MAGNETO HYDRO DYNAMIC POWER GENERATION (MHD)

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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**.

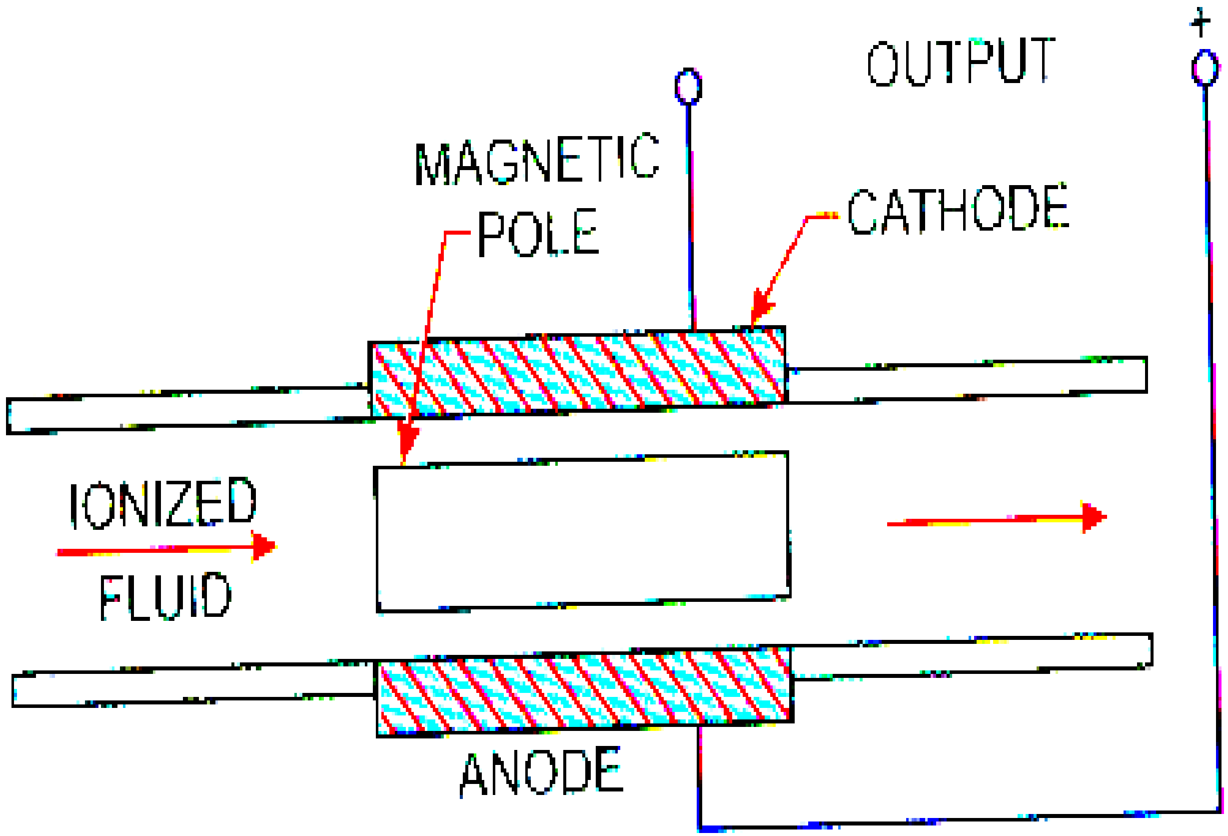
INTRODUCTION

- 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.

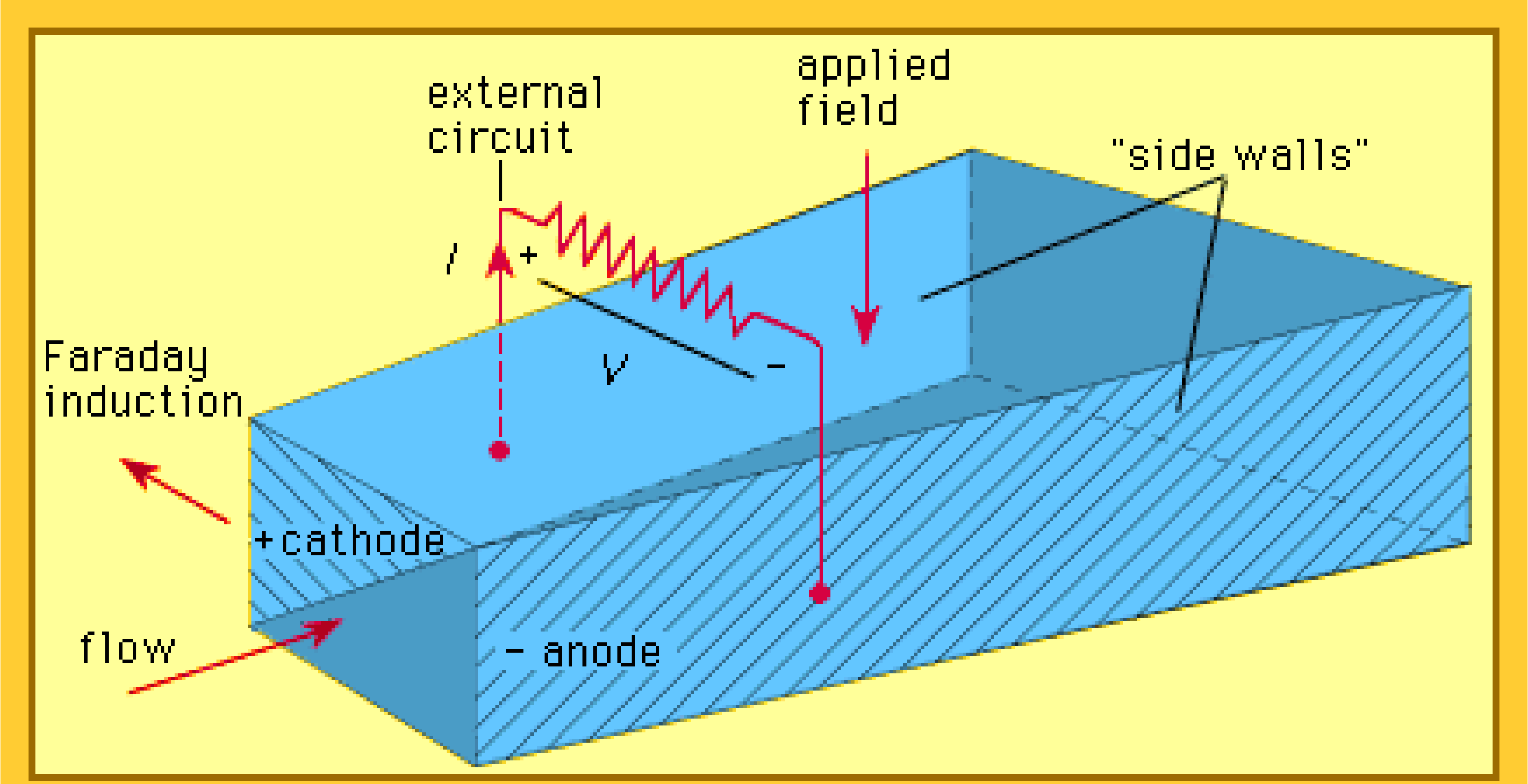
PRINCIPLES OF MHD POWER GENERATION

- 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



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

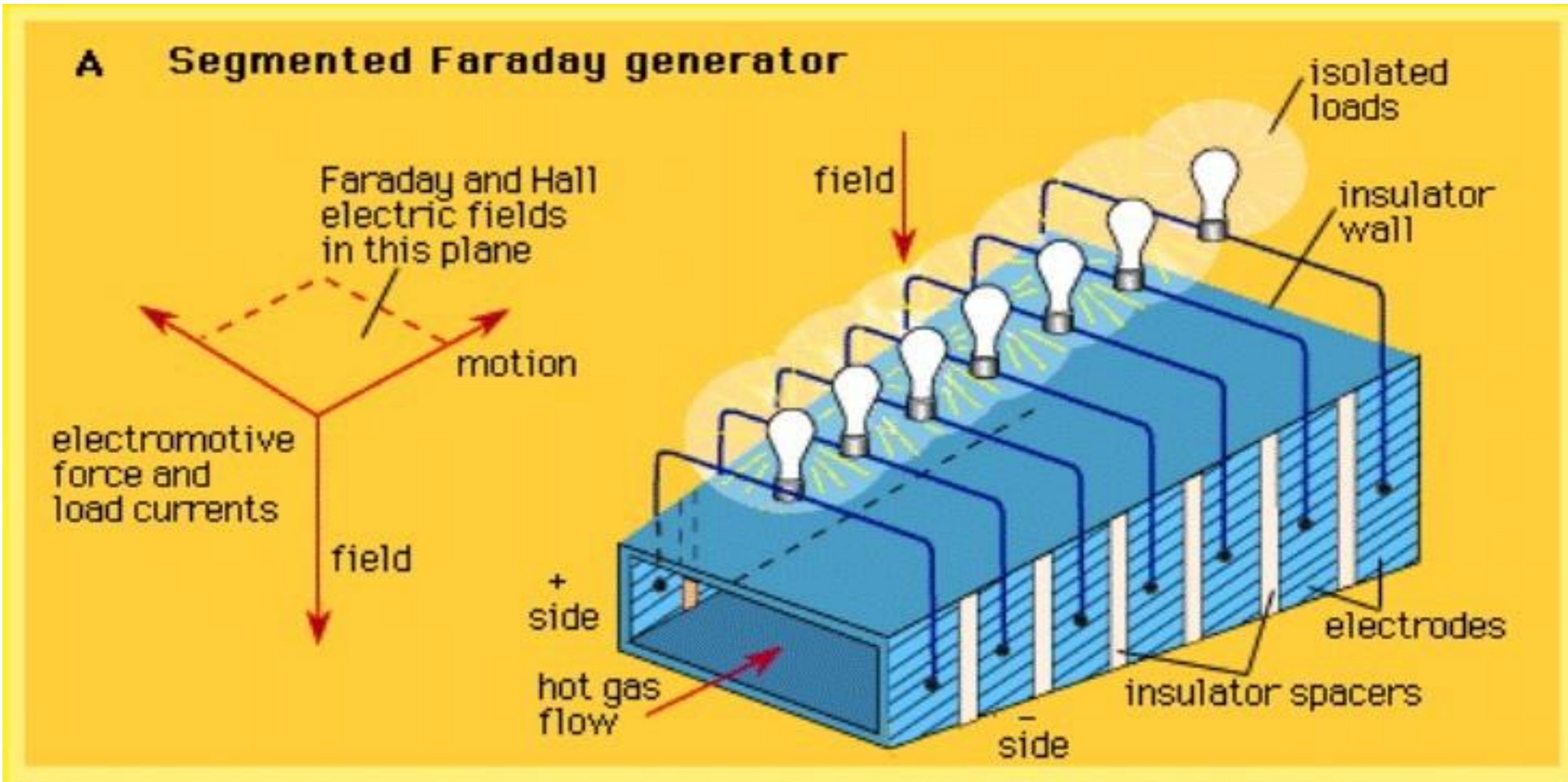
  where C = electric conductivity
- The retarding force on the conductor is the Lorentz force given by

  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.

