MAGNETO HYDRO DYNAMIC POWER GENERATION (MHD)

CONTENTS

INTRODUCTION

- 80 % of total electricity produced in the world is hydal, while remaining 20% is produced from nuclear, thermal, solar, geothermal energy and from magneto hydro dynamic (mhd) generator.
- MHD power generation is a new system of electric power generation which is said to be of high efficiency and low pollution. In advanced countries MHD generators are widely used but in developing countries like INDIA, it is still under construction, this construction work in in progress at TRICHI in TAMIL NADU, under the joint efforts of BARC (Bhabha atomic research center), Associated cement corporation (ACC) and Russian technologists.
- As its name implies, magneto hydro dynamics (MHD) is concerned with the flow of a conducting fluid in the presence of magnetic and electric field. The fluid may be gas at elevated temperatures or liquid metals like sodium or potassium- **SEEDING**.

INTRODUCTION

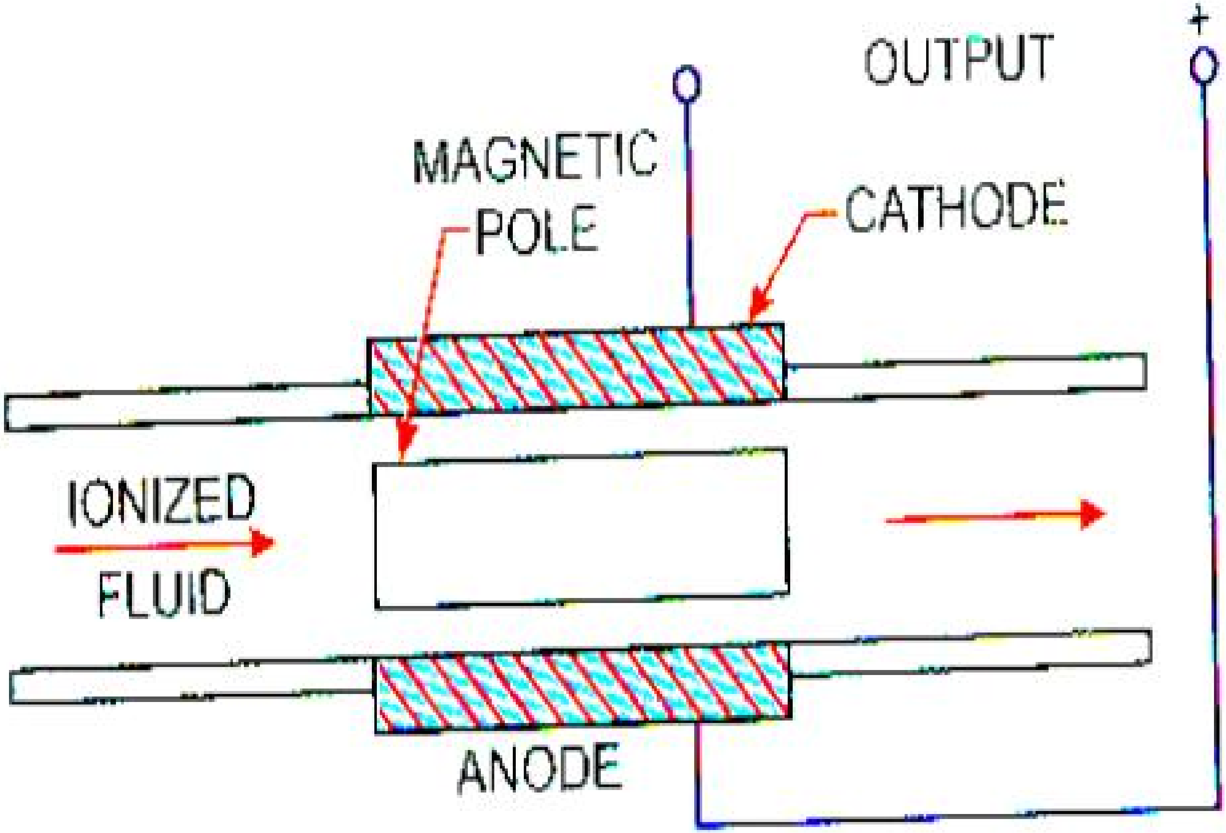
- An MHD generator is a device for converting heat energy of a fuel directly into electrical energy without conventional electric generator.

- In this system. An MHD converter system is a heat engine in which heat taken up at a higher temperature is partly converted into useful work and the remainder is rejected at a temperature. Like all heat engines, the thermal efficiency of an MHD converter is increased by supplying the heat at the highest practical temperature and rejecting it at the lowest practical temperature.
- The output of the MHD is supplied to the conventional Thermal Plants.

