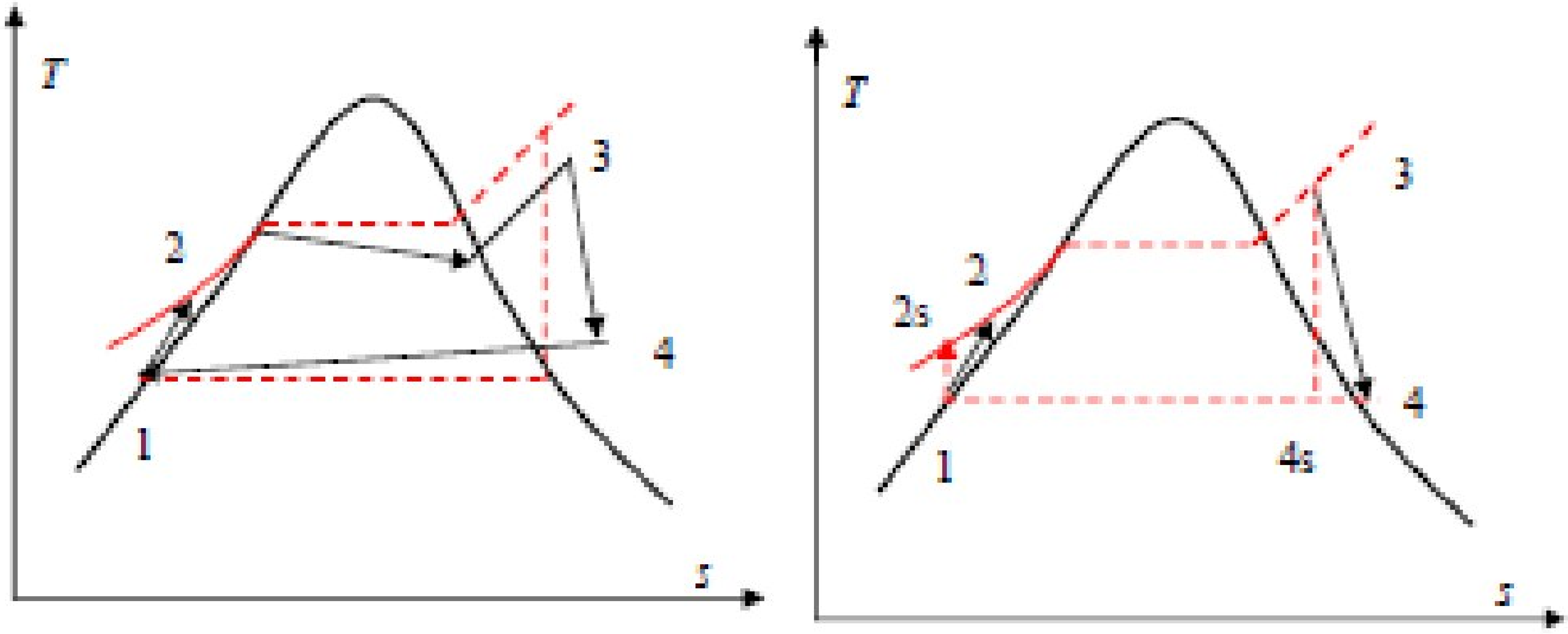


Fig. 3: Deviation from ideal Rankine cycle.

Increasing the Efficiency of Rankine Cycle

We know that the efficiency is proportional to: $\eta_{th} \propto 1 - \frac{T_L}{T_H}$

That is, to increase the efficiency one should increase the average temperature at which heat is transferred to the working fluid in the boiler, and/or decrease the average temperature at which heat is rejected from the working fluid in the condenser.

Decreasing the of Condenser Pressure (Lower T_L)

Lowering the condenser pressure will increase the area enclosed by the cycle on a *T-s* diagram which indicates that the net work will increase. Thus, the thermal efficiency of the cycle will be increased.