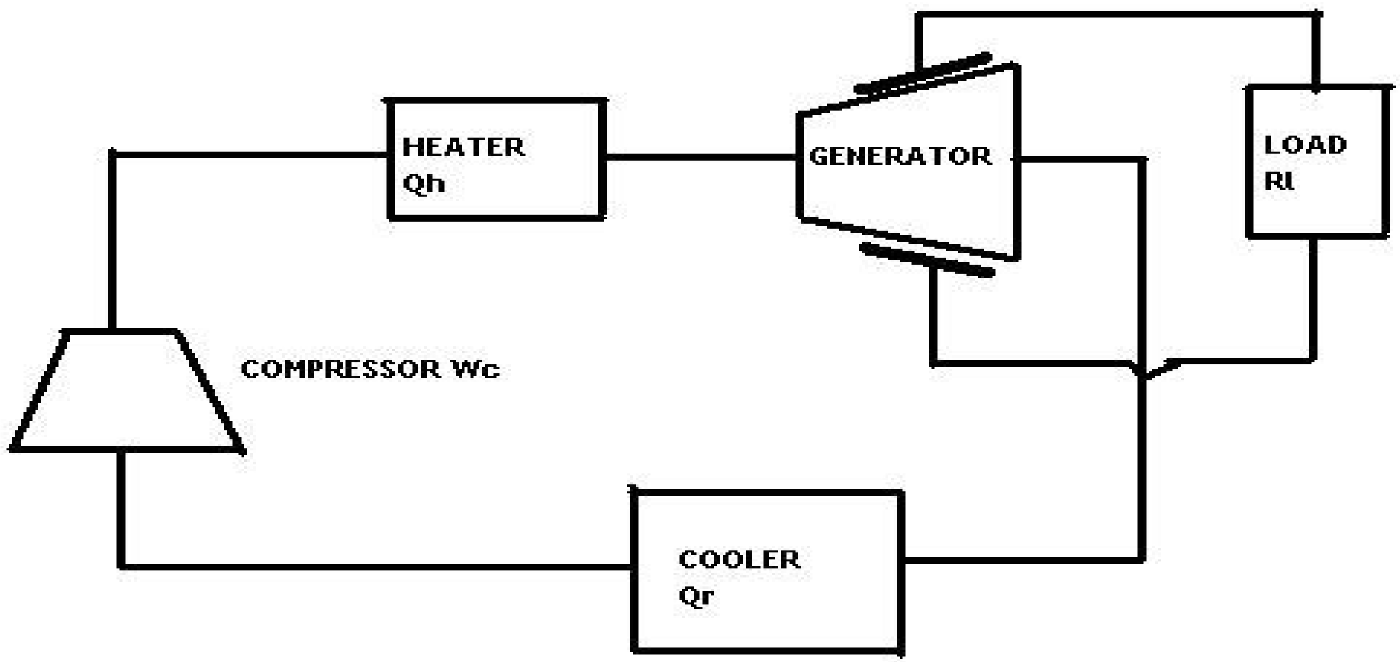
PRINCIPLES OF MHD POWER GENERATION



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



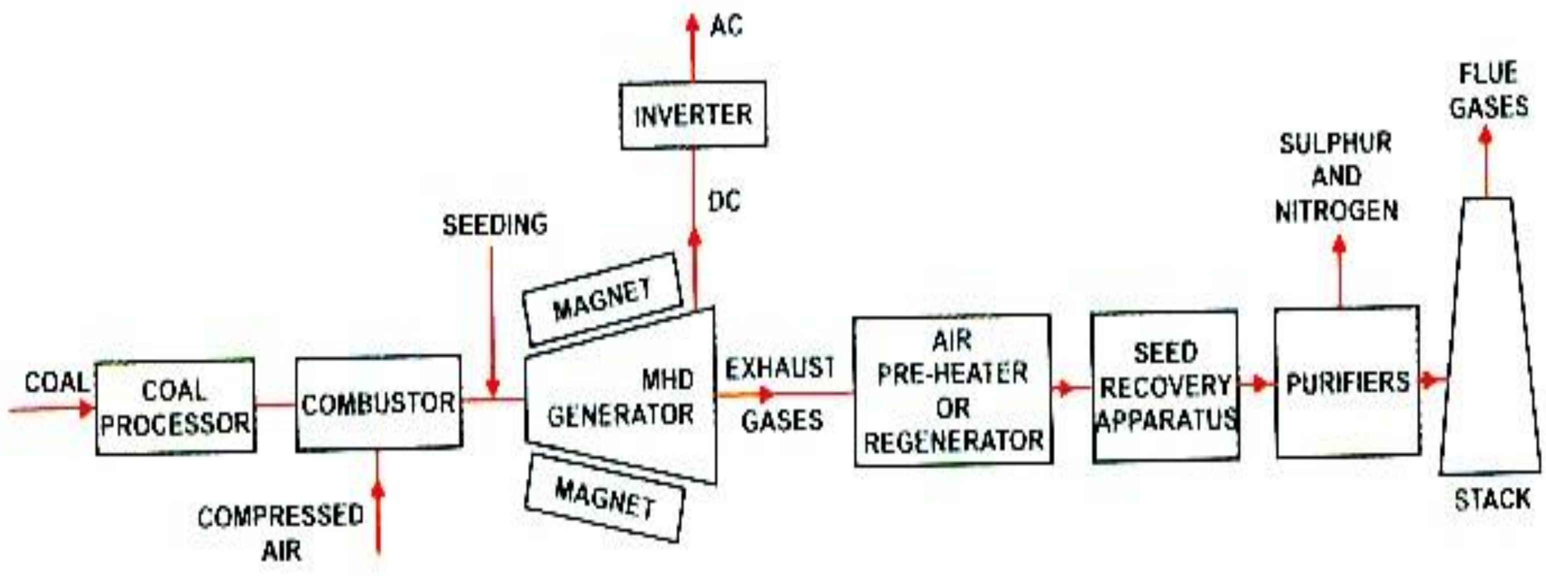
VARIOUS MHD SYSTEMS

- 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

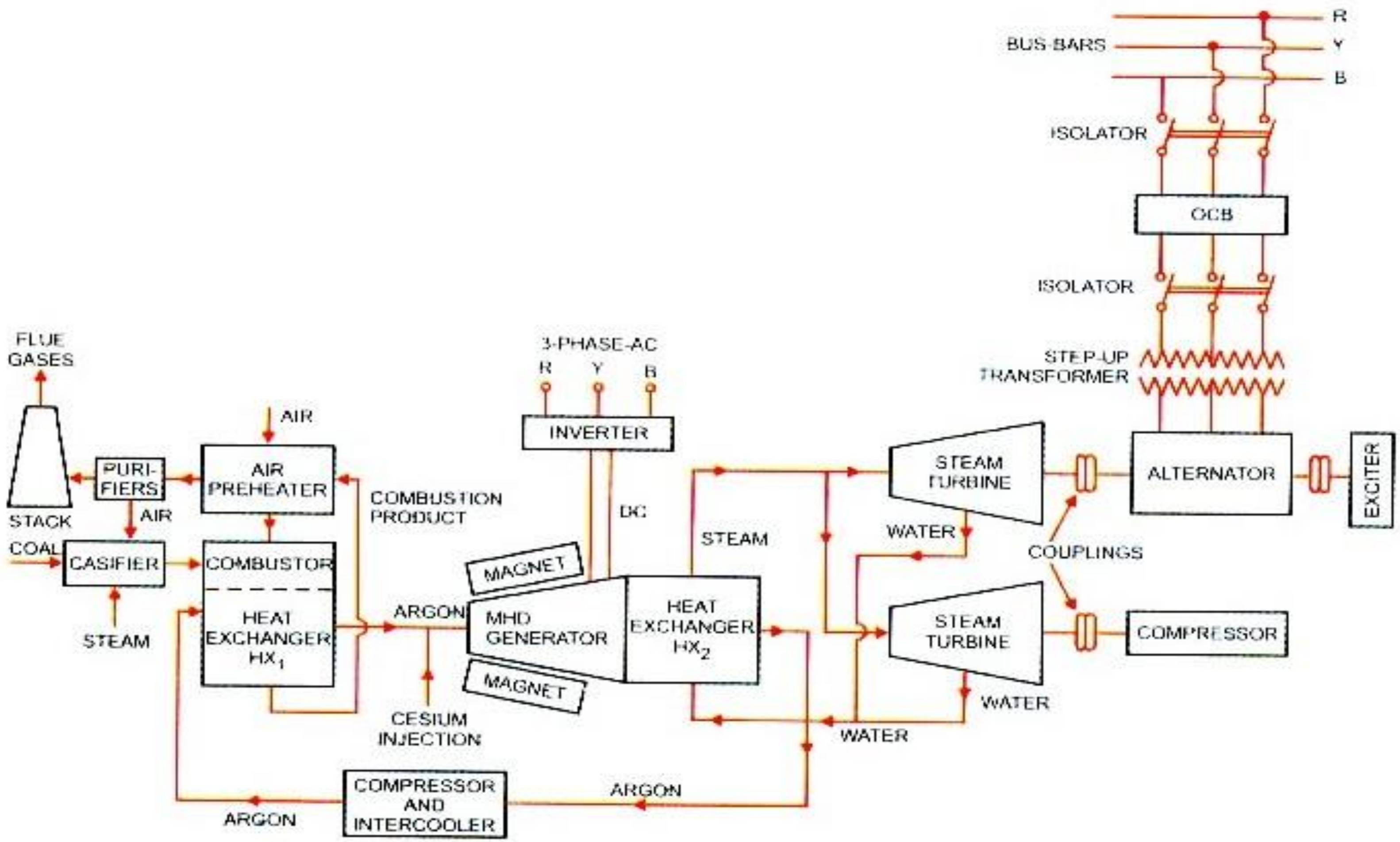
- The MHD generator is a divergent channel made of a heat resistant alloy with external water cooling. The hot gas expands through the rocket like generator surrounded by powerful magnet. During motion of the gas the +ve and –ve ions move to the electrodes and constitute an electric current.

- 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.

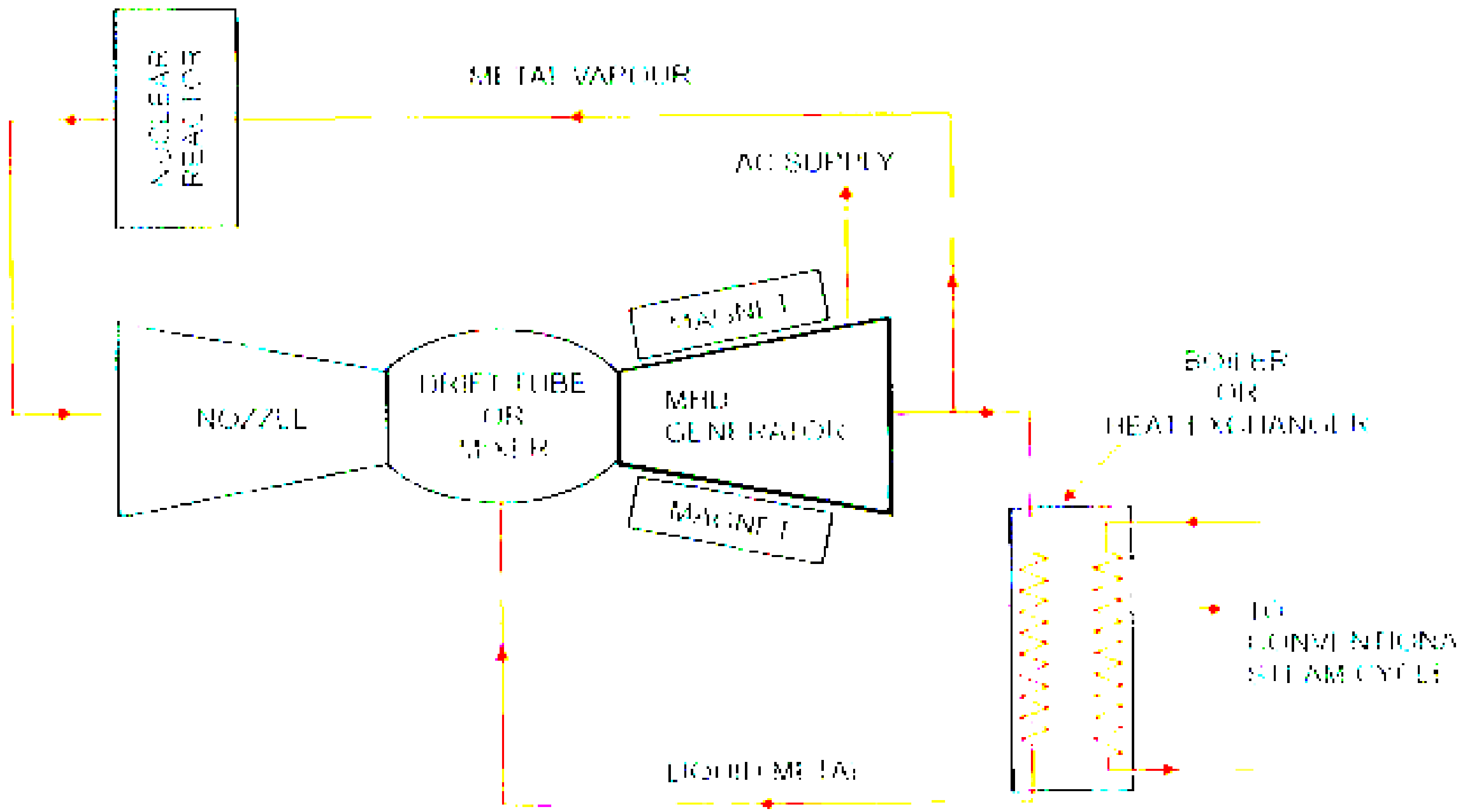
SEEDED INERT GAS SYSTEM

- 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.