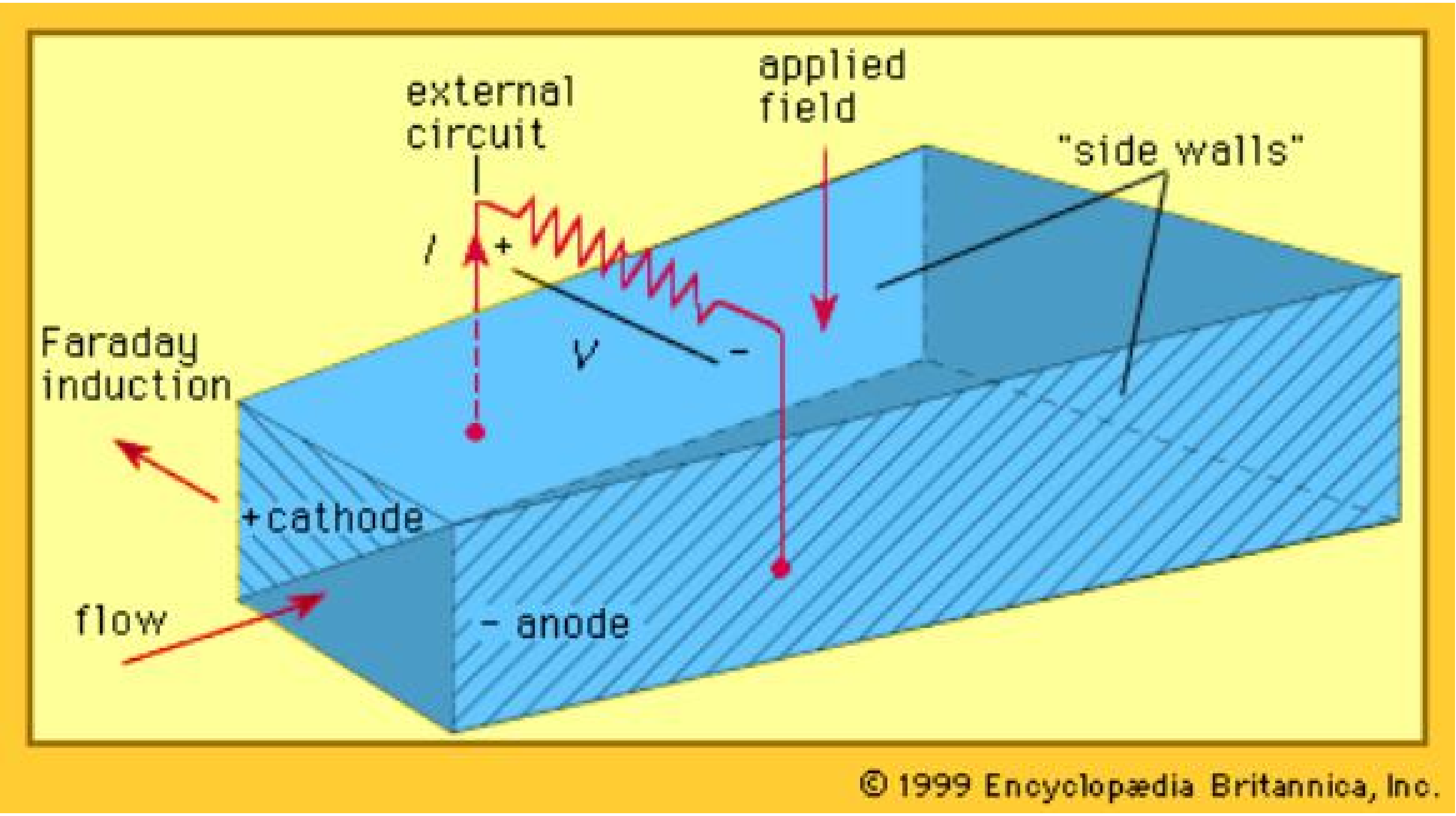
PRINCIPLES OF MHD POWER GENERATION

- When an electric conductor moves across a magnetic field, a voltage is induced in it which produces an electric current.
- This is the principle of the conventional generator where the conductors consist of copper strips.
- In MHD generator, the solid conductors are replaced by a gaseous conductor, an ionized gas. If such a gas is passed at a high velocity through a powerful magnetic field, a current is generated and can be extracted by placing electrodes in suitable position in the stream.
- The principle can be explained as follows. An electric conductor moving through a magnetic field experiences a retarding force as well as an induced electric field and current.

PRINCIPLES OF MHD POWER GENERATION



PRINCIPLES OF MHD POWER GENERATION



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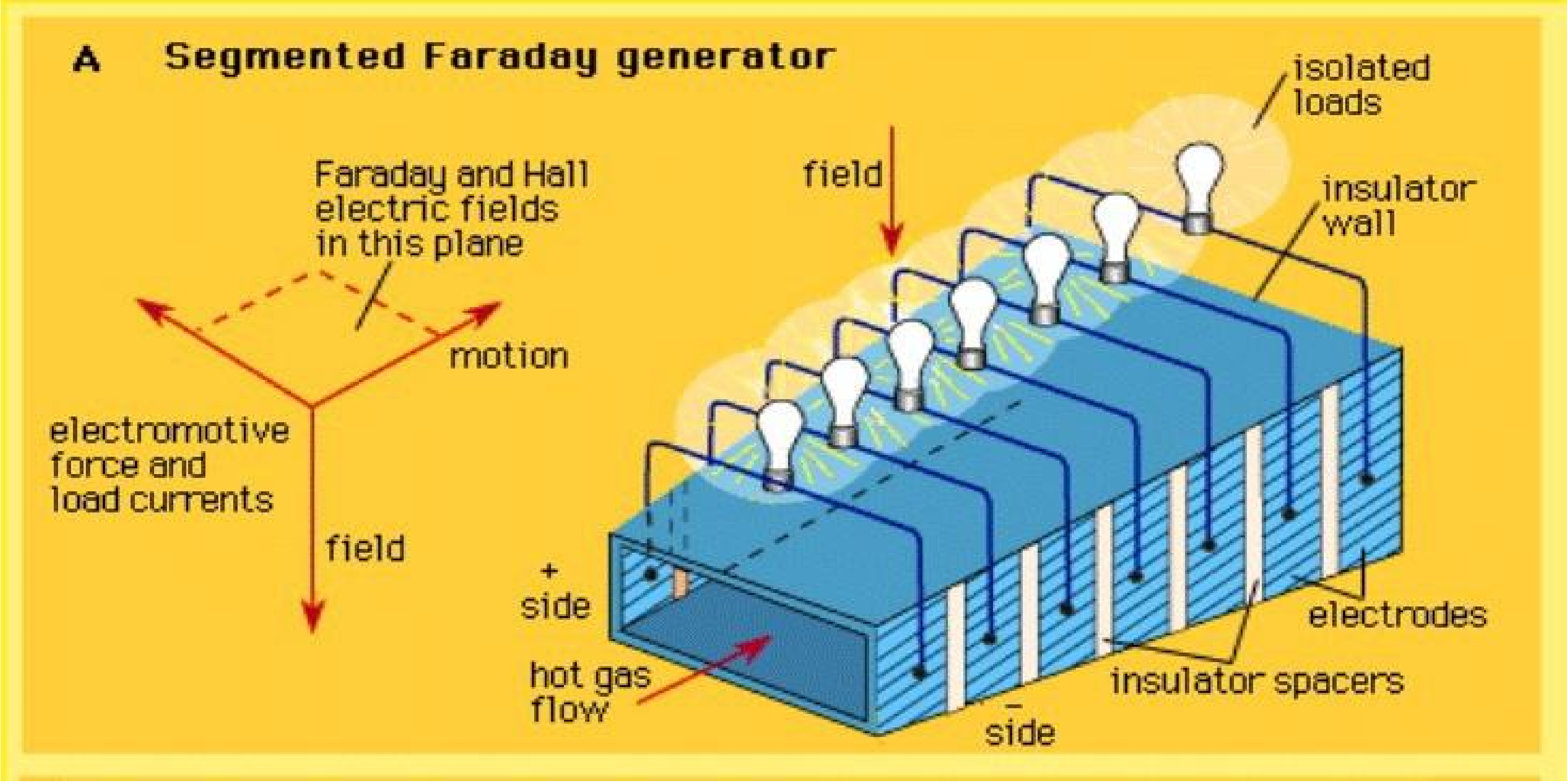
PRINCIPLES OF MHD POWER GENERATION

- This effect is a result of FARADAYS LAWS OF ELECTRO MAGNETIC INDUCTION.
- The induced EMF is given by
  Eind = u x B
  where u = velocity of the conductor.
  B = magnetic field intensity.
- The induced current is given by,
  Jind = C x Eind
  where C = electric conductivity
- The retarding force on the conductor is the Lorentz force given by
  Find = Jind X B

PRINCIPLES OF MHD POWER GENERATION

- The electro magnetic induction principle is not limited to solid conductors. The movement of a conducting fluid through a magnetic field can also generate electrical energy.
- When a fluid is used for the energy conversion technique, it is called MAGNETO HYDRO DYNAMIC (MHD), energy conversion.
- The flow direction is right angles to the magnetic fields direction. An electromotive force (or electric voltage) is induced in the direction at right angles to both flow and field directions, as shown in the next slide.