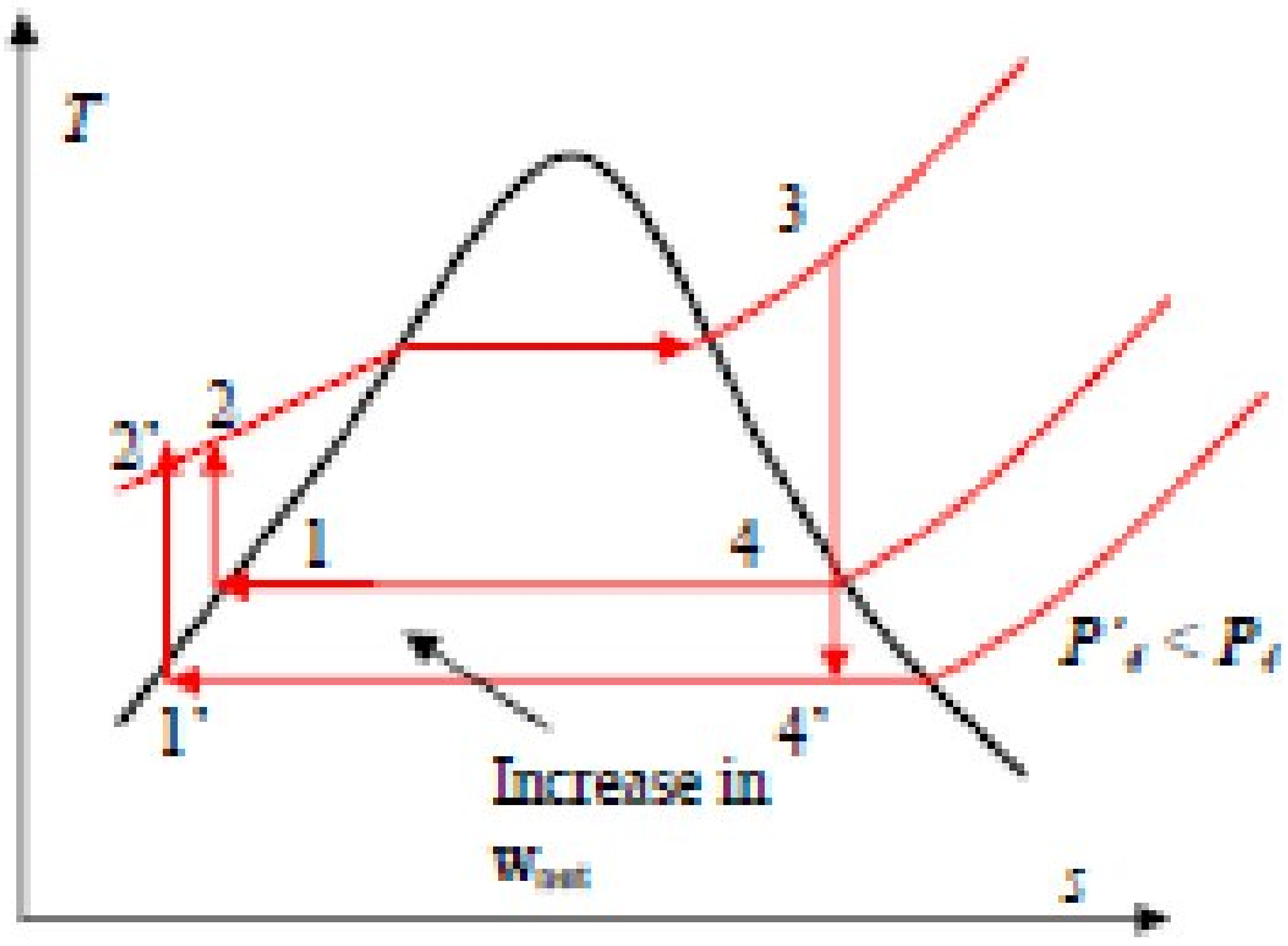


Fig. 4: Effect of lowering the condenser pressure on ideal Rankine cycle.

The condenser pressure cannot be lowered than the saturated pressure corresponding to the temperature of the cooling medium. We are generally limited by the thermal reservoir temperature such as lake, river, etc. Allow a temperature difference of 10°C for effective heat transfer in the condenser. For instance lake @ 15°C + ΔT (10°C) = 25°C. The steam saturation pressure (or the condenser pressure) then will be ⇒ P_{sat} = 3.2 *kPa*.

Superheating the Steam to High Temperatures (Increase T_H)

Superheating the steam will increase the net work output and the efficiency of the cycle. It also decreases the moisture contents of the steam at the turbine exit. The temperature to which steam can be superheated is limited by metallurgical considerations (~ 620°C).