Magneto Hydro Dynamic Power Generation

By: Mudit M. Saxena, Dept. of Mech. Engineering

CONTENTS

- INTRODUCTION
- PRINCIPLE
- VARIOUS SYSTEM
- ADVANTAGES
- LIMITATIONS
- PROBLEMS ENCOUNTERED
- CONCLUSION

INTRODUCTION

MHD power generation is a new system of electric power generation which is said to be of high efficiency and low pollution.

As its name implies, Magneto Hydro Dynamics (MHD) 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.

Magnetohydrodynamics (**MHD**) (*magneto fluid dynamics* or *hydromagnetics*) is the studyof the dynamics of electrically conducting fluids.

Examples of such fluids include plasmas, liquidmetals, and salt water orelectrolytes.

The field of MHD was initiated by Hannes Alfven, forwhich

PRINCIPLES OF MHD POWER GENERATION

When an 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 copperstrips.

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 thestream.

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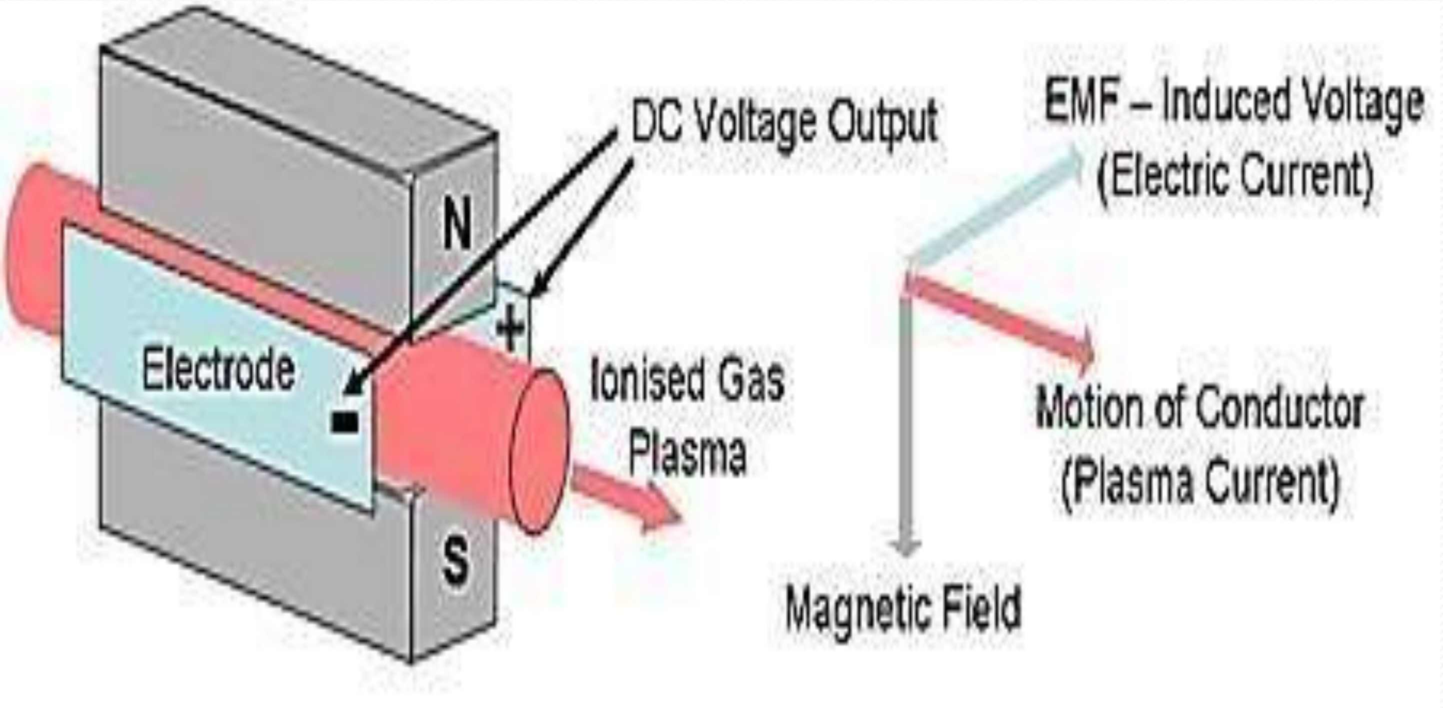
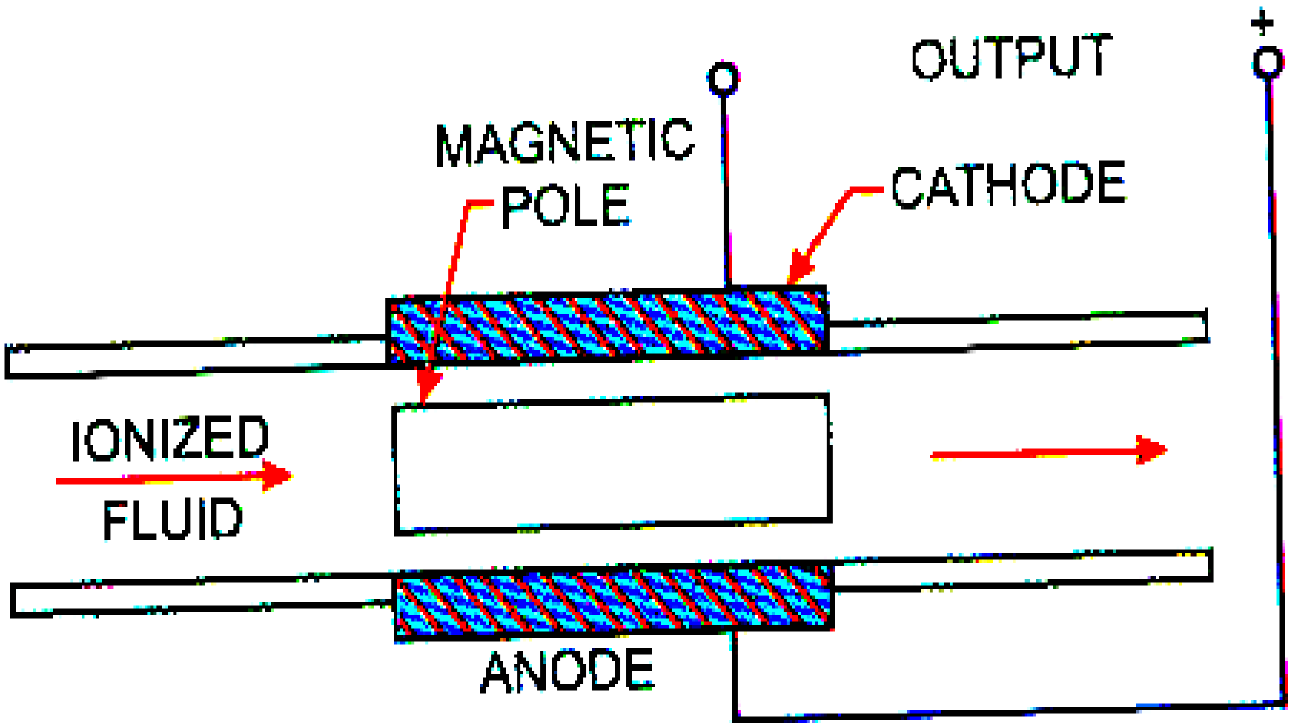


Magnetohydrodynamic Power Generation (Principle)

PRINCIPLES OF MHD POWER GENERATION



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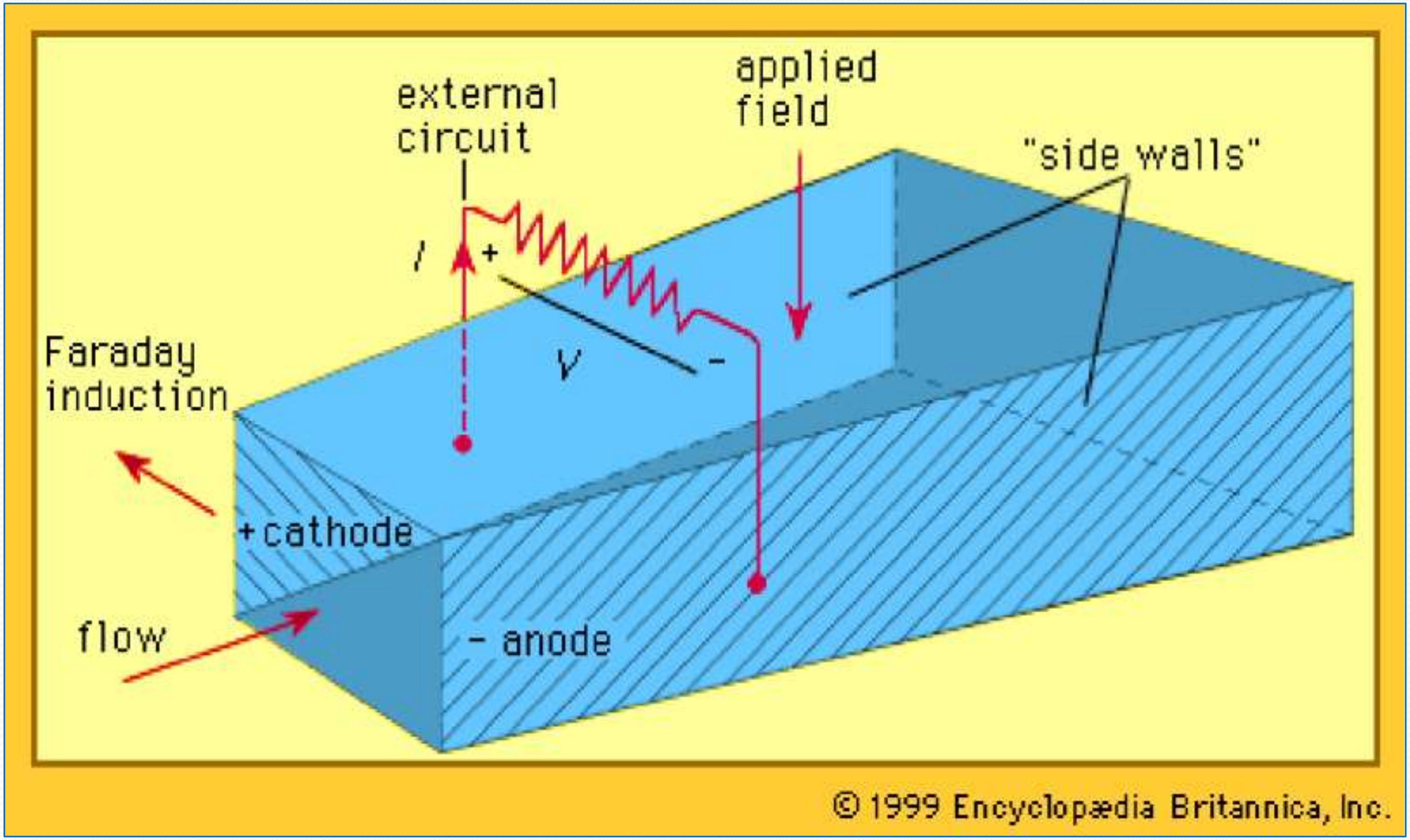