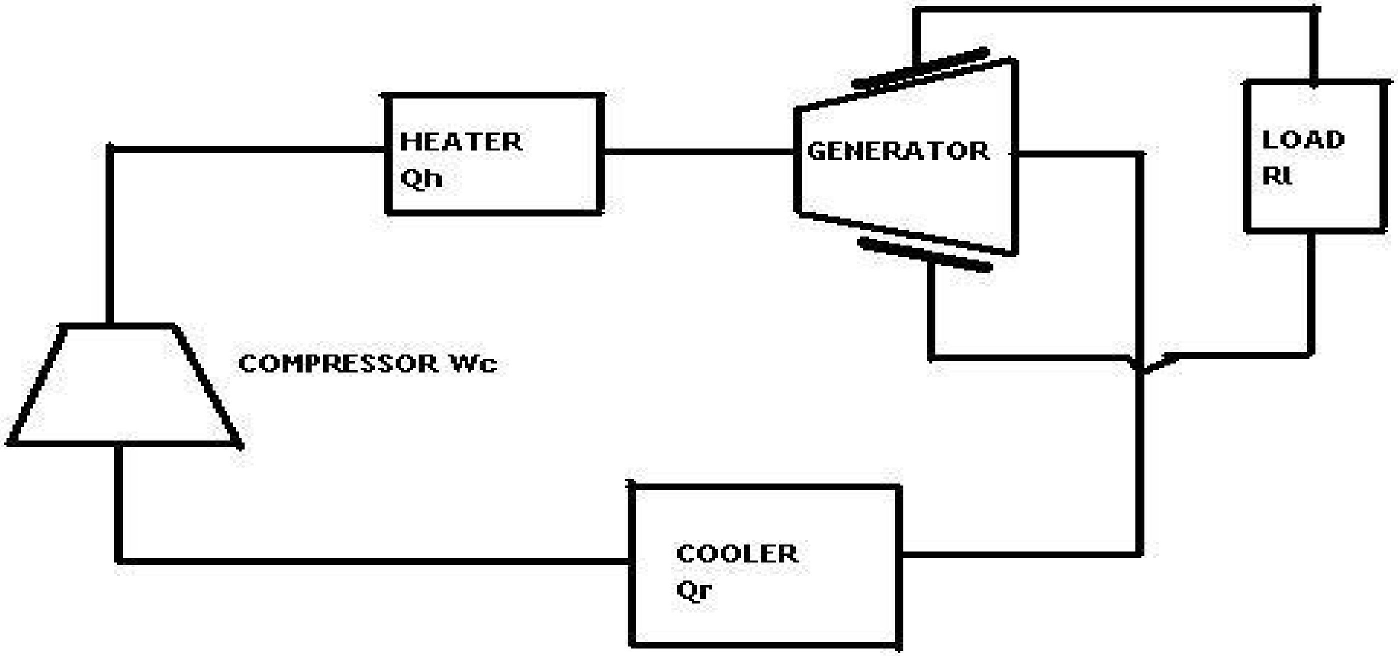
PRINCIPLES OF MHD POWER GENERATION



PRINCIPLES OF MHD POWER GENERATION

- The conducting flow fluid is forced between the plates with a kinetic energy and pressure differential sufficient to over come the magnetic induction force Find.
- The end view drawing illustrates the construction of the flow channel.
- An ionized gas is employed as the conducting fluid.
- Ionization is produced either by thermal means I.e. by an elevated temperature or by seeding with substance like cesium or potassium vapors which ionizes at relatively low temperatures.
- The atoms of seed element split off electrons. The presence of the negatively charged electrons makes the gas an electrical conductor.

PRINCIPLES OF MHD POWER GENERATION



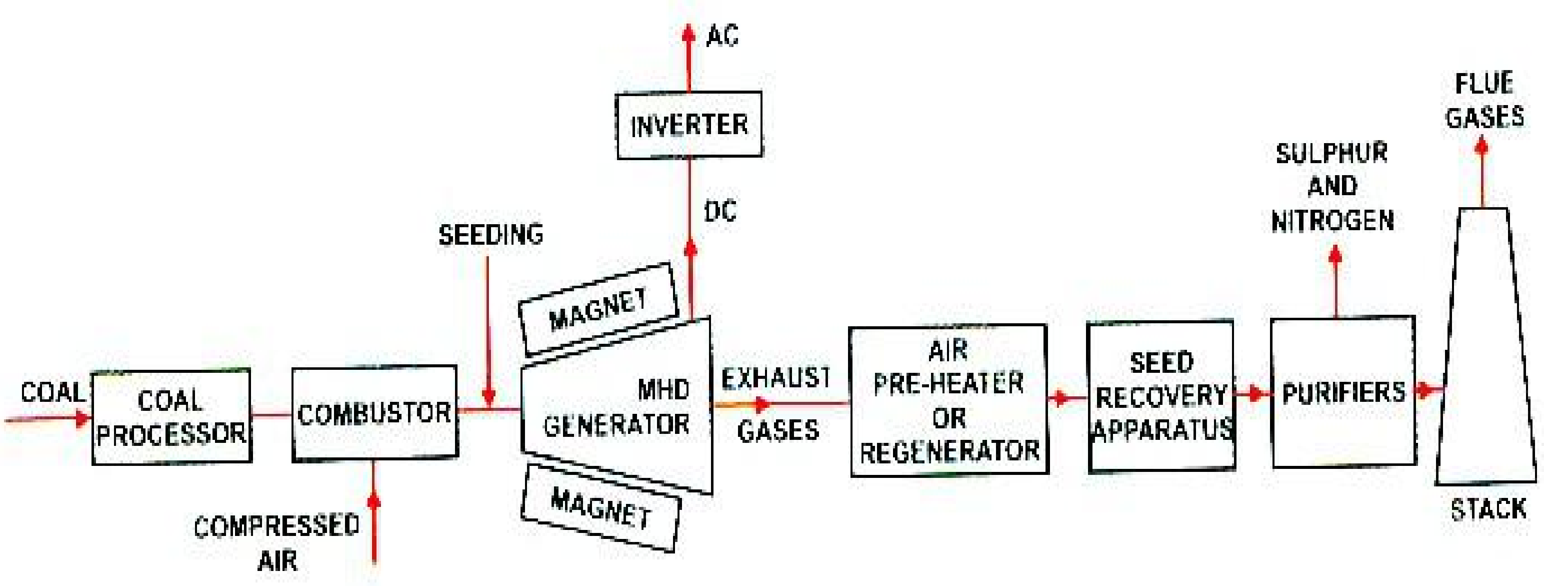
VARIOUS MHD SYSTEMS

- The MHD systems are broadly classified into two types.
- OPEN CYCLE SYSTEM
- CLOSED CYCLE SYSTEM
  - Seeded inert gas system
  - Liquid metal system

OPEN CYCLE SYSTEM

- The fuel used maybe oil through an oil tank or gasified coal through a coal gasification plant
- The fuel (coal, oil or natural gas) is burnt in the combustor or combustion chamber.
- The hot gases from combustor is then seeded with a small amount of ionized alkali metal (cesium or potassium) to increase the electrical conductivity of the gas.
- The seed material, generally potassium carbonate is injected into the combustion chamber, the potassium is then ionized by the hot combustion gases at temperature of roughly 2300’ c to 2700’c.