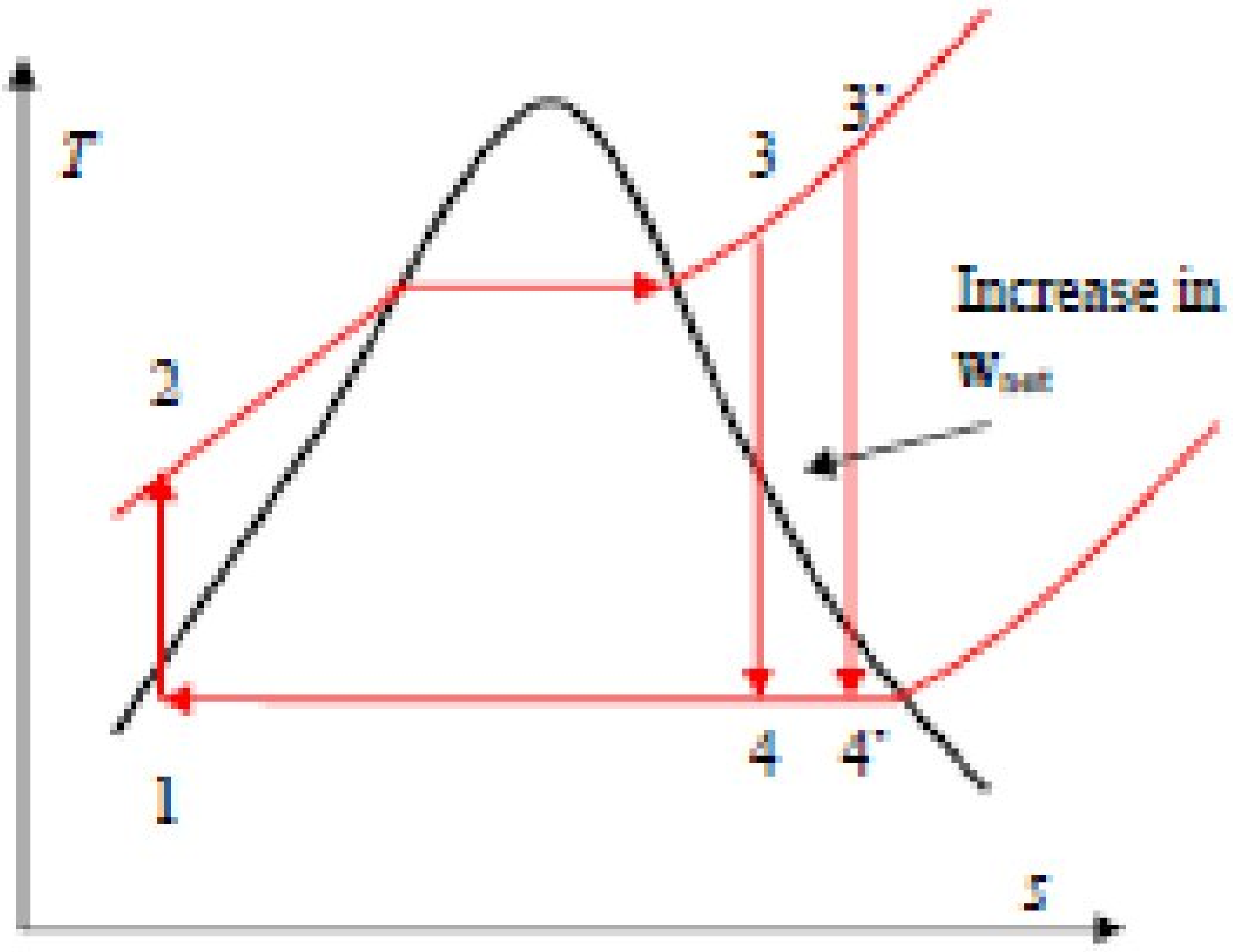


Fig. 5: The effect of increasing the boiler pressure on the ideal Rankine cycle.

Increasing the Boiler Pressure (Increase T_H)

Increasing the operating pressure of the boiler leads to an increase in the temperature at which heat is transferred to the steam and thus raises the efficiency of the cycle.