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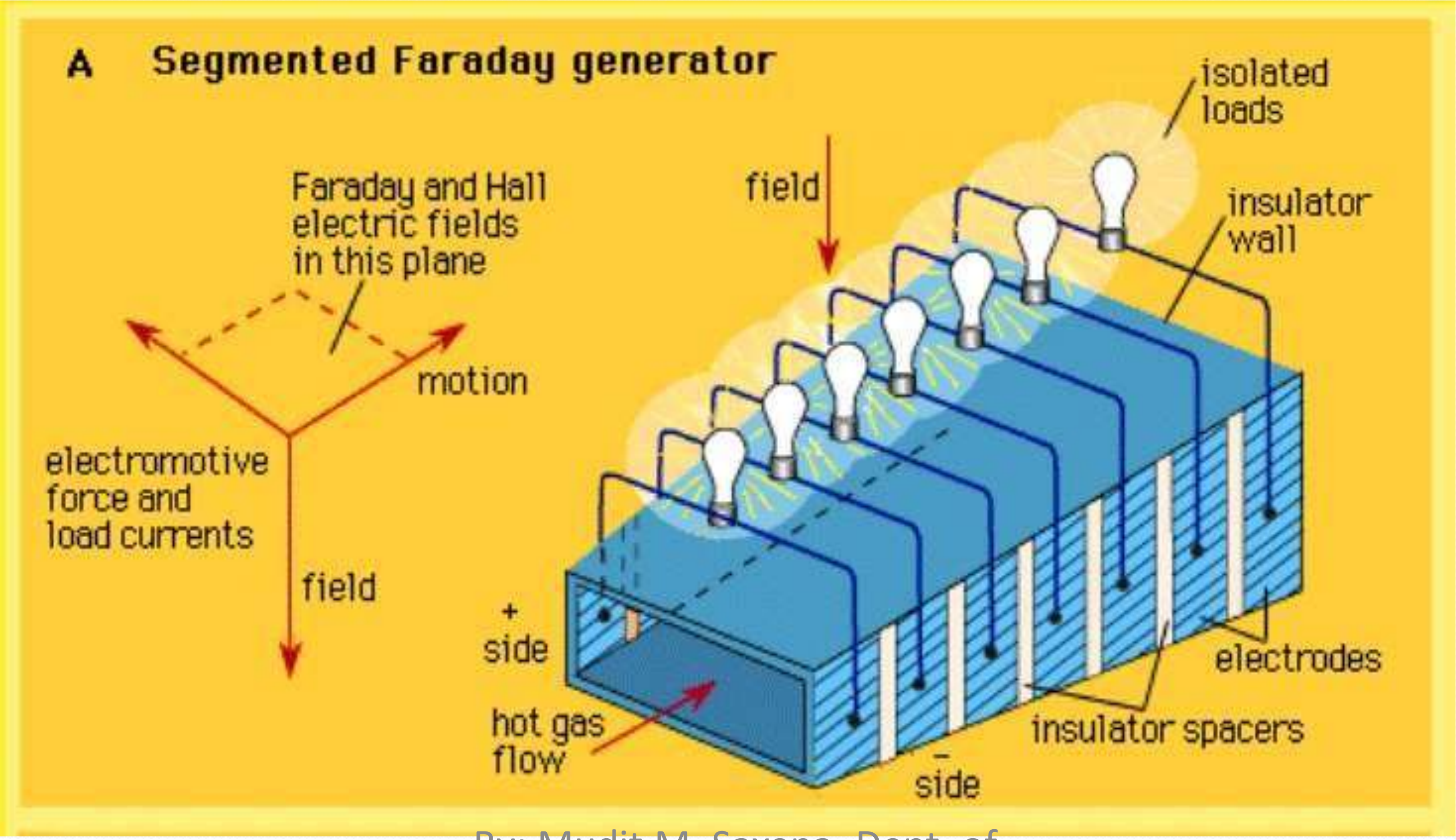

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LIQUID METAL SYSTEM

- When a liquid metal provides the electrical conductivity, it is called a liquid metal MHD system.
- 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 or Lithium to form the working fluid.
- 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.

ADVANTAGES

- The conversion efficiency of a MHD system can be around 50% much higher compared to the most efficient steam plants.
- 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 of the plant is considerably smaller than conventional fossil fuel plants.

LIMITATIONS

- The metallic vapours are poor electrical conductors.
- High velocities cannot be obtained by expansion in the system while it is much easier to achieve a high fluid velocity .
- employing a gas and a nozzle. This is because the liquids are practically in compressible.
- The overall conversions efficiencies obtainable with liquid metal system are quite below to that of plasma system.

APPLICATIONS

- Laser power MHD Generators.
- Plasma physics applications.
- Power generation in space crafts.
- Hypersonic wind tunnel experiments.
- Defense applications.

PROBLEMS ENCOUNTERED

- Seed material potassium attacks insulating materials and make them conducting.
- Electrode materials are chemically eroded by combustion of gases.
- It has been reported that capital costs of MHD plants will be competitive to conventional steam plants.
- Most of the problems are related to material problems caused by high temperature and highly corrosive and abrasive environment.

CONCLUSION

This power resource play a minor role presently and its use on a vast scale is yet to be confirmed as it is in its childhood stage.

These systems permit better fuel utilization. The reduced fuel consumption would offer additionaleconomic and special benefits and would also lead to conservation of energy resources.

The magneto hydro dynamic power generation is one of the examples of a new unique method of generation of electricity.

ENERGY ECONOMICS

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Economics of Energy

- Energy economics is the field that studies human utilization of energy resources and energy commodities and the consequences of that utilization. In physical science terminology, "energy" is the capacity for doing work, e.g., lifting, accelerating, or heating material. In economic terminology, "energy" includes all energy commodities and energy resources, commodities or resources that embody significant amounts of physical energy and thus offer the ability to perform work.

- Energy commodities - e.g., gasoline, diesel fuel, natural gas, propane, coal, or electricity – can be used to provide energy services for human activities, such as lighting, space heating, water heating, cooking, motive power, electronic activity.

- Energy resources - e.g., crude oil, natural gas, coal, biomass, hydro, uranium, wind, sunlight, or geothermal deposits – can be harvested to produce energy Commodities.

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Economics of Energy

- Energy economics studies forces that lead economic agents – firms, individuals, governments to supply energy resources, to convert those resources into other useful energy forms, to transport them to the users, to use them, and to dispose of the residuals.

- It studies roles of alternative market and regulatory structures on these activities, economic distributional impacts, and environmental consequences. It studies economically efficient provision and use of energy commodities and resources and factors that lead away from economic efficiency.

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Properties of Energy Resources and Energy Commodities

- Other than all embodying significant amounts of physical energy, energy resources or commodities vary greatly. They may embody chemical energy (e.g., oil, natural gas, coal, biomass), mechanical energy (e.g., wind, falling water), thermal energy (geothermal deposits), radiation (sunlight, infrared radiation), electrical energy (electricity), or the potential to create energy through nuclear reactions (uranium, plutonium.) They have differing physical forms. Crude oil, most refined petroleum products, and water are liquids. Of water includes available energy only through its motion. Coal, most biomass, and uranium are solids. Natural gas and wind are in gases, with wind including available energy based only on its movement.

  Geothermal energy is available through hot liquids (normally water) or solids (subterranean rock formations). Solar radiation is a pure form of energy. Electricity consists of electrons moving under an electrical potential. Resources can be viewed as renewable or depletable. Some renewable resources can be stored; others are not storable.

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Energy Conversion Processes

- A fundamental property of energy is expressed by the first law of thermodynamics: energy can be neither created nor destroyed (except through nuclear reactions transforming matter to energy.)

- Energy can be converted between forms and human use of energy typically involves such conversions for human ends. Energy conversion processes are basic to human experience. Fire, providing heat and light, is a process by which chemical energy stored in the fuel, say, wood, is converted to thermal energy and radiant energy.

- Chemical energy stored in wood is the result of photosynthesis, whereby plants convert energy in sunlight to chemical energy, stored in the plant material Carbohydrates in food are converted within the human body to thermal energy and mechanical energy, providing body warmth and movement.

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Energy Conversion Processes

- The industrial revolution was characterized by a change from use of hand tools, using human mechanical energy, to machine and power tools. Machine tools allowed conversion of energy in falling water to mechanical energy (water wheels) or conversion of chemical energy in wood or coal to mechanical energy (steam engines) for industrial processes.

- Humans now routinely harness complex sequences of energy conversion processes to provide desired services.

- Crude oil is separated into refined products such as gasoline, diesel oil, jet fuel, heavy distillates, that embody chemical energy.

- Gasoline or diesel oil are explosively burned in internal combustion engines, converting chemical energy into thermal energy. Heated gases push engine pistons, converting thermal energy into mechanical energy. Some is lost as heated gases or as radiant energy.

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Energy Conversion Processes

- The mechanical energy moves the automobile and, in the process, is converted to thermal energy through friction within the automobile or between the automobile and the road or air. Some mechanical energy is converted to electrical energy by a generator in the automobile, to power electrical equipment. Some electrical energy is converted into chemical energy in the automobile battery. To start the car, chemical energy in the battery is converted to electrical energy, that is then converted to mechanical energy to turn the engine.

- Similarly, coal combustion converts chemical energy into thermal energy to create steam, which powers a turbine in an electric generating plant, converting the thermal energy into mechanical energy and then into electrical energy. Electricity can power a motor (converting to mechanical energy), heat a room (to thermal energy), or light a bulb (to thermal energy,then to light). This energy is later converted to thermal energy, which ultimately is radiated into space.

- Energy economics recognizes the fundamental physical realities that 1) no energy is created ordestroyed but that energy can be converted among its various forms, and 2) energy comes from the physical environment and ultimately is released back into the physical environment. Thus, energy economics is the study of human activities using energy resources from naturally 5 available forms, through often complex conversion processes, to forms providing energy services. Several issues of the demand for energy will be examined next.

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Demand for Energy as a Derived Demand

- Demand for energy is derived from wishes to use energy to obtain desired services. It is not derived from preferences for the energy commodity itself. Energy demand depends primarily on demand for desired services, availability and properties of energy conversion technologies, and costs of energy and technologies used for conversion. For example, consumers use gasoline to fuel an automobile or other motorized vehicle, converting gasoline to mechanical energy for motive power.
- The amount of gasoline used is proportional to the miles the auto is driven and inversely proportionate to the efficiency by which gasoline is converted to useful mechanical energy, measured as miles per gallon (Mpg) of gasoline of the automobile. Demand for gasoline is thus derived from choices about distances vehicles are driven and their energy conversion efficiencies.
- Similarly, electricity is purchased by consumers only to perform functions using electricity. Typical electricity uses include lighting, refrigeration, space heating, air conditioning, clothes washing, drying, dish washing, water heating, operating electronic equipment such as computers or televisions

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Demand for Energy as a Derived Demand

- Electrical energy is converted to mechanical energy (motors in refrigerators, air-conditioning units, vacuum cleaners), thermal energy (space heating, clothes dryers, water heating), or radiation (lighting, television, computer monitors.)

- Electricity demand is derived from demand for the underlying services – comfortable space, refrigeration, cleaning, entertainment, information processing. In each case, efficiency of energy conversion equipment also determines energy demand. Typically, energy conversion equipment is long-lived – automobiles, air-conditioning units, refrigerators, televisions, computer systems, furnaces.

- Consumers or firms can usually choose among alternatives with various conversion efficiencies; such choices significantly influence energy demand. To the extent that consumers and firms purchase these units with an understanding of their conversion efficiencies, expectations of future energy prices can influence choices of particular equipment. For example, high natural gas prices can motivate consumers to invest in home insulation.

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Demand for Energy as a Derived Demand

- In general, increased energy prices reduce demand by reducing use of energy services and motivating selection of higher conversion efficiency equipment. For example, gasoline prices influence demand through vehicle miles and fuel efficiency of vehicles.
- Vehicle miles is influenced by cost per mile of driving, including per mile gasoline costs, equal to the ratio Pg/Mpg (where Pg is the gasoline price), and other costs. Increased gasoline prices lead consumers to purchase more fuel efficient cars.
- Both factors imply that increased gasoline prices reduce gasoline demand, with the vehicle miles adjusting relatively quickly and vehicular fuel efficiency adjusting slowly as vehicles enter the fleet. Except for firms selling energy resources or energy commodities, the same issues are important for industrial and commercial use of energy.

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Demand Substitution Among Energy Commodities

- Some energy services can be provided by several different energy commodities. Homes could be heated using electricity, natural gas, oil, or wood, since each can be converted to thermal energy.

- Cooking could use electricity, natural gas, propane, wood, or charcoal. Thus, energy commodities are typically economic substitutes for one another: the demand for a particular energy commodity is an increasing function of prices of other energy commodities. This substitutability of energy is made possible by and is limited by the available set of energy conversion technologies.

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Demand Substitution Among Energy Commodities

- Typically one conversion technology can be used only for one particular energy commodity. For home heating, a natural gas furnace cannot use oil, electricity, or wood. Because conversion equipment typically is very long lived, substitution among energy commodities occurs only slowly, and then when new equipment is purchased.

- Short-run substitution usually can occur only if several energy conversion technologies are simultaneously available for use by particular consumers, e.g., homes that have a central natural gas heating system plus portable electric space heating units. Thus, usually various energy commodities can be viewed as imperfect substitutes for one another, with much greater substitutability in the long run than in the short run.

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Demand Substitution Among Energy Commodities

- The degree of substitutability can be sharply altered by development of new conversion alternatives. For example, automobiles historically were fueled only by gasoline or diesel fuel, but technologies currently being developed would allow autos to be powered by electricity, natural gas, propane, hydrogen, or other energy commodities.

- Once such conversion technologies are successfully commercialized, gasoline and other energy commodities will become highly substitutable in transportation.

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Is Energy an Essential Good?