OPEN CYCLE SYSTEM



OPEN CYCLE SYSTEM

- To attain such high temperatures, the compressed air is used to burn the coal in the combustion chamber, must be adequate to at least 1100’c. A lower preheat temperature would be adequate if the air is enriched in oxygen. An alternative is used to compress oxygen alone for combustion of fuel, little or no preheating is then required. The additional cost of oxygen might be balanced by saving on the preheater.
- The hot pressurized working fluid living in the combustor flows through a convergent divergent nozzle. In passing through the nozzle, the random motion energy of the molecules in the hot gas is largely converted into directed, mass of energy. Thus , the gas emerges from the nozzle and enters the MHD generator unit at a high velocity.

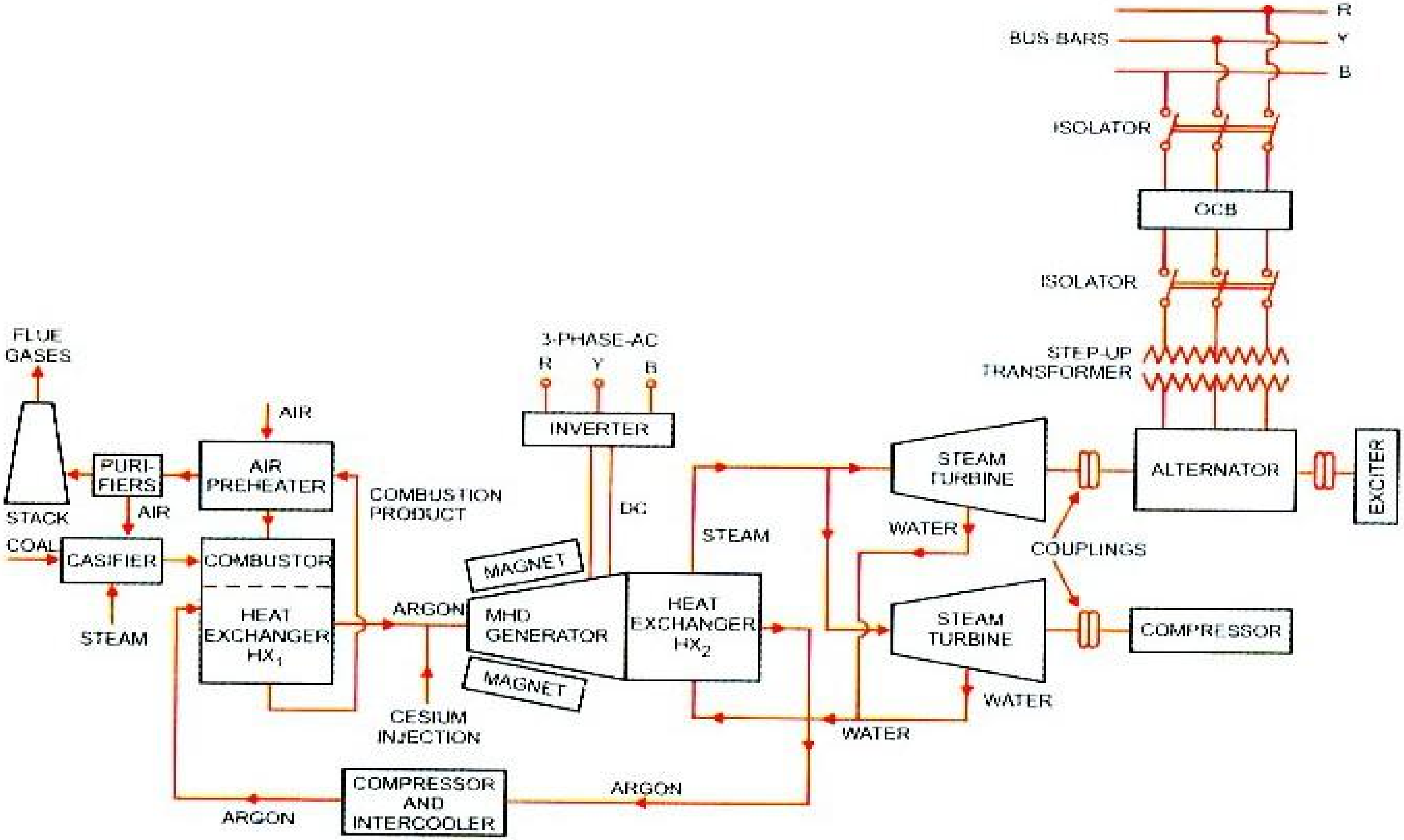
OPEN CYCLE SYSTEM

- The MHD generator is a divergent channel made of a heat resistant alloy with external water cooling. The hot gas expands through the rocket like generator surrounded by powerful magnet. During motion of the gas the +ve and –ve ions move to the electrodes and constitute an electric current.
- The arrangement of the electrode connection is determined by the need to reduce the losses arising from the Hall effect. By this effect, the magnetic field acts on the MHD-generated current and produces a voltage in flow direction of the working fluid.

CLOSED CYCLE SYSTEM

- Two general types of closed cycle MHD generators are being investigated.
- Electrical conductivity is maintained in the working fluid by ionization of a seeded material, as in open cycle system.
- A liquid metal provides the conductivity.
- The carrier is usually a chemical inert gas, all through a liquid carrier is been used with a liquid metal conductor. The working fluid is circulated in a closed loop and is heated by the combustion gases using a heat exchanger. Hence the heat sources and the working fluid are independent. The working fluid is helium or argon with cesium seeding.

SEEDED INERT GAS SYSTEM



SEEDED INERT GAS SYSTEM

- In a closed cycle system the carrier gas operates in the form of Brayton cycle. In a closed cycle system the gas is compressed and heat is supplied by the source, at essentially constant pressure, the compressed gas then expands in the MHD generator, and its pressure and temperature fall. After leaving this generator heat is removed from the gas by a cooler, this is the heat rejection stage of the cycle. Finally the gas is recompressed and returned for reheating.
- The complete system has three distinct but interlocking loops. On the left is the external heating loop. Coal is gasified and the gas is burnt in the combustor to provide heat. In the primary heat exchanger, this heat is transferred to a carrier gas argon or helium of the MHD cycle. The combustion products after passing through the air preheated and purifier are discharged to atmosphere.