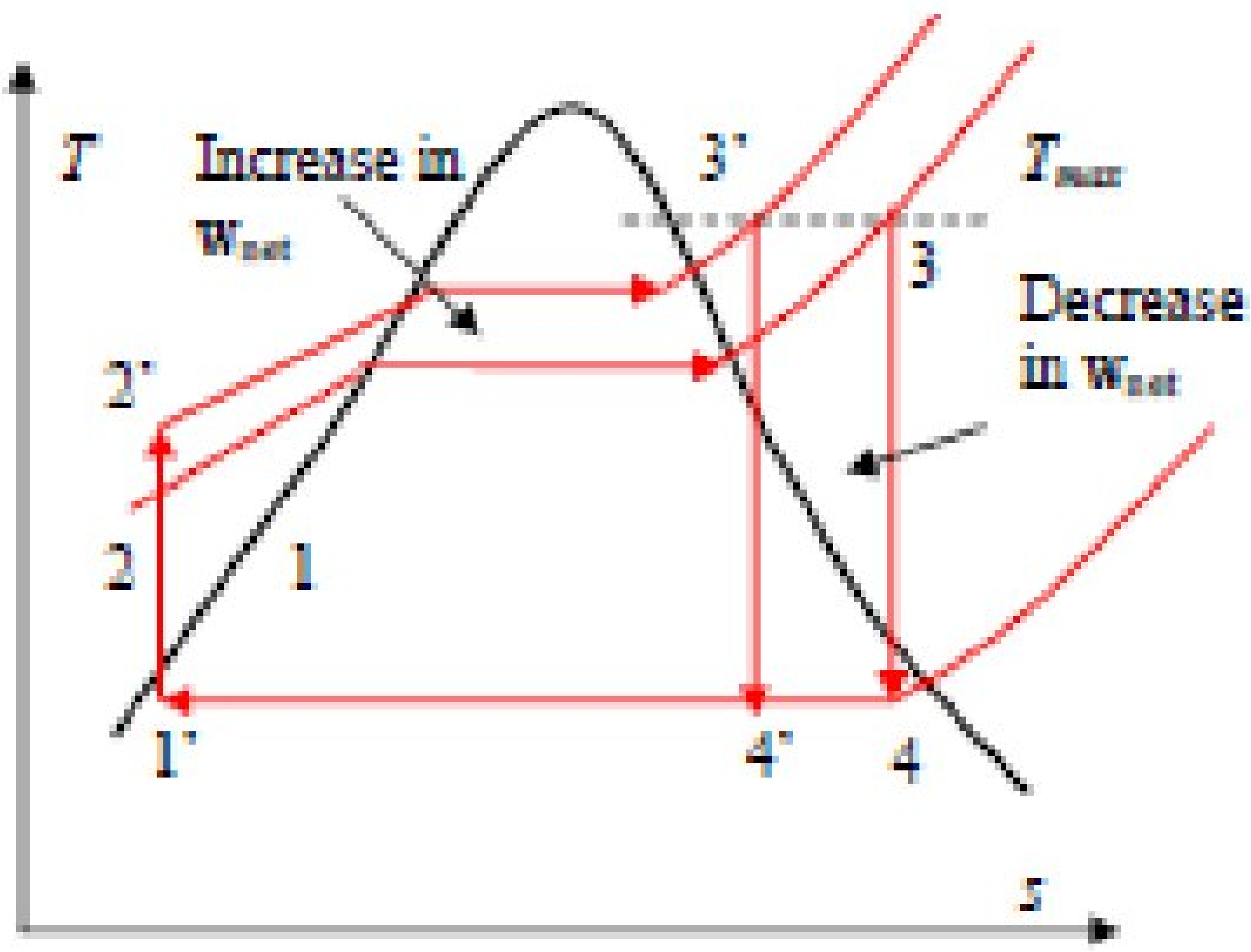


Fig.6: The effect of increasing the boiler pressure on the ideal cycle.

Note that for a fixed turbine inlet temperature, the cycle shifts to the left and the moisture content of the steam at the turbine exit increases. This undesirable side effect can be corrected by *reheating* the steam.

The Ideal Reheat Rankine Cycle

To take advantage of the increased efficiencies at higher boiler pressure without facing the excessive moisture at the final stages of the turbine, reheating is used. In the ideal reheating cycle, the expansion process takes place in two stages, i.e., the high-pressure and low-pressure turbines.

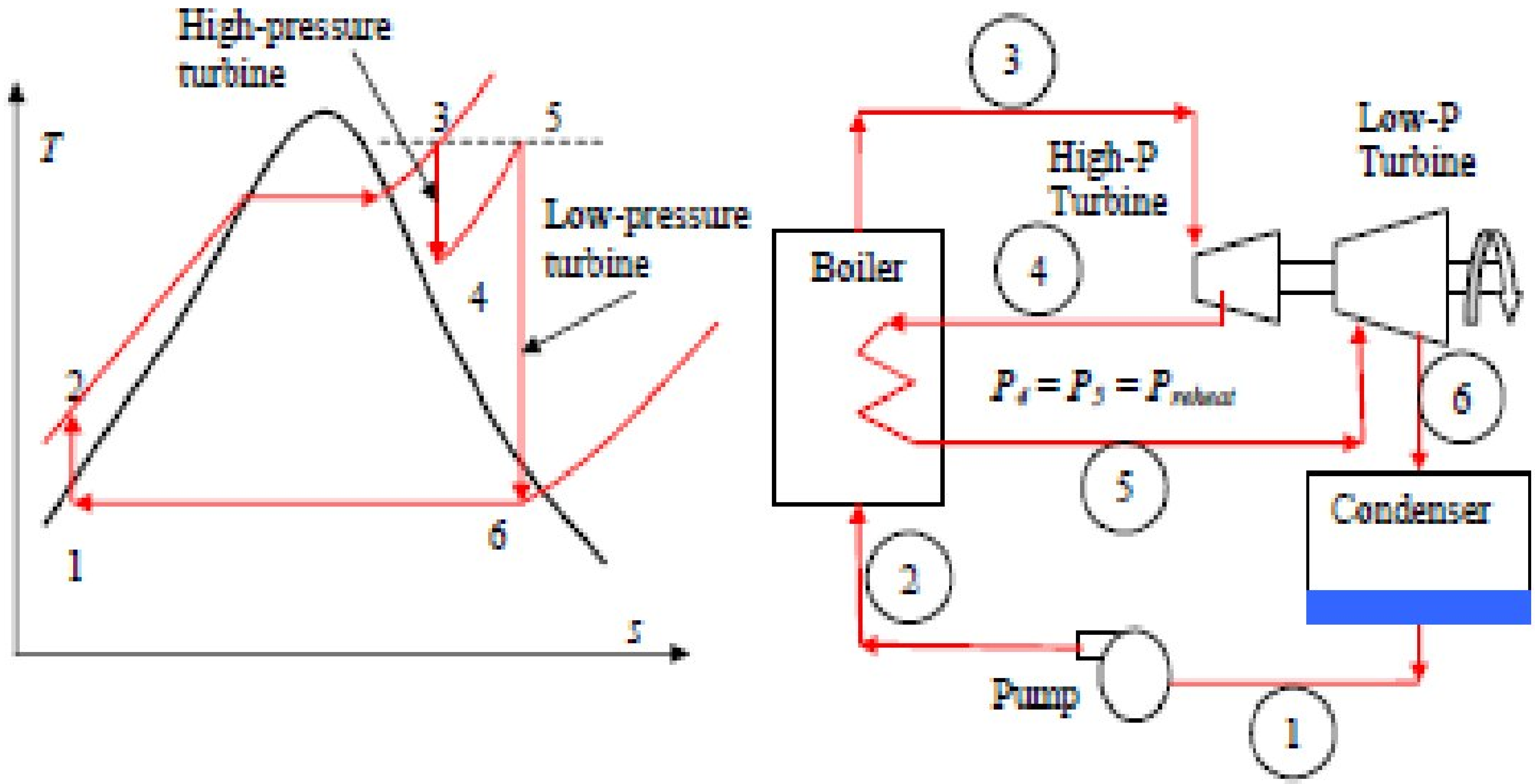


Fig. 7: The ideal reheat Rankine cycle.