- In economics, an essential good is one for which the demand remains positive no matter how high its price becomes. In the theoretical limit, for prices unboundedly high, consumers would allocate all of their income to purchases of the essential good.
- Energy is often described as an essential good because human activity would be impossible absent use of energy: living requires food embodying chemical energy. Although energy is essential to humans, neither particular energy commodities nor any purchased energy commodities are essential goods. Particular energy commodities are not essential because consumers can convert one form of energy into another. Even the aggregate of all purchased energy cannot be viewed as an essential good. Experience from low-energy research facilities shows that an extremely energy efficient home needs relatively little energy. Solar energy could generate electricity or heat water. Travel could be limited to walking or riding bicycles.
- Solar-generated electricity or wood fires could be used for cooking. For high enough prices of purchased energy, demand for purchased energy by consumers could be reduced to zero.

  Thus, purchased energy is not an essential good.

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Optimality of Consumer Choice

- Debate is ongoing about the extent to which consumers understand conversion efficiencies of alternative technologies and act on this understanding and the extent to which manufacturers

  of conversion equipment respond to consumer preferences. Labeling requirements have been one policy response to concerns that consumers otherwise would have insufficient information to choose among energy conversion equipment. New cars have stickers with estimates of their Mpg under different driving cycles. Refrigerator labels estimate their annual electricity use and cost. The concern has led to adoption of energy efficiency standards for household equipment, such as refrigerators, under the belief that labeling is not sufficient to motivate optimal consumer choices. Similarly, the imposition of corporate average fuel efficiency standards (CAFE) for automobiles is a legislative response to concern that, on their own, automobile manufacturers will make automobiles less fuel efficient than optimal. These behavioral issues and the appropriate policy responses have not been fully resolved in either the existing literature or the policy community.

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Depletable, Storable Renewable, Non-storable Renewable Resources

- Based on the speed of natural processes, one can classify primary energy resources as depletable or renewable. Renewable resources can be further subdivided into storable or nonstorable resources. Renewable resources are self renewing within a time scale important for economic decision making. Storable renewable resources typically exist as a stock which can be used or can be stored. Biomass, hydro power, and some geothermal, fall in this category.
- The amount used at one time influences the amount available in subsequent times. Nonstorable renewable resources – wind, solar radiation, run-of-the-river hydro resources can be used or not, but the quantity used at a given time has no direct influence on the quantity available subsequently. Most energy commodities are storable (refined petroleum products, processed natural gas, coal, batteries), but electricity is not storable as electricity. Depletable resources are those whose renewal speeds are so slow that it is appropriate to view them as made available once and only once by nature. Crude oil, natural gas, coal, and uranium all fallin this category.

Depletable, Storable Renewable, Non-storable Renewable Resources

- Initially all human energy use depended on renewable resources, in particular biomass resources used for food, heat, or light. In the United States, renewable energy – human, animal, water, wood, and wind power – dominated energy supply through the middle of the 19th century. Only during the second half of the 19th century did a depletable resource, coal, surpass renewable resource use. Crude oil and natural gas started supplying large quantities of energy only in the 1920s.

- Now the dominant use of energy in developed nations is based on depletable resources, particularly fossil fuels. Table 2 shows that of the total sources of energy consumed in the United States in 1999, 92% was from a depletable resource and only 8% was from a renewable resource, of which almost all was hydroelectric and biomass (wood and waste.) But depletable resource use cannot dominate forever. Once particular deposits have been used, they cannot be reused. Therefore, a future transition from depletable resources, particularly from fossil fuels, is inevitable.

- However, which renewable energy sources will dominate future consumption is not clear. And there is great uncertainty about the timing of a shift to renewable energy resources. Related is the unresolved question of future energy adequacy: will the renewable sources of energy be adequate to satisfy demands for energy, once the fossil fuel supplies move close to ultimate depletion?

Depletable Resource Economics and the Transition to Renewable Resources

- The study of depletable resource economics began with articles by Lewis Grey (1914) and
- Harold Hotelling (1931), which examined economically inter-temporal optimal extraction from a perfectly known stock of the resource, with perfectly predictable future prices of the extracted commodity. Many, but not all, subsequent articles maintained the perfect knowledge assumptions. The essential result is that under optimal extraction paths the resource owner recognizes (explicitly or implicitly) an opportunity cost, or rent, in addition to the marginal extraction costs. All information about the role of future prices and costs would be embodied in this opportunity cost. The competitive firm would extract at a rate such that the marginal extraction cost plus opportunity cost would equal the selling price for the extracted commodity. Price would thus exceed marginal cost, even if the firm were operating perfectly competitively. This opportunity cost would evolve smoothly over time. As the resource neared depletion, the opportunity cost and the marginal extraction cost even at very low extraction rates would together have increased until they equaled the commodity price, at which time extraction would cease. In depletable resource theory, market prices would increase gradually to the cost of producing substitutes, reaching that cost only as the depletable resource were nearing depletion.

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Depletable Resource Economics and the Transition to Renewable Resources

- Substitutes would be produced only in small quantities until near the time of depletion. Market forces would automatically and optimally guide commodity prices upward so that when the depletable resources were nearing depletion, commodity prices would have risen to a point at which the demands could be fully satisfied by the substitutes.

- In reality, the economic cycle for depletable resources is far more complex and more prone to error and surprises. The cycle typically begins with innovations that allow the resource to be utilized. Technologies improve over time, partially guided by economic forces and public policy decisions, but often in somewhat unpredictable ways. Generally the magnitude and location of the resource base remains unknown and exploration is required to identify resource deposits. But exploration is costly. Therefore typically it is optimal for companies to explore only until they find sufficient resources to satisfy their expectations of near-term extraction.

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Depletable Resource Economics and the Transition to Renewable Resources

- These discovered resources – referred to as "reserves" – are typically only a fraction of the resource base and do not provide reliable estimates of the overall size of the resource stock. Firms may optimally extract from the proven reserves but cannot know with any certainty the quantity or extraction costs of the undiscovered resources. Opportunity cost would depend on the future prices of the extracted commodity, but future commodity prices will themselves depend on future demand and supply, which in turn depends on the uncertain future discoveries, and which therefore are very unpredictable.

- With this additional complexity and uncertainty, although the opportunity cost concept remains important, it seems appropriate to focus more attention on responses of markets to random changes in technologies, reserves, and other market information. And it seems appropriate to abandon the notion that markets will automatically and optimally guide the system to a smooth transition to renewable resources.

- One central result does remain, however. If there is only a limited stock of a resource – undiscovered plus discovered – then there will be only a limited number of years during which the resource can be extracted. Here there is an important commonality between energy economics and ecological economics (see article on ecological economics).

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Depletable Resource Economics and the Transition to Renewable Resources

- The typical pattern includes an initial period in which the resource is not used, before technology for extracting and/or using the resource is developed. Extraction rates rise over time, perhaps rapidly, as that technology develops and demand increases. Commodity prices would fall with falling extraction and finding costs. However, at some time, rising costs due to depletion of the resource start overtaking the decreasing costs due to technology advances.

- The extraction rate declines until ultimately all of the economical resource stocks are depleted. At that point, the consumers of the depletable resource must substitute some other means of satisfying energy service demand. If markets work well, the renewable resources will then be available in sufficient quantities and at reasonable costs. A transition to renewable energy resources will have been successfully accomplished and there would always be an adequate energy supply to satisfy all demands at the prevailing market price.

- However, given the complexity and the uncertainty, it is not obvious that the transition will work as automatically, as smoothly, or as optimally as suggested above. It may be that fossil fuels saved for the future will ultimately never be needed because substitute forms of energy become available at a lower cost and at an earlier time than expected. Or it may be that fossil fuels are rapidly depleted but that costs of renewable resources remain well above expected levels or that quantities of renewable resources are more limited than expected. In either case, in retrospect everyone might wish to have made very different public policy decisions.

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Energy Conversion Industries

- In addition are activities associated with commercial conversion of energy from one form to another, particularly to electricity, from hydro power, coal, natural gas, oil, nuclear fission, wood and waste products, geothermal, wind, or solar radiation. Energy conversion industries, for economic success, must be able to sell their product at a price higher than the cost of energy commodities used as inputs plus per unit capital and operating costs of the facilities. Energy conversion is never perfectly efficient and some input energy is lost into the environment. Therefore, the price per Btu of electricity must be substantially greater than the price of energy commodities used to generate electricity.

- Technological advance can be very important. New technologies are becoming available that increase the conversion efficiency from natural gas or coal to electricity and which can be expected to have lower operating and capital costs. Such technological advances can be expected to bring prices of these energy commodities closer together over time.

- In addition to these technological changes, there are important ongoing changes in economic structure of the electricity production and distribution industry, throughout the world.

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Energy Conversion Industries

- In many countries, state-owned industries generate, transmit, and distribute electricity. In others, private electricity suppliers are subject to special economic regulation. The reason for governmental ownership or control seems to stem from two factors. Electricity is 19 fundamental to economic activity and many people have not trusted private industry.

- Second, production, transmission, and distribution of electricity have shown significant increasing returns to scale and the industry has been viewed as a natural monopoly. Fearful that an unregulated monopoly would exercise market power and overprice electricity, most nations have chosen to tightly control or own the industry.

- Recently, however, smaller geographically distributed electric generating plants, that could reasonably compete with one another, have become economically attractive.

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Energy Conversion Industries

- Thus, the possibility for competition in electricity generation has been recognized. In addition, it is now realized that an electric utility sells two classes of products: electricity delivery services (wires) and electricity. Although these two classes of products traditionally were bundled together into a price per kilowatt hour of electricity, in principle, these two classes could be unbundled and sold by separate companies.

- Electricity delivery service is characterized by increasing returns to scale, but electricity itself is not. Therefore the possibility is open for a competitive market structure to sell electricity to consumers, separately from the electricity delivery services.

- In some localities this movement toward privatization and deregulation seems to be very successful; in others, for example, California, it has not been. At the time of this writing, there is an intense heated debate about whether deregulation of the electricity industry is appropriate and if so, what is the appropriate form of deregulation.

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Environmental Consequences of Energy Use

- Many important environmental damages stem from the production, conversion, and consumption of energy. Costs of these environmental damages generally are not incorporated into prices for energy commodities and resources; this omission leads to overuse of energy. Concern about this issue is common to energy economics, environmental economics (see environmental economics entry), and ecological economics (see ecological economics entry), with energy economics and environmental economics literature attempting to assign monetary valuation of the impacts and ecological economics rejecting the idea that a monetary value could be placed on environmental impacts. Environmental impacts currently receiving most attention are associated with the release of greenhouse gases into the atmosphere, primarily carbon dioxide, from combustion of fossil fuels. The three primary fossil fuels – coal, petroleum, and natural gas – each include carbon.

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Environmental Consequences of Energy Use

- During combustion, carbon combines with oxygen to produce carbon dioxide, the primary greenhouse gas. Carbon dioxide accumulates in the atmosphere and is expected to result in significant detrimental impacts on the world's climate, including global warming, rises in the ocean levels, increased intensity of tropical storms, and losses in biodiversity.

- Fossil fuels account for 98% of the US carbon dioxide net releases into the atmosphere and 82% of the releases of greenhouse gases, measured on a carbon equivalent basis. Energy use leads to additional environmental damages. Coal combustion, particularly high sulfur coal combustion, emits oxides of sulfur, which, through atmospheric chemical reactions, result in acid rain.

- Automobile gasoline combustion releases oxides of nitrogen and volatile organic compounds, which, in the presence of sunlight, result in smog. Electric generating facilities often use much water for cooling and release the heated water into lakes or oceans, leading to local impacts on the ecosystem. Extraction of oil or mining of coal can lead to subsidence of the land overlying of the extracted deposits. Pervasive environmental impacts of energy use, absent governmental intervention, imply that significant costs of energy use are not included in the price energy users face. These so-called externalities (see environmental economics entry) lead to overuse of energY and provide strong motivation for interventions designed to reduce energy use.

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Energy Management & Audit

WHAT IS ENERGY?

- **Definition:** Energy is the capacity of a physical system to perform work. Energy exists in several forms such as heat, kinetic or mechanical energy, light, potential energy, electrical or other forms.
- According to the law of conservation of energy, the total energy of a system remains constant, though energy may transform into another form.
- For example, two billiard balls colliding, may come to rest, with the resulting energy converting to sound and perhaps a little bit of heat, at the point of collision.