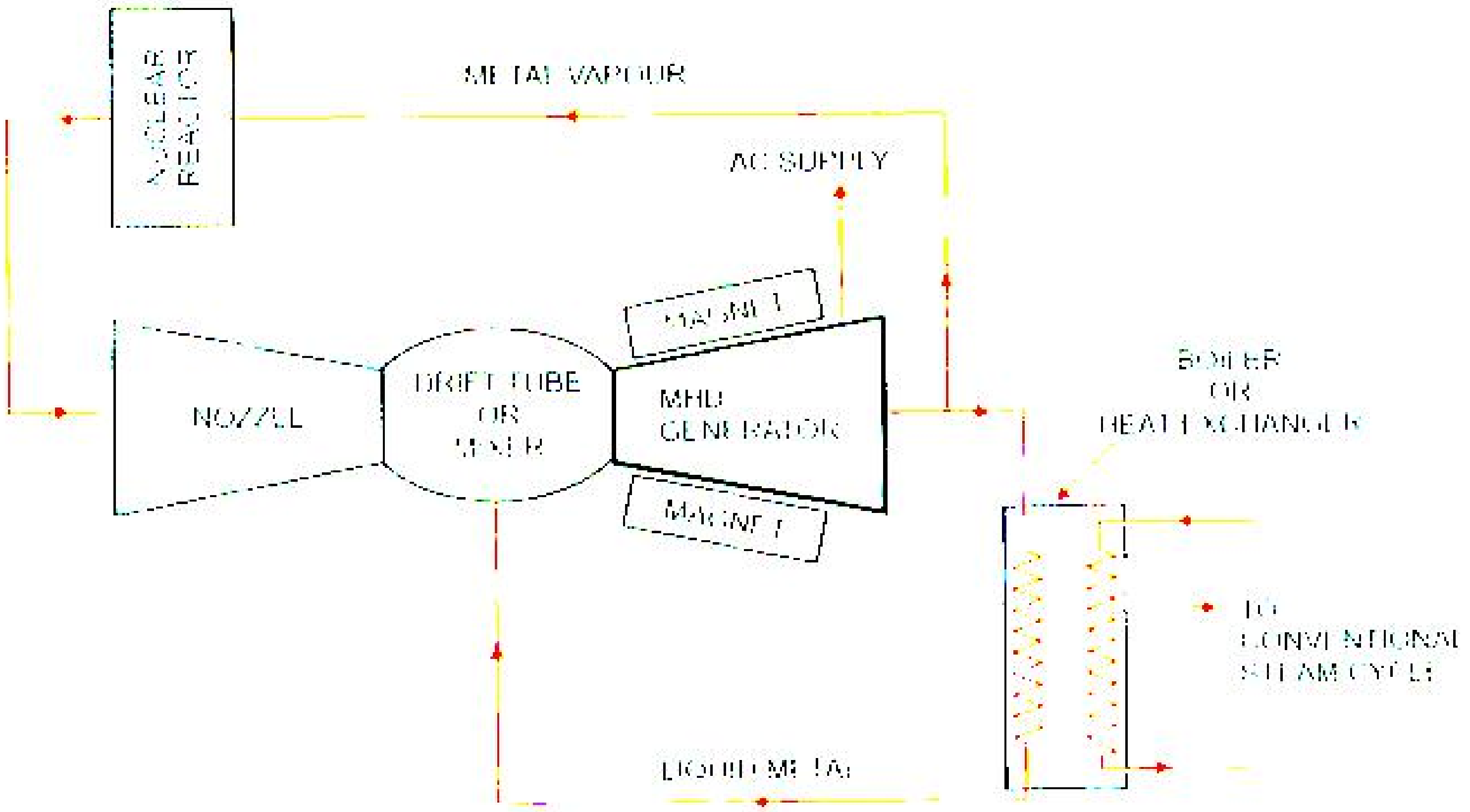
SEEDED INERT GAS SYSTEM

- Because the combustion system is separate from the working fluid, so also are the ash and flue gases. Hence the problem of extracting the seed material from fly ash does not arise. The fuel gases are used to preheat the incoming combustion air and then treated for fly ash and sulfur dioxide removal, if necessary prior to discharge through a stack to the atmosphere.
- The loop in the center is the MHD loop. The hot argon gas is seeding with cesium and resulting working fluid is passed through the MHD generator at high speed. The dc power out of MHD generator is converted in ac by the inverter and is then fed to the grid.

LIQUID METAL SYSTEM

- When a liquid metal provides the electrical conductivity, it is called a liquid metal MHD system.
- An inert gas is a convenient carrier
- The carrier gas is pressurized and heated by passage through a heat exchanger within combustion chamber. The hot gas is then incorporated into the liquid metal usually hot sodium to form the working fluid. The latter then consists of gas bubbles uniformly dispersed in an approximately equal volume of liquid sodium.
- The working fluid is introduced into the MHD generator through a nozzle in the usual ways. The carrier gas then provides the required high direct velocity of the electrical conductor.

LIQUID METAL SYSTEM



LIQUID METAL SYSTEM

- After passage through the generator, the liquid metal is separated from the carrier gas. Part of the heat exchanger to produce steam for operating a turbine generator. Finally the carrier gas is cooled, compressed and returned to the combustion chamber for reheating and mixing with the recovered liquid metal. The working fluid temperature is usually around 800’c as the boiling point of sodium even under moderate pressure is below 900’c.
- At lower operating temp, the other MHD conversion systems may be advantageous from the material standpoint, but the maximum thermal efficiency is lower. A possible compromise might be to use liquid lithium, with a boiling point near 1300’c as the electrical conductor lithium is much more expensive than sodium, but losses in a closed system are less.

ADVANTAGES

- The conversion efficiency of a MHD system can be around 50% much higher compared to the most efficient steam plants. Still higher efficiencies are expected in future, around 60 – 65 %, with the improvements in experience and technology.
- Large amount of power is generated.
- It has no moving parts, so more reliable.
- The closed cycle system produces power, free of pollution.
- It has ability to reach the full power level as soon as started.
- The size if the plant is considerably smaller than conventional fossil fuel plants.

ADVANTAGES

- Although the cost cannot be predicted very accurately, yet it has been reported that capital costs of MHD plants will be competitive to conventional steam plants.
- It has been estimated that the overall operational costs in a plant would be about 20% less than conventional steam plants.
- Direct conversion of heat into electricity permits to eliminate the turbine (compared with a gas turbine power plant) or both the boiler and the turbine (compared with a steam power plant) elimination reduces losses of energy.
- These systems permit better fuel utilization. The reduced fuel consumption would offer additional economic and special benefits and would also lead to conservation of energy resources.
- It is possible to use MHD for peak power generations and emergency service. It has been estimated that MHD equipment for such duties is simpler, has capability of generating in large units and has the ability to make rapid start to full load.

Assignment

Q 1. what is MHD power plant ? Explain principle of MHD power generation.

Q2. Explain open cycle MHD system.

Q 3. Explain closed cycle MHD system.

Q 4. Explain liquid metal MHD system.

Q 5. Write advantages of MHD power plant.

Q 6. Explain seeded inert gas MHD system.

OTEC
(Ocean Thermal Energy Conversion)

OTEC (Ocean Thermal Energy Conversion)

Ocean thermal energy conversion (OTEC) generates electricity indirectly from solar energy by harnessing the temperature difference between the sun-warmed surface of tropical oceans and the colder deep waters.

A significant fraction of solar radiation incident on the ocean is retained by seawater in tropical regions, resulting in average year-round surface temperatures of about 28 C.

Deep, cold water, meanwhile, forms at higher latitudes and descends to flow along the seafloor toward the equator. The warm surface layer, which extends to depths of about 100-200m, is separated from the deep cold water by a thermocline. The temperature difference, ƛ*T, between the surface and thousand-meter depth* ranges from 10 to 25 C, with larger differences occurring in equatorial and tropical waters.