The total heat input and total turbine work output for a reheat cycle become:

$$q_{in} = q_{primary} + q_{reheat} = (h_3 - h_2) + (h_5 - h_4)$$

$$w_{turbine,out} = w_{H-P\ turbine} + w_{L-P\ turbine} = (h_3 - h_4) + (h_5 - h_6)$$

The incorporation of the single reheat in a modern power plant improves the cycle efficiency by 4 to 5 percent by increasing the average temperature at which heat is transferred to the steam.

The Ideal Regenerative Rankine Cycle

The regeneration process in steam power plants is accomplished by extracting (or bleeding) steam from turbine at various stages and feed that steam in heat exchanger where the feedwater is heated. These heat exchangers are called regenerator or feedwater heater (FWH).

FWH also help removing the air that leaks in at the condenser (deaerating the feedwater).

There are two types of FWH's, open and closed.

Open (Direct-Contact) Feedwater Heaters

An open FWH is basically a mixing chamber where the steam extracted from the turbine mixes with the feedwater exiting the pump. Ideally, the mixture leaves the heater as a saturated liquid at the heater pressure.

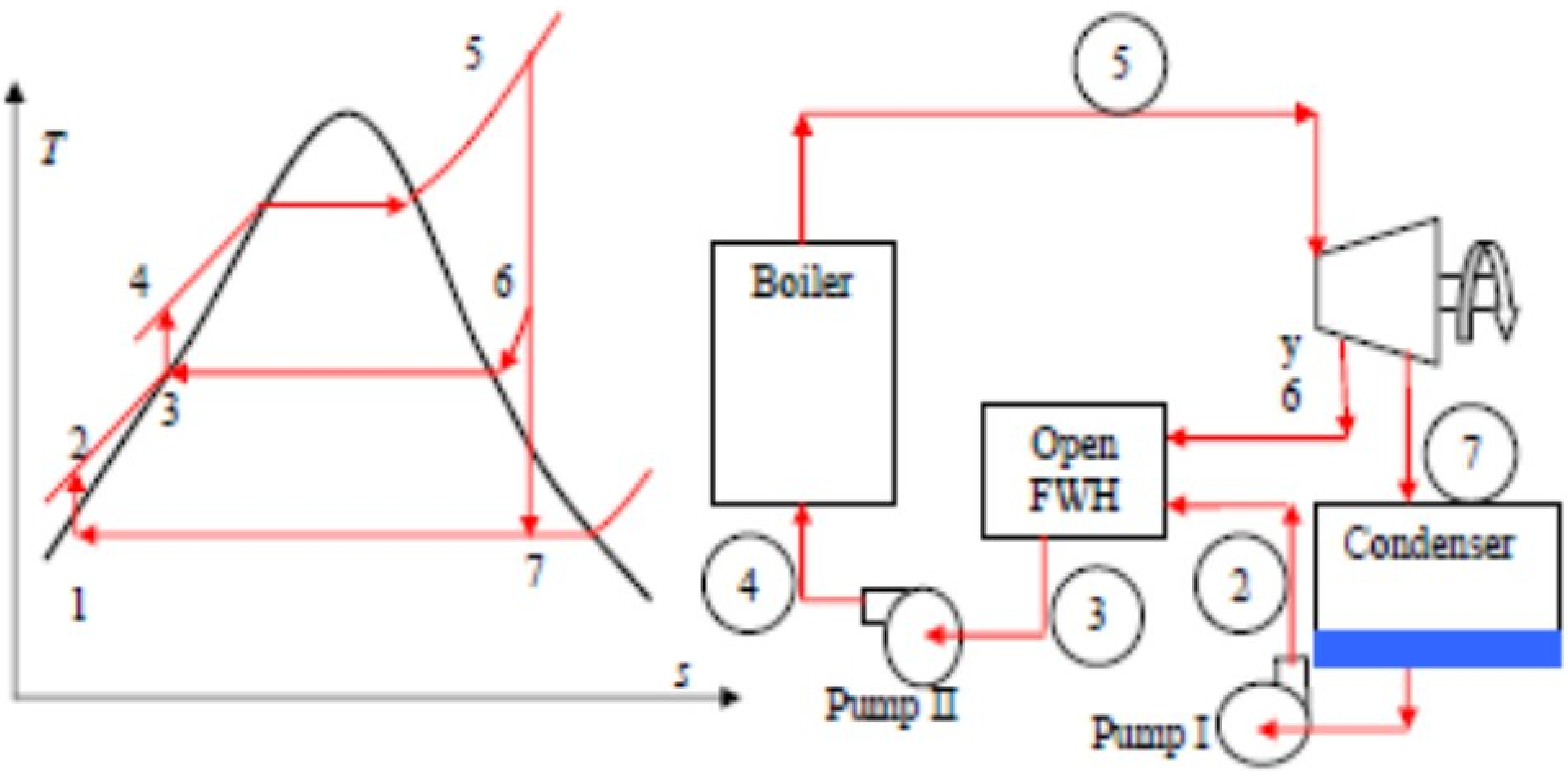


Fig. 8: The ideal regenerative Rankine cycle with an open FWH.

Using Fig. 8, the heat and work interactions of a regenerative Rankine cycle with one FWH can be expressed per unit mass of steam flowing through the boiler as:

$$q_{in} = h_5 - h_4$$
$$q_{out} = (1-y)(h_7 - h_1)$$
$$w_{turbine,out} = (h_5 - h_6) + (1-y)(h_6 - h_7)$$
$$w_{pump,in} = (1-y)w_{PumpI} + w_{PumpII}$$

where

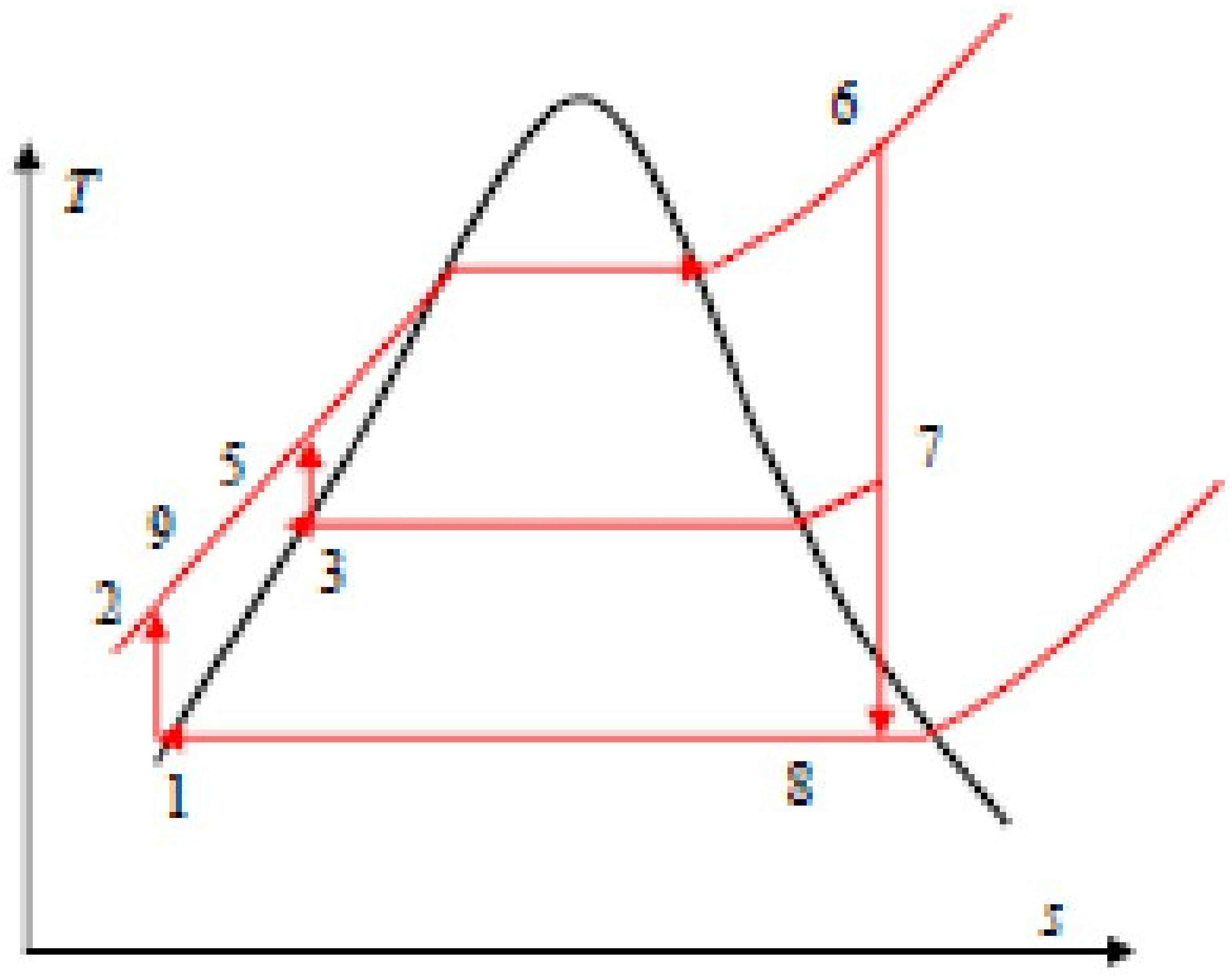
$$y = \dot{m}_6 / \dot{m}_5$$
$$w_{PumpI} = v_1(P_2 - P_1) \qquad w_{PumpII} = v_3(P_4 - P_3)$$

Thermal efficiency of the Rankine cycle increases as a result of regeneration since FWH raises the average temperature of the water before it enters the boiler. Many large power plants have as many as 8 FWH's.