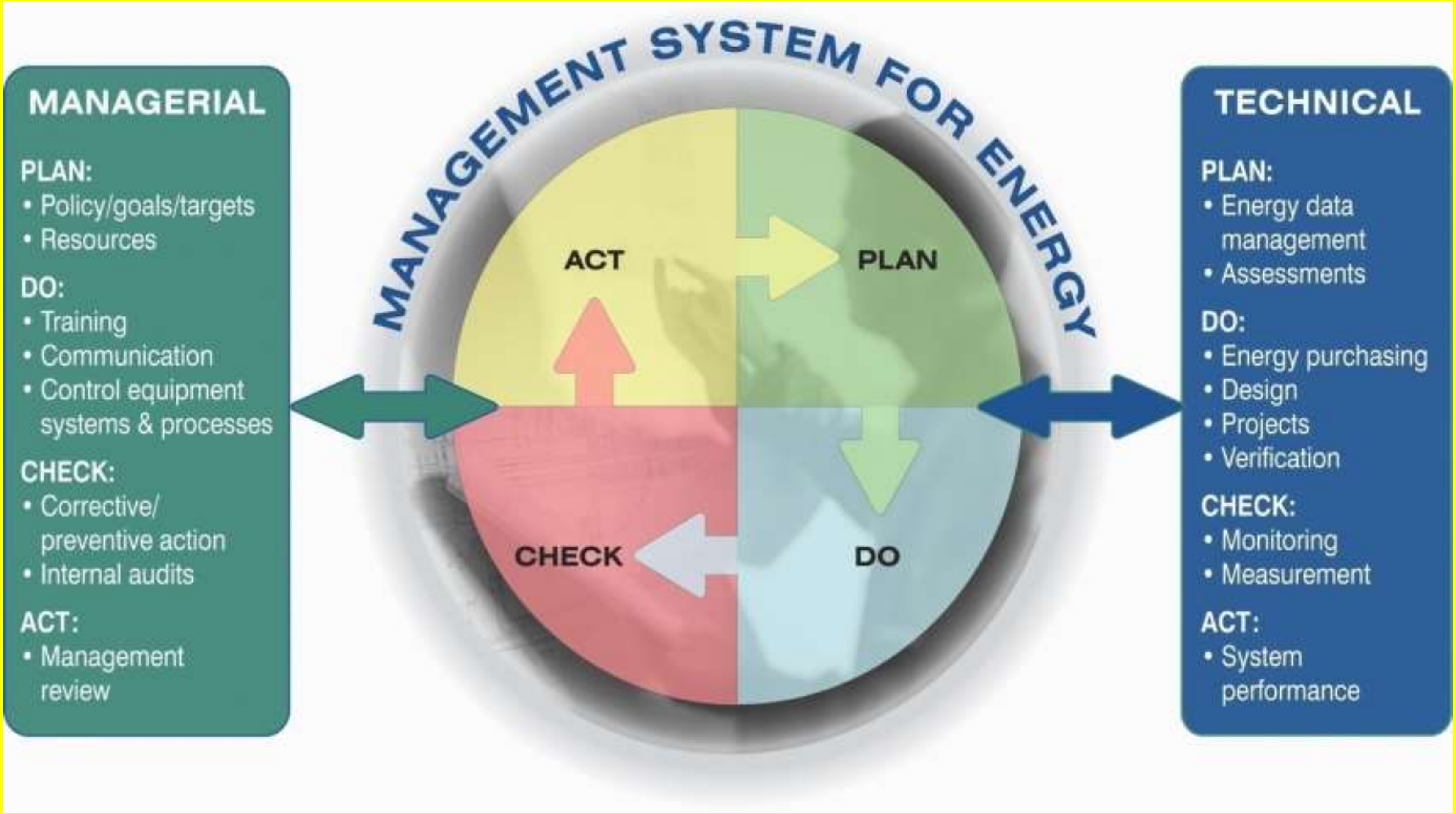
TYPES OF ENERGY

- **Mechanical energy**
  Mechanical energy is energy that results from movement or the location of an object. Mechanical energy is the sum of Kinetic and Potential Energy.
- **Thermal energy**
  Thermal energy or heat energy reflects the temperature difference between two systems.
- **Nuclear energy**
  Nuclear energy is energy resulting from changes in the atomic nuclei or from nuclear
- **Chemical energy**
  Chemical energy results from chemical reactions between atoms or molecules. There are different types of chemical energy, such as electrochemical energy etc.
- **Electromagnetic energy**
  Electromagnetic energy is energy from light or electromagnetic waves.

Definition of Energy Management

Energy Management is defined as "The strategy of adjusting and optimizing energy, using systems and procedures so as to reduce energy requirements per unit of output while holding constant or reducing total costs of producing the output from these systems"

The Energy Management System



The Objectives of Energy Management

1. To achieve and maintain optimum energy procurement and utilisation, throughout the organization

2. To minimise energy costs /waste without affecting production & quality

3. To minimise environmental effects.

Energy Management Objectives Clarified

The basic objective of any Energy Management System is to answer five simple questions:

- How much energy is consumed
- How is the energy consumed
- Where is the energy consumed
- When is the energy consumed
- What is the quality of the energy consumed

- **In order to address these queries Energy Audits are conducted. Lets understand audits -**

Definition of Energy Audit

- **As per Indian Energy Conservation Act 2001, Energy Audit is definedas:**

"the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption "

Why the Need for Energy Audit

- The three top operating expenses are energy (both electrical and thermal), labour and materials.
- Energy would emerge as a top ranker for cost reduction
- primary objective of Energy Audit is to determine ways to reduce energy consumption per unit of product output or to lower operating costs
- Energy Audit provides a "bench-mark" (Reference point) for managing energy in the organization

Types of Energy Audits

1. Preliminary Energy Audit
2. Targeted Energy Audit
3. Detailed Energy Audit

Preliminary Energy Audit

Preliminary energy audit uses existing or easily obtained data

Establishes the energy consumption in the organization

Estimates the scope for saving

Identifies the most likely areas for attention

Identifies immediate(no cost or low cost) improvements

Sets a ‘reference point’

Identifies areas for more detailed study/measurement

Targeted Energy Audits

Targeted energy audits are mostly based upon the outcome of the preliminary audit results.

They provide data and detailed analysis on specified target projects.

As an example, an organization may target its lighting system or boiler system or compressed air system with a view to bring about energy savings.

Targeted audits therefore involve detailed surveys of the target subjects/areas with analysis of the energy flows and costs associated with those targets.

Detailed Energy Audit

Detailed Energy Audit evaluates all systems and equipment which consume energy and the audit comprises a detailed study on energy savings and costs.

Detailed Energy Audit is carried out in 3 phases

- The Pre-audit Phase
- The Audit Phase
- The Post-Audit Phase

The Ten Steps for Detailed Audit

Step No	PLAN OF ACTION	PURPOSE / RESULTS
	Phase I – Pre Audit Phase	
Step 1	• Plan and organise • Walk through Audit • Informal Interview with Energy Manager, Production / Plant Manager	• Resource planning, Establish/organize a Energy audit team • Organize Instruments & time frame • Macro Data collection (suitable to type of industry.) • Familiarization of process/plant activities • First hand observation & Assessment of current level operation and practices
Step 2	• Conduct of brief meeting / awareness programme with all divisional heads and persons concerned (2-3 hrs.)	• Building up cooperation • Issue questionnaire for each department • Orientation, awareness creation

Step 3	<u>Phase II –Audit Phase</u> • Primary data gathering, Process Flow Diagram, & Energy Utility Diagram	• Historic data analysis, Baseline data collection • Prepare process flow charts • All service utilities system diagram (Example: Single line power distribution diagram, water, compressed air & steam distribution. • Design, operating data and schedule of operation • Annual Energy Bill and energy consumption pattern (Refer manual, log sheet, name plate, interview)
Step 4	• Conduct survey and monitoring	• Measurements : Motor survey, Insulation, and Lighting survey with portable instruments for collection of more and accurate data. Confirm and compare operating data with design data.

Step 5	• Conduct of detailed trials /experiments for selected energy guzzlers	• Trials/Experiments: - 24 hours power monitoring (MD, PF, kWh etc.). - Load variations trends in pumps, fan compressors etc. - Boiler/Efficiency trials for (4 – 8 hours) - Furnace Efficiency trials Equipments Performance experiments etc
Step6	• Analysis of energy use	• Energy and Material balance & energy loss/waste analysis
Step 7	• Identification and development of Energy Conservation (ENCON) opportunities	• Identification & Consolidation ENCON measures ♣ Conceive, develop, and refine ideas ♣ Review the previous ideas suggested by unit personal ♣ Review the previous ideas suggested by energy audit if any ♣ Use brainstorming and value analysis techniques ♣ Contact vendors for new/efficient technology
Step 8	• Cost benefit analysis	• Assess technical feasibility, economic viability and prioritization of ENCON options for implementation • Select the most promising projects • Prioritise by low, medium, long term measures
Step9	● Reporting & Presentation to the Top Management	Documentation, Report Presentation to the top Management.

Step10	<u>Phase III –Post Audit phase</u> ● Implementation and Follow-up	Assist and Implement ENCON recommendation measures and Monitor the performance ♣ Action plan, Schedule for implementation ♣ Follow-up and periodic review

Questions which an Energy Auditor should ask

- What function does this system serve?
- How does this system serve its function?
- What is the energy consumption of this system?
- What are the indications that this system is working properly ?
- If this system is not working, how can it be restored to good working conditions/
- How can the energy cost of this system be reduced?

DETAILED ENERGY AUDIT
A TYPICAL INDUSTRIAL FORMAT

Energy Audit Team
Executive Summary –Scope & Purpose

Energy Audit Options & Recommendations

1. Introduction about the plant
    2. General Plant details and descriptions
    3. Component of production cost (Raw materials, energy, chemicals, manpower, overhead, others)
4. Major Energy use and Areas
5. Production Process Description
    6. Brief description of manufacturing process
    7. Process flow diagram and Major Unit operations
    8. Major Raw material Inputs, Quantity and Costs
9. Energy and Utility System Description
    10. List of Utilities
    11. Brief Description of each utility
        1. Electricity
        2. Steam
        3. Water
        4. Compressed air
        5. Chilled water
        6. Cooling water

1. Detailed Process flow diagram and Energy& Material balance

    2.Flow chart showing flow rate, temperature, pressures of all input-Output streams

    4Water balance for entire industry

1. Energy efficiency in utility and process systems
    2. Specific Energy consumption
    3. Boiler efficiency assessment
    4. Thermic Fluid Heater performance assessments
    5. Furnace efficiency Analysis
    6. Cooling water system performance assessment
    7. DG set performance assessment
    8. Refrigeration system performance
    9. Compressed air system performance
    10. Electric motor load analysis
    11. Lighting system

12. Energy Conservation Options & Recommendations

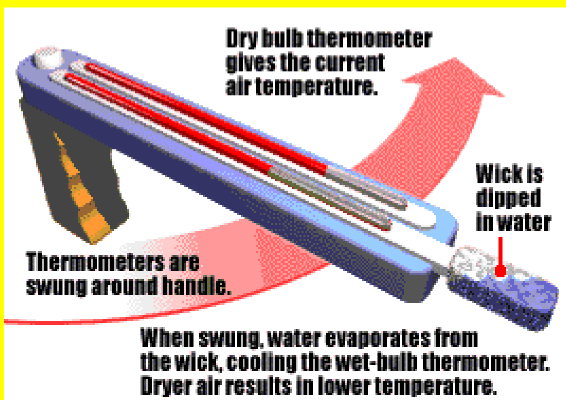
    13.List of options in terms of no cost, low cost, medium cost and high cost, annual energy savings and payback

    14. Implementation plan for energy saving measures/Projects

ANNEXURE

Al. List of instruments

A2. List of Vendors and Other Technical details



All Energy Audits require many measurements. Some common Instruments used are shown above

Some more Energy Audit Instruments

Identification of Energy Conservation Factors & Areas

Steps for conserving energy can be taken if we know the correct factors and areas to be studied and also details of fuels used.

These can be:

- Energy generation
- Energy distribution
- Energy usage by processes
- Fuel substitution

Technical and Economic feasibility- Factors

Technology availability, space, skilled manpower, reliability, service,Impact of measure on safety, quality, production or process.Maintenance requirements and spares availability

Sample Worksheet for Economic Feasibility

Name of Energy Efficiency Measure

i. Investment

a. Equipments
b. Civil works
c. Instrumentation
d. Auxiliaries

2. Annual operating costs

- Cost of capital
- Maintenance
- Manpower
- Energy
- Depreciation

3. Annual savings

- Thermal Energy
- Electrical Energy
- Raw material
- Waste disposal

Net Savings /Year (Rs./year)
= (Annual savings-annual operating costs)

Payback period in months
= (Investment/net savings/year) x 12

Understanding energy costs

An industrial energy bill summary

ENERGY BILL EXAMPLE			
Type of energy	Original units	Unit Cost	Monthly Bill (Rs)
Electricity	5,00,000 kWh	Rs.4.00/kWh	20,00,000
Fuel oil	200,kL	Rs.11,000 KL	22,00,000
Coal	1000 tons	Rs.2,200/ton	22,00,000
Total			64,00,000

Conversion to common unit of energy

Electricity	(1 kWh)	= 860 kcal/kWh (0.0036 GJ)
Heavy fuel oil	(calorific value, GCV)	=10.000 kcal/litre (0.0411 GJ/litre)
Coal	(calorific value, GCV)	=4000 kcal/kg (28 GJ/ton)

Benchmarking

- Benchmarking can be a useful tool for understanding energy consumption patterns in the industrial sector and also to take requisite measures for improving energy efficiency.