OTEC (Ocean Thermal Energy Conversion)

ƛT establishes the limits of the performance of OTEC power cycles; the rule–of thumb is that a differential of about 20 C is necessary to sustain viable operation of an OTEC facility.

Since OTEC exploits renewable solar energy, recurring costs to generate electrical power are minimal. However, the fixed or capital costs of OTEC systems per kilowatt of generating capacity are very high because large pipelines and heat exchangers are needed to produce relatively modest amounts of electricity.

These high fixed costs dominate the economics of OTEC to the extent that it currently cannot compete with conventional power systems, except in limited niche markets.

State of the Technology

OTEC power systems operate as cyclic heat engines.

They receive thermal energy through heat transfer from surface sea water warmed by the sun, and transform a portion of this energy to electrical power.

The Second Law of Thermodynamics precludes the complete conversion of thermal energy in to electricity. A portion of the heat extracted from the warm sea water must be rejected to a colder thermal sink. The thermal sink employed by OTEC systems is sea water drawn from the ocean depths by means of a submerged pipeline.

A steady-state control volume energy analysis yields the result that net electrical power produced by the engine must equal the difference between the rates of heat transfer from the warm surface water and to the cold deep water. The limiting (i.e., maximum) theoretical Carnot energy conversion efficiency of a cyclic heat engine scales with the difference between the temperatures at which these heat transfers occur.

State of the Technology

For OTEC, this difference is determined by ƛ*T and is* very small; hence, OTEC efficiency is low. Although viable OTEC systems are characterized by Carnot efficiencies in the range of 6–8%, state-of-the-art combustion steam power cycles, which tap much higher temperature energy sources, are theoretically capable of converting more than 60% of the extracted thermal energy into electricity.

The low energy conversion efficiency of OTEC means that more than 90% of the thermal energy extracted from the ocean’s surface is ‘wasted’ and must be rejected to the cold, deep sea water.

This necessitates large heat exchangers and seawater flow rates to produce relatively small amounts of electricity. In spite of its inherent inefficiency, OTEC, unlike conventional fossil energy systems, utilizes a renewable resource and poses minimal threat to the environment.

State of the Technology

In fact, it has been suggested that widespread adoption of OTEC could yield tangible environmental benefits through avenues such as reduction of greenhouse gas CO_2 emissions; enhanced uptake of atmospheric CO_2 by marine organism populations sustained by the nutrient-rich, deep OTEC sea water; and preservation of corals and hurricane amelioration by limiting temperature rise in the surface ocean through energy extraction and artificial upwelling of deep water.

Carnot efficiency applies only to an ideal heat engine. In real power generation systems, irreversibilities will further degrade performance. Given its low theoretical efficiency, successful implementation of OTEC power generation demands careful engineering to minimize irreversibilities. Although OTEC consumes what is essentially a free resource, poor thermodynamic performance will reduce the quantity of electricity available for sale and, hence, negatively affect

Closed Cycle OTEC

D’Arsonval’s original concept employed a pure working fluid that would evaporate at the temperature of warm sea water. The vapor would subsequently expand and do work before being condensed by the cold sea water. This series of steps would be repeated continuously with the same working fluid, whose flow path and thermodynamic process representation constituted closed loops } hence, the name ‘closed cycle.’

The specific process adopted for closed cycle OTEC is the Rankine, or vapor power, cycle. The principal components are the heat exchangers, turbogenerator, and seawater supply system, which, although not shown, accounts for most of the parasitic power consumption and a significant fraction of the capital expense. Also not included are ancillary devices such as separators to remove residual liquid downstream of the evaporator and subsystems to hold and supply working fluid lost through leaks or contamination.

Closed Cycle OTEC

In this system, heat transfer from warm surface sea water occurs in the evaporator, producing a saturated vapor from the working fluid.

Electricity is generated when this gas expands to lower pressure through the turbine. Latent heat is transferred from the vapor to the cold sea water in the condenser and the resulting liquid is pressurized with a pump to repeat the cycle.

The success of the Rankine cycle is a consequence of more energy being recovered when the vapor expands through the turbine than is consumed in re-pressurizing the liquid. In conventional (e.g.,combustion) Rankine systems, this yields net electrical power.

For OTEC, however, the remaining balance may be reduced substantially by an amount needed to pump large volumes of sea water through the heat exchangers. (One misconception about OTEC is that tremendous energy must be expended to bring cold sea water up from depths approaching 1000 meters. In reality, the natural hydrostatic pressure gradient provides for most of the increase inthe gravitational potential energy of a fluid particle moving with the gradient from the ocean depths to the surface.)