Closed Feedwater Heaters

In closed FWH, heat is transferred from the extracted steam to the feedwater without any mixing taking place. Thus; two streams can be at different pressures, since they don't mix.

In an ideal closed FWH, the feedwater is heated to the exit temperature of the extracted steam, which ideally leaves the heater as a saturated liquid at the extraction pressure.



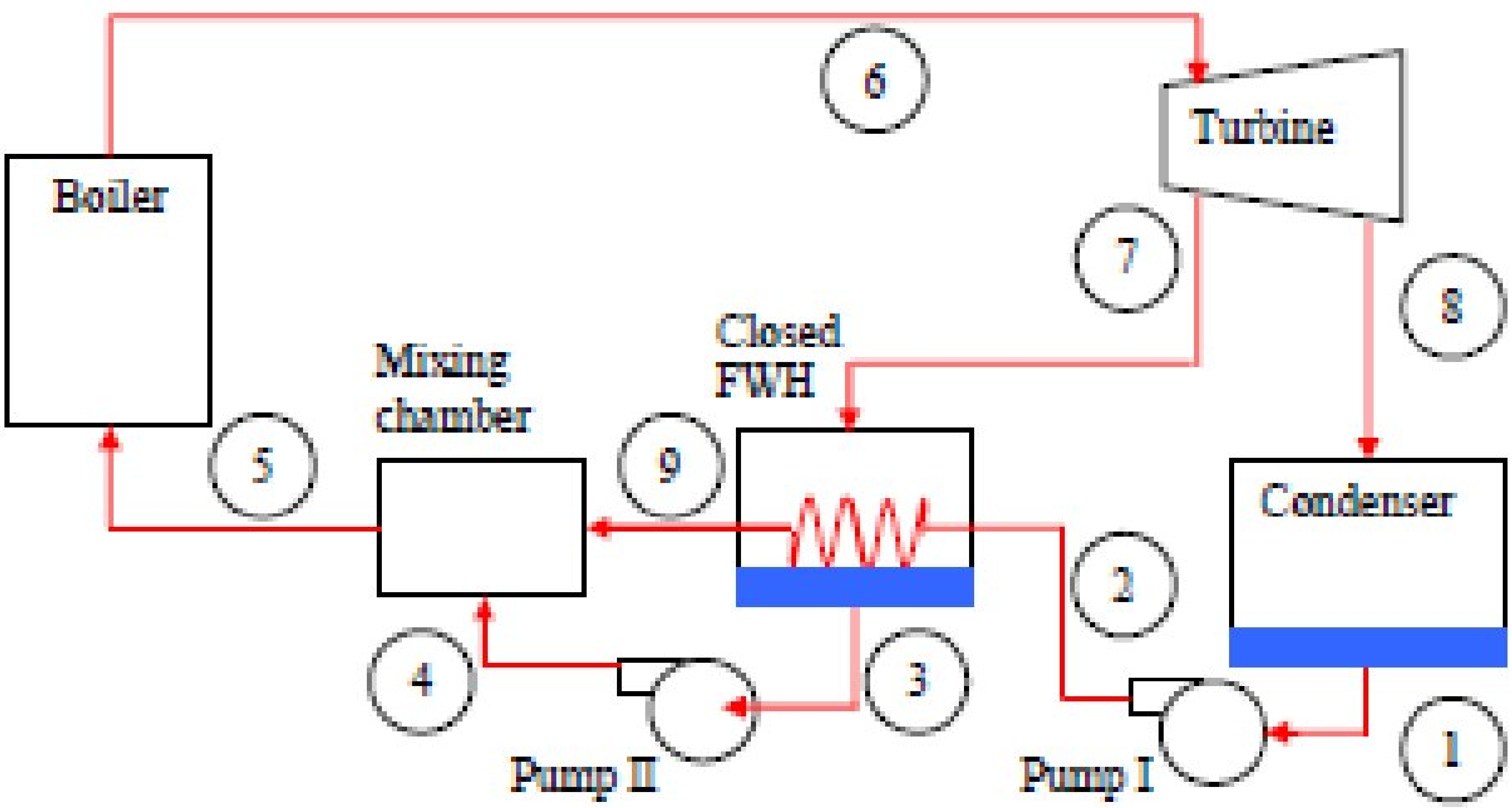


Fig.9: Ideal regenerative Rankine cycle with a closed FWH.