- FACTORS INVOLVED:
  - Scale of operation
  - Vintage of technology
  - Raw material specifications and quality
  - Product specifications and quality

Benchmarking for Energy Performance

- **Internal Benchmarking**
  - **Historical and trend analysis**
- **External Benchmarking**
  - **Across similar industries**

    Scale of operation, vintage of technology, raw material specification and quality and product specification and quality

Bench Marking Energy Performance

- Quantification of fixed and variable energy consumption trends vis-à-vis production levels
- Comparison of the industry energy performance w.r.t. various production levels (capacity utilization)
- Identification of best practices (based on the external benchmarking data)
- Scope and margin available for energy consumption and cost reduction
- Basis for monitoring and target setting exercises

Benchmarking parameters

Production or Equipment Related

- **Gross production related**

e.g. kWh/MT clinker or cement produced (Cement plant)
e.g. kWh/MT, kCal/kg, paper produced (Paper plant)

- **Equipment / utility related**

e.g. kWh/ton of refrigeration (on Air conditioning plant)
e.g. kWh /litre in a diesel power generation plant.

Measuring Energy Performance

Production Factor = Current year's production / Reference year's production

- **ReferenceYear Equivalent Energy Use**
- The *reference year's equivalent energy use (or reference year equivalent)* is the energy that would have been used to produce the current year's production output.
- The reference year equivalent is obtained by multiplying the reference year energy use by the production factor (obtained above)
- **Reference year equivalent = Reference year energy use x Production factor**
- Plant Energy Performance is the improvement or deterioration from the reference year. It is a measure of plant's energy progress.

- **Plant energy performance = (Reference year equivalent – Current year's energy) / Reference year equivalent x 100**

Maximizing System Efficiencies - Some Measures

- Replace pumps, fans, air compressors, refrigeration compressors, boilers, furnaces, heaters and other energy conservation equipment, wherever significant energy efficiency margins exist
- Eliminate steam leakages by trap improvements
- Maximize condensate recovery
- Adopt combustion controls for maximizing combustion efficiency

Matching Energy Usage to Requirement

- The mismatch between equipment capacity and user requirement often leads to inefficiencies due to part load operations, wastages etc. It is thus essential that proper energy matching studies are carried out & actions implemented.

Examples :

Eliminate throttling

Eliminate damper operations

Fan resizing for better efficiency.

Moderation of chilled water temperature for process chilling needs

Optimising Energy Input Requirement

- **In order to ensure that the energy given to the system is being put to optimal use, site specific measures and checks should be carried out regularly.**

- EXAMPLES:
- Shuffling of compressors to match needs.
- Periodic review of insulation thickness
- Identify potential for heat exchanger networking and process integration.

Fuel and Energy Substitution – key steps towards conservation

<u>Fuel substitution</u>

- Replacement of coal by coconut shells, rice husk etc
- Replacement of LDO by LSHS

<u>Energy substitution</u>

- Replacement of electric heaters by steam heaters
- Replacement of steam based hot water by solar systems

Assignment

Q 1. Define energy management and energy audit.
Q 2. Explain the phases of detailed energy audit.
Q 3. What is the need for energy audit ? Explain the types of energy audit.
Q 4. What are the questions which an Energy Auditor should ask ?
Q 5. What are the objectives of energy management ?

Energy Conservation

ENERGY

- Energy can neither be created nor it can be destroyed. It can only be converted from one form to another.

- **For example :**

- In a room heater, electrical energy is converted to thermal energy.
- Turbine converts mechanical energy stored in steam to electrical energy.

TYPES OF ENERGY

¬Energy can be broadly divided into two categories-

- Renewable energy

- Non-renewable energy

RENEWABLE ENERGY

- Renewable energy can be generated continuously practically without decay of source.
- **Example :**
  - Solar
  - Wind
  - Geothermal
  - Hydro
  - Biomass
  - Tidal

SOLAR ENERGY

- Solar Energy can be converted into electrical energy by using solar panels.
- Solar powered electrical generation depands on heat engines and photovoltaic's.
- **Examples :**
  - Solar cooker
  - Solar heater
  - Solar cells
- **Advantages :**
  - Solar energy doesn't produce Carbon dioxide.
  - It have minimal impact on environment.
- **Disadvantages :**
  - It is not constant, it depends on weather conditions, time and location.


SOLAR CELLS

SOLAR HEATER

WIND ENERGY

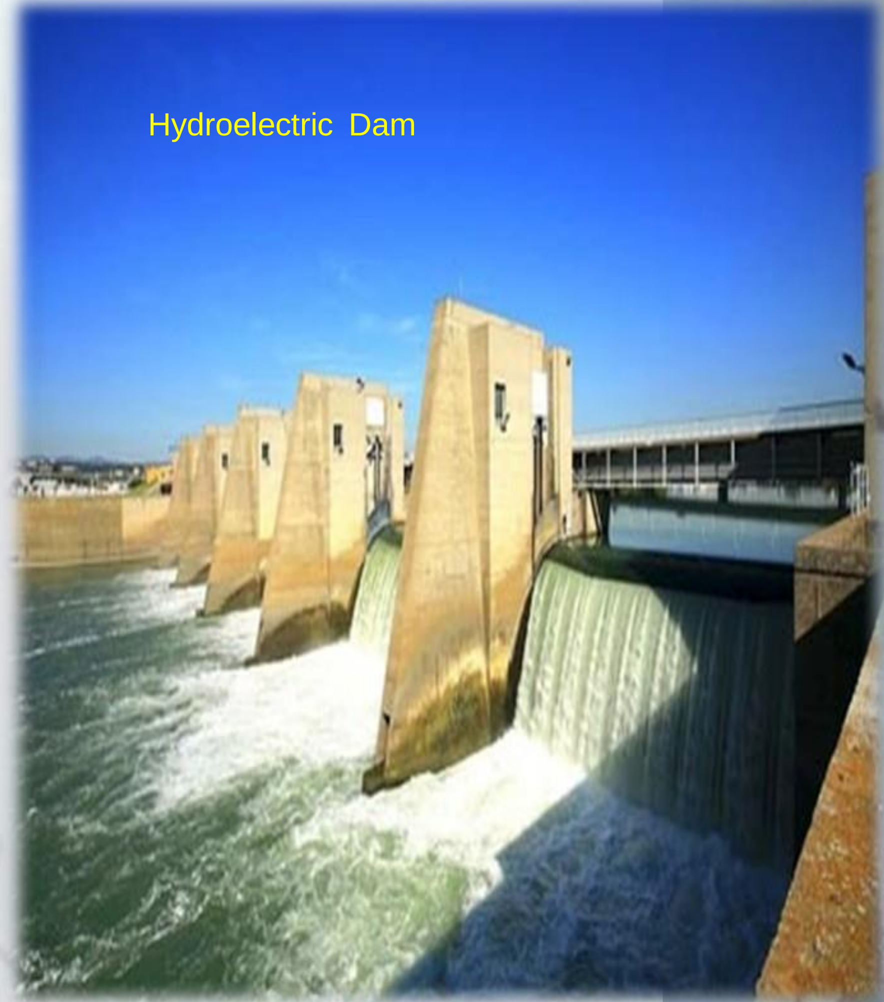
- Wind energy generated by wind turbines is mainly used to generate electricity. India is world's fifth largest producer of electricity generation in this area.
- **Advantages** :
  - Wind turbines (often called windmills) do not release emissions that pollute the air or water.
- **Disadvantages** :
  - Installation and maintenance cost is very high.
  - Only few places are there in world where wind blow continuously throughout the year.

GEOTHERMAL ENERGY

- Geothermal energy is heat from within the Earth. We can recover this heat as steam or hot water and use it to heat buildings or generate electricity.
- **Examples :**
  - Hot springs
  - Fumaroles (smoke)
  - Geysers
- **Advantages :**
  - Carbon dioxide emission levels are very low. They release less than 1% of the carbon dioxide.
- **Disadvantages :**
  - Installation cost is very high.
  - Release various kind of harmful gases.

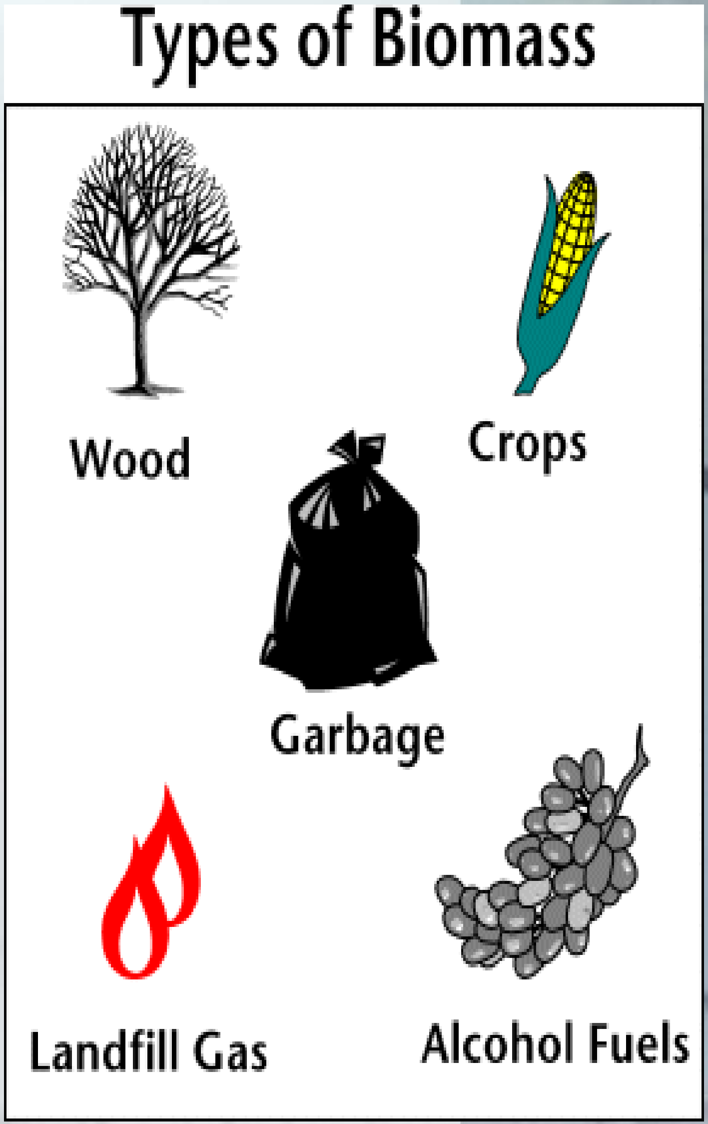
HYDRO ENERGY

- Hydro energy is generally generated from running water using various mechanical methods.
- **Examples**:
  - Dams
  - Tidal Barrages
  - Ocean Thermal Energy Conversion (OTEC) system
- **Advantages :**
  - Produces very less amount of carbon dioxide.
  - It is also being used to control flood and for irrigation purposes.
- **Disadvantages:**
  - Natural environment is destroyed.



BIOMASS ENERGY

- Biomass is organic material made from plants and animals waste. (microorganisms).
- When it is burned, the chemical energy in biomass is released as heat .
- **Examples :**
  - Methanol (from animal waste)
  - Ethanol
  - Biodiesel(liquid biomass)
- **Advantages :**
  - Equipment (biogas plant) installation cost is less.
  - Helps in garbage reduction.
- **Disadvantages :**
  - Releases high amount of *sulphurous* gases.



TIDAL ENERGY

¬The energy contained in ocean waves can potentially provide an unlimited source of renewable energy.

¬Ocean waves are created by the interaction of wind with the surface of the sea.

¬Advantages :

•It doesn't produce greenhouse gases and its life is very long.

•It’s efficiency is around 80%.It doesn’t require any kind of fuel to run.

¬Disadvantages :

•Cost of construction of tidal power plant is high.

Sea-Gen tidal turbine, installed in Strangford Lough, County Down, Northern Ireland, (image courtesy of Marine Current Turbines (MCT))

NON-RENEWABLE ENERGY

¬ Non renewable energy can’t be generated again and again form the same source.