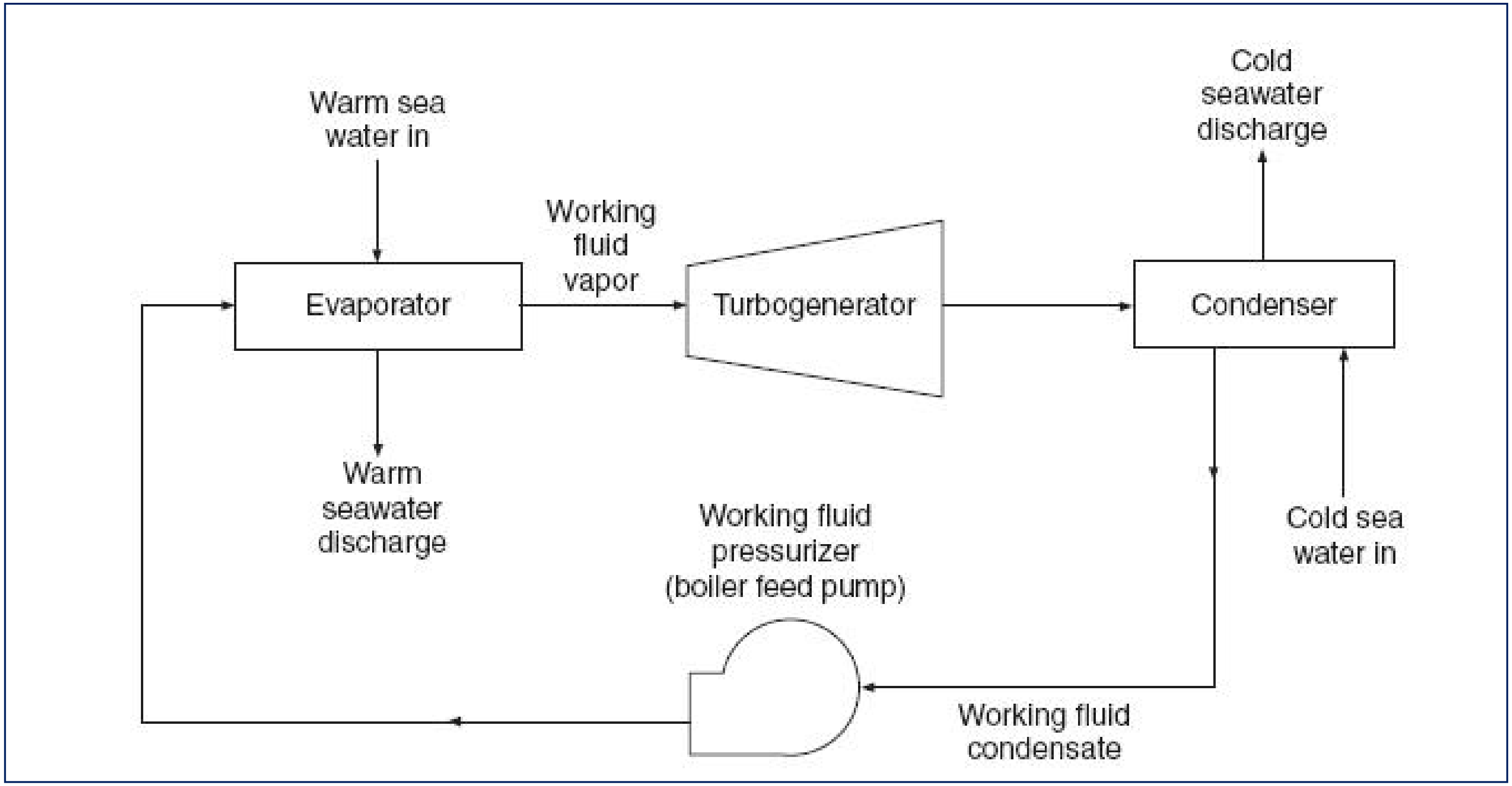
Closed Cycle OTEC

Irreversibilities in the turbomachinery and heat exchangers reduce cycle efficiency below the Carnot value. Irreversibilities in the heat exchangers occur when energy is transferred over a large temperature difference. It is important, therefore, to select a working fluid that will undergo the desired phase changes at temperatures established by the surface and deep sea water. Insofar as a large number of substances can meet this requirement (because pressures and the pressure ratio across the turbine variations are viable alternatives. and pump are design parameters), other factors must be considered in the selection of a working fluid including: cost and availability, compatibility with system materials, toxicity, and environmental hazard. Leading candidate working fluids for closed cycle OTEC applications are ammonia and various fluorocarbon refrigerants. Their primary disadvantage is the environmental hazard posed by leakage;

Closed Cycle OTEC

ammonia is toxic in moderate concentrations and certain fluorocarbons have been banned by the Montreal Protocol because they deplete stratospheric ozone. The Kalina, or adjustable proportion fluid mixture (APFM), cycle is a variant of the OTEC closed cycle. Whereas simple closed cycle OTEC systems use a pure working fluid, the Kalina cycle proposes to employ a mixture of ammonia and water with varying proportions at different points in the system. The advantage of a binary mixture is that, at a given pressure, evaporation or condensation occurs over a range of temperatures; a pure fluid, on the other hand, changes phase at constant temperature This additional degree of freedom allows heat transfer-related irreversibilities in the evaporator and condenser to be reduced Although it improves efficiency, the Kalina cycle needs additional capital equipment and may impose severe demands on the evaporator and condenser. The efficiency improvement will require some combination of higher heat transfer coefficients, more heat transfer surface area, and increased seawater flow rates. Each has an associated cost or power penalty. Additional analysis and testing are required to confirm whether the Kalina cycle and assorted

Closed Cycle OTEC



Open Cycle OTEC

Open Cycle OTEC Claude’s concern about the cost and potential biofoulingof closed cycle heat exchangers led him to propose using steam generated directly from the warm sea water as the OTEC working fluid. The steps of the Claude, or open, cycle are: (1) flash evaporation of warm sea water in a partial vacuum; (2) expansion of the steam through a turbine to generate power; (3) condensation of the vapor by direct contact heat transfer to cold sea water; and (4) compression and discharge of the condensate and any residual noncondensable gases. Unless fresh water is a desired by-product, open cycle OTEC eliminates the need for surface heat exchangers. The name ‘open cycle’ comes from the fact that the working fluid (steam) is discharged after a single pass and has different initial and final thermodynamic states; hence, the flow path and process are ‘open.’ The entire system, from evaporator to condenser, operates at partial vacuum, typically at pressures of 1}3% of atmospheric.

Open Cycle OTEC

Initial evacuation of the system and removal of non-condensable gases during operation are performed by the vacuum compressor, which, along with the sea water and discharge pumps, accounts for the bulk of the open cycle OTEC parasitic power consumption.

The low system pressures of open cycle OTEC are necessary to induce boiling of the warm sea water. Flash evaporation is accomplished by exposing the sea water to pressures below the saturation pressure corresponding to its temperature. This is usually accomplished by pumping it into an evacuated chamber through spouts designed to maximize heat and mass transfer surface area. Removal of gases dissolved in the sea water, which will come out of solution in the low-pressure evaporator and compromise operation, may be performed at an intermediate pressure prior to evaporation.Vapor produced in the Sash evaporator is relativelypure steam. The heat of vaporization is extracted from the liquid phase, lowering its temperature and preventing any further boiling. Flash evaporation may be perceived, then, as a transfer of thermal energy from the bulk of the warm sea water of the small fraction of mass that is vaporized. Less than 0.5% of the mass of warm sea water entering the evaporator is converted into steam.

Open Cycle OTEC

The pressure drop across the turbine is established by the cold seawater temperature. At 43C, steam condenses at 813 Pa. The turbine (or turbine diffuser) exit pressure cannot fall below this value. Hence, the maximum turbine pressure drop is only about 3000Pa, corresponding to about a 3:1 pressure ratio. This will be further reduced to account for other pressure drops along the steam path and differences in the temperatures of the steam and seawater streams needed to facilitate heat transfer in the evaporator and condenser.

Open Cycle OTEC

Condensation of the low-pressure steam leaving the turbine may employ a direct contact condenser (DCC), in which cold sea water is sprayed over the vapor, or a conventional surface condenser that physically separates the coolant and the condensate. DCCs are inexpensive and have good heat transfer characteristics because they lack a solid thermal boundary between the warm and cool fluids. Surface condensers are expensive and more difficult to maintain than DCCs; however, they produce a marketable freshwater by-product. Effluent from the condenser must be discharged to the environment. Liquids are pressurized to ambient levels at the point of release by means of a pump, or, if the elevation of the condenser is suitably high.