Open FWH	Closed FWH
• simple • inexpensive • good heat transfer characteristics • bring feedwater to the saturation state • a pump is required for each FWH	• more complex (internal tubing) • less effective (no mixing) • do not require a pump for each FWH

Cogeneration

Many system and industries require energy input in the form of heat, called *process heat*. Some industries such as chemical, pulp and paper rely heavily on process heat. The process heat is typically supplied by steam at 5 to 7 atm and 150 to 200 C. These plants also require large amount of electric power. Therefore, it makes economical and engineering sense to use the already-existing work potential (in the steam entering the condenser) to use as process heat. This is called cogeneration.

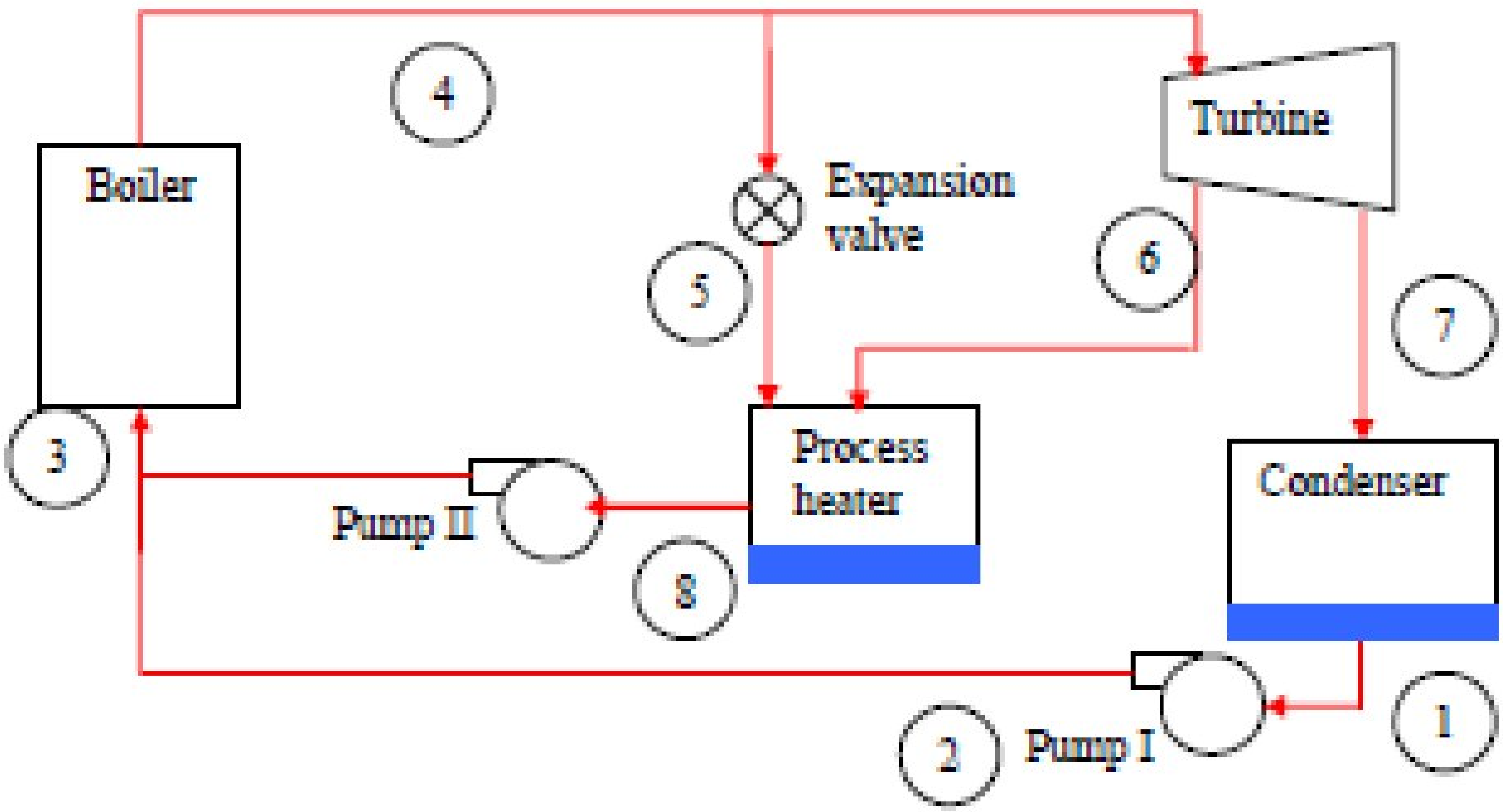


Fig. 10: A cogeneration plant with adjustable loads.

In the cogeneration cycle shown in the above figure, at times of high demands for process heat, all the steam is routed to the process heating unit and none to the condenser.

Combined Gas-Vapor Power Cycle

Gas-turbine cycles typically operate at considerably higher temperatures than steam cycles. The maximum fluid temperature at the turbine inlet is about 620C for modern steam power plants, but over 1425C for gas-turbine power plants. It is over 1500C at the burner exit of turbojet engines.

It makes engineering sense to take advantage of the very desirable characteristics of the gas-turbine cycle at high-temperature and to use the high temperature exhaust gases as the energy source for the bottoming cycle as a steam power cycle. This is called *combined cycle*. Combined cycles can achieve high thermal efficiencies, some of recent ones have η about 60%.