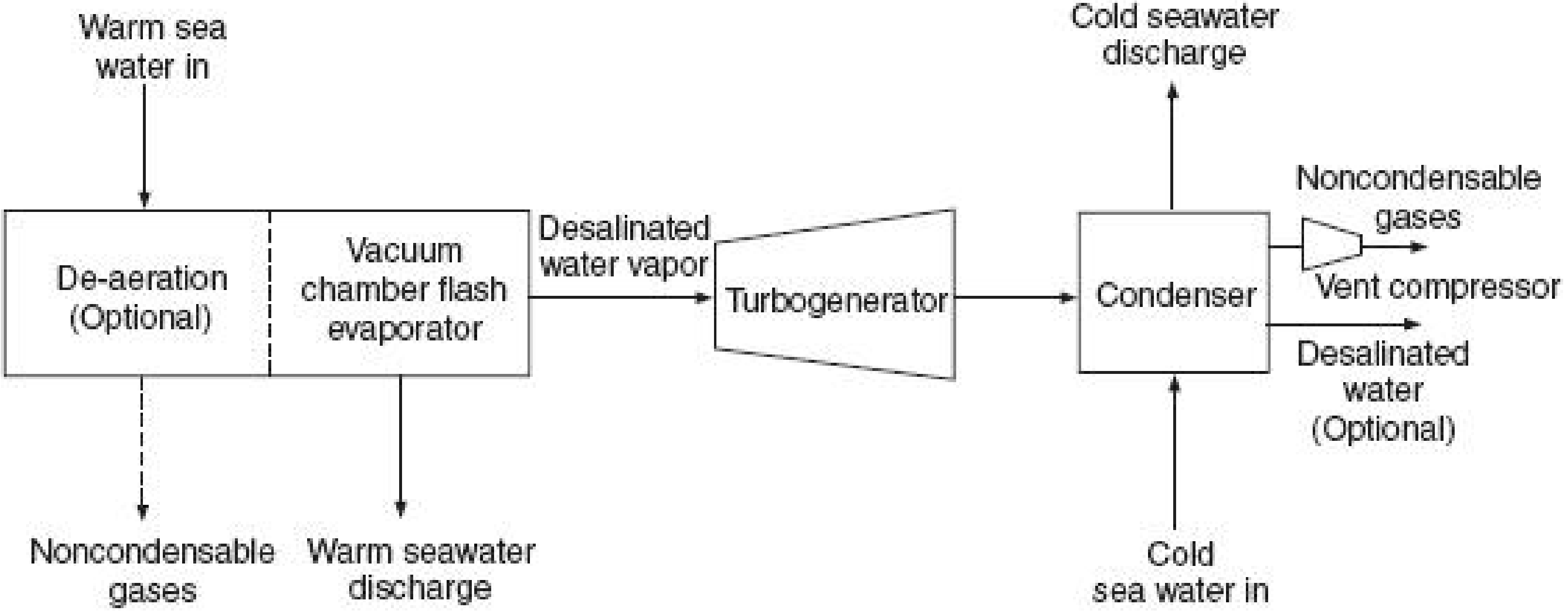
Open Cycle OTEC

can be compressed hydrostatically. As noted previously, noncondensable gases, which include any residual water vapor, dissolved gases that have come out of solution, and air that may have leaked into the system, are removed by the vacuum compressor. Open cycle OTEC eliminates expensive heat exchangers at the cost of low system pressures. Partial vacuum operation has the disadvantage of making the system vulnerable to air in-leakage and promotes the evolution of noncondensable gases dissolved in sea water. Power must ultimately be expended to pressurize and remove these gases. Furthermore, as a consequence of the low steam density, volumetric flow rates are very high per unit of electricity generated. Large components are needed to accommodate these flow rates. In particular, only the largest conventional steam turbine stages have the potential for integration into open cycle OTEC systems of a few megawatts gross generating capacity.

Open Cycle OTEC

It is generally acknowledged that higher capacity plants will require a major turbine development effort. The mist lift and foam lift OTEC systems are variants of the OTEC open cycle. Both employ the sea water directly to produce power. Unlike Claude’s open cycle, lift cycles generate electricity with a hydraulic turbine. The energy expended by the liquid to drive the turbine is recovered from the warm sea water. In the lift process, warm seawater is flash evaporated to produce a two-phase, liquid}vapor mixture } either a mist consisting of liquid droplets suspended in a vapor, or a foam, where vapor bubbles are contained in a continuous liquid phase. The mixture rises, doing work against gravity. Here, the thermal energy of the vapor is expended to increase the potential energy of the fluid. The vapor is then condensed with cold sea water and discharged back into the ocean. Flow of the liquid through the hydraulic turbine may occur before or after the lift process. Advocates of the mist and foam lift cycles contend that they are cheaper to implement than closed cycle OTEC because they require no expensive heat exchangers, and are superior to the Claude cycle because they utilize a hydraulic turbine rather than a low pressure steam turbine. These claims await verification.

Open Cycle OTEC



Hybrid Cycle OTEC

Some marketing studies have suggested that OTEC systems that can provide both electricity and water may be able to penetrate the marketplace more readily than plants dedicated solely to power generation. Hybrid cycle OTEC was conceived as a response to these studies. Hybrid cycles combine the potable water production capabilities of open cycle OTEC with the potential for large electricity generation capacities offered by the closed cycle Several hybrid cycle variants have been proposed. Typically, as in the Claude cycle, warm surface seawater is Sash evaporated in a partial vacuum. This low pressure steam Sows into a heat exchanger where it is employed to vaporize a pressurized, low-boiling-point Suid such as ammonia. During this process, most of the steam condenses, yielding desalinated potable water

Hybrid Cycle OTEC

The ammonia vapor flows through a simple closed-cycle power loop and is condensed using cold sea water. The uncondensed steam and other gases exiting the ammonia evaporator may be further cooled by heat transfer to either the liquid ammonia leaving the ammonia condenser or cold sea water. The non-condensables are then compressed and discharged to the atmosphere. Steam is used as an intermediary heat transfer medium between the warm sea water and the ammonia; consequently, the potential for biofouling in the ammonia evaporator is reduced significantly. Another advantage of the hybrid cycle related to freshwater production is that condensation occurs at significantly higher pressures than in an open cycle OTEC condenser, due to the elimination of the turbine from the steam Sow path.

Hybrid Cycle OTEC

This may, in turn, yield some savings in the amount of power consumed to compress and discharge the non-condensable gases from the system. These savings (relative to a simple Claude cycle producing electricity and water), however, are offset by the additional back work of the closed-cycle ammonia pump. One drawback of the hybrid cycle is that water production and power generation are closely coupled. Changes or problems in either the water or power subsystem will compromise performance of the other. Furthermore, there is a risk that the potable water may be contaminated by an ammonia leak. In response to these concerns, an alternative hybrid cycle has been proposed, comprising decoupled power and water production components.

Hybrid Cycle OTEC

The basis for this concept lies in the fact that warm sea water leaving a closed cycle evaporator is still sufficiently warm, and cold seawater exiting the condenser is sufficiently cold, to sustain an independent freshwater production process. The alternative hybrid cycle consists of a conventional closed-cycle OTEC system that produces electricity and a downstream Sash-evaporation-based

desalination system. Water production and electricity generation can be adjusted independently, and either can operate should a subsystem fail or require servicing. The primary drawbacks are that the ammonia evaporator uses warm seawater directly and is subject to biofouling; and additional equipment, such as the potable water surface condenser, is required, thus increasing capital expenses.

Assignment

Q 1. Explain with a neat diagram close cycle OTEC power plant.

Q 2. Explain with a neat diagram closed cycle OTEC power plant.

Q 3. Explain Hybrid OTEC power plant.

Q 4. Write a short note on OTEC.