¬ **Examples:**

¬ Petroleum products (kerosene, petrol, diesel, etc)

¬ Coal

¬ Uranium

COAL

- Coal is a combustible black or brownish-black sedimentary rock composed mostly of carbon and hydrocarbons.
- For millions of years, a layer of dead plants at the bottom of the swamps was covered by layers of water and dirt, trapping the energy of the dead plants.
- The heat and pressure from the top layers helped the plant remains turn into what we today call coal .

- **Disadvantages :**
- Responsible for 57% of carbon dioxide in the air.

URANIUM

- Nuclear energy is energy in the nucleus (core) of an uranium-235 atom. Atoms are tiny particles that make up every object in the universe.
- It can be released from atoms in two ways: nuclear fusion and nuclear fission.
- **Advantages :**
  - Even a small amount can release enough energy to light-up thousand of energy for months. (1 kg uranium-235 corresponds to 2.7 million kg coal equivalent.)
- **Disadvantages :**
  - After using it in nuclear reactor then also it radioactive substances is very dangerous for human . Eg : carbonyl accident and fukushima plant accident.

DIFFERENCE BETWEEN RENEWABLE AND NON-RENEWABLE SOURCE OF ENERGY

¬RENEWABLE SOURCE

- Definition : Renewable energy can be generated continuously practically without decay of source.
- Responsible for 3-4% of carbon dioxide in environment.
- Not a reason behind "global warming".

¬NON-RENEWABLE SOURCE

- Definition : Non-renewable can't be generated continuously without decay of source.
- Responsible for 91-94% of carbon dioxide in environment.
- Main reason behind "global warming".

ENERGY CONSERVATION

- Energy conservation refers to efforts made to reduce energy consumption.

- Energy conservation can be achieved through increased efficient energy use or reduced consumption from non-renewable energy sources.

- Energy conservation is often the most economical solution to energy shortages.

WHY TO CONSERVE ?

- We have limited fuels available on earth.
- Our demand for energy is increasing day-by-day.
- It is possible that someday, most of fuels will be exhausted , and we will have to switch to alternate energy.

ENERGY CONSERVATION IN 'INDIA'

- In India , government has passed " energy conservation bill, 2001 " for better utilization of energy and conservation of the same.

- By this act, it is mandatory for energy intensive sectors to get their "energy audit " conducted by energy auditor.

- Bureau of energy efficiency : this body keeps watch on energy consumption patterns, develops norm for appliances etc.

- Star ratings : BEE has also initiated "star rating system" for electrical appliances e.g. - CFL'S , geysers, refrigerator, etc.

DATA RELATED TO ENERGY CONSUMPTION IN 'INDIA'

¬ About 70% of India's energy generation capacity is from fossil fuels, with coal accounting for 40% of India's total energy consumption followed by crude oil and natural gas at 24% and 6% respectively.

¬By 2030, India's dependence on energy imports is expected to exceed 53% of the country's total energy consumption. In 2009-10, the country imported 159.26 million tonnes of crude oil which amount to 80% of its domestic crude oil consumption .

¬ In India 31% of the country's total imports are oil imports.

What we can do ?

- Always switch off light and fans while going out of room.
- We should not open fridge frequently.
- While going to purchase new products eg. Geysers, television, CFL, etc. insist for ratings ranging from 4-5 .
- Increase everyone's understanding of the benefits of energy efficiency.

What we can do ?

¬**RECYCLE** waste materials into new products to prevent waste of potentially useful materials.

¬**REPLACE** old light bulbs with energy saving fluorescent bulbs. They may cost more, but will save you much more in the long run.

RECYCLING IS AN EXCELLENT WAY OF SAVING ENERGY AND CONSERVING THE ENVIRONMENT.

Do you know that:

¬1 recycled tin would save enough energy to power a television for 3 hours.

¬1 recycled glass bottle would save enough energy to power a computer for 25 minutes.

¬1 recycled plastic bottle would save enough energy to power a 60-watt light bulb for 3 hours.

¬ 70% less energy is required to recycle paper compared with making it from raw materials.

RECYCLE

REDUCE

REUSE

THREE R's

¬ The slogan *reduce, reuse, recycle* is widely used to raise awareness against the use of non-renewable source of energy.

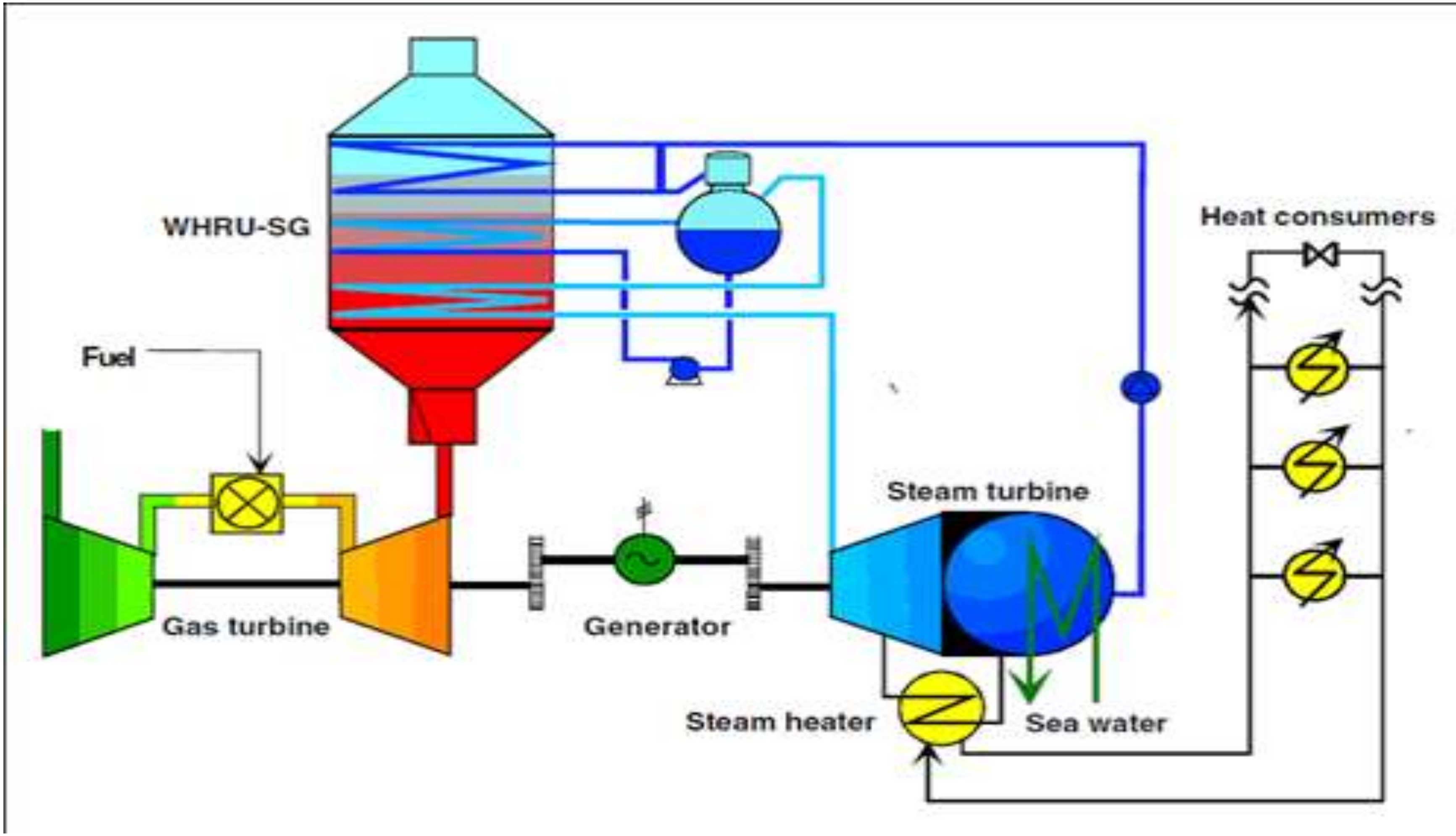
- Reduce consumption
- Reuse manufactured products
- Recycle raw materials

Assignment

Q 1. What is energy conservation ? Why it is needed. Explain recycle, reuse and reduce to conserve energy.

Combined Cycle Plants

Combined cycle power plant



Combined Cycle Plant for Power Generation:

- **Introduction**
- The process for converting the energy in a fuel into electric power involves the creation of mechanical work, which is then transformed into electric power by a generator. Depending on the fuel type and thermodynamic process, the overall efficiency of this conversion can be as low as 30 percent. This means that two-thirds of the latent energy of the fuel ends up wasted. For example, steam electric power plants which utilize boilers to combust a fossil fuel average 33 percent efficiency. Simple cycle gas turbine (GTs) plants average just under 30 percent efficiency on natural gas, and around 25 percent on fuel oil. Much of this wasted energy ends up as thermal energy in the hot exhaust gases from the combustion process.
- To increase the overall efficiency of electric power plants, multiple processes can be combined to recover and utilize the residual heat energy in hot exhaust gases. In combined cycle mode, power plants can achieve electrical efficiencies up to 60 percent. The term "combined cycle" refers to the combining of multiple thermodynamic cycles to generate power. Combined cycle operation employs a heat recovery steam generator (HRSG) that captures heat from high temperature exhaust gases to produce steam, which is then supplied to a steam turbine to generate additional electric power. The process for creating steam to produce work using a steam turbine is based on the Rankine cycle.

Combined Cycle Plant for Power Generation:

- The most common type of combined cycle power plant utilizes gas turbines and is called a combined cycle gas turbine (CCGT) plant. Because gas turbines have low efficiency in simple cycle operation, the output produced by the steam turbine accounts for about half of the CCGT plant output. There are many different configurations for CCGT power plants, but typically each GT has its own associated HRSG, and multiple HRSGs supply steam to one or more steam turbines. For example, at a plant in a 2x1 configuration, two GT/HRSG trains supply to one steam turbine; likewise there can be 1x1, 3x1 or 4x1 arrangements. The steam turbine is sized to the number and capacity of supplying GTs/HRSGs.

Combined Cycle Principles of Operation

- The HRSG is basically a heat exchanger, or rather a series of heat exchangers. It is also called a boiler, as it creates steam for the steam turbine by passing the hot exhaust gas flow from a gas turbine or combustion engine through banks of heat exchanger tubes. The HRSG can rely on natural circulation or utilize forced circulation using pumps. As the hot exhaust gases flow past the heat exchanger tubes in which hot water circulates, heat is absorbed causing the creation of steam in the tubes. The tubes are arranged in sections, or modules, each serving a different function in the production of dry superheated steam. These modules are referred to as economizers, evaporators, superheaters/reheaters and preheaters.

Combined Cycle Principles of Operation

- The economizer is a heat exchanger that preheats the water to approach the saturation temperature (boiling point), which is supplied to a thick-walled steam drum. The drum is located adjacent to finned evaporator tubes that circulate heated water. As the hot exhaust gases flow past the evaporator tubes, heat is absorbed causing the creation of steam in the tubes. The steam-water mixture in the tubes enters the steam drum where steam is separated from the hot water using moisture separators and cyclones. The separated water is recirculated to the evaporator tubes. Steam drums also serve storage and water treatment functions. An alternative design to steam drums is a once-through HRSG, which replaces the steam drum with thin-walled components that are better suited to handle changes in exhaust gas temperatures and steam pressures during frequent starts and stops. In some designs, duct burners are used to add heat to the exhaust gas stream and boost steam production; they can be used to produce steam even if there is insufficient exhaust gas flow.

Combined Cycle Principles of Operation

- Saturated steam from the steam drums or once-through system is sent to the superheater to produce dry steam which is required for the steam turbine. Preheaters are located at the coolest end of the HRSG gas path and absorb energy to preheat heat exchanger liquids, such as water/glycol mixtures, thus extracting the most economically viable amount of heat from exhaust gases.
- The superheated steam produced by the HRSG is supply to the steam turbine where it expands through the turbine blades, imparting rotation to the turbine shaft. The energy delivered to the generator drive shaft is converted into electricity. After exiting the steam turbine, the steam is sent to a condenser which routes the condensed water back to the HRSG.

Cogeneration system and total energy system

Electricity generator that recovers and reuses its own waste heat to generate steam that drives auxiliary turbines to produce additional power is called cogeneration system. It is also called total energy system.

Assignment

Q 1. Explained combined cycle plant for power generation.

Waste Heat Recovery

Training Agenda: Waste

- Introduction
- Type of waste heat recovery
- Assessment of waste heat recovery

Introduction

What is Waste Heat?

- "Dumped" heat that can still be reused
- "Value" (quality) more important than quantity
- Waste heat recovery saves fuel

Introduction

Source and Quality

Table: Waste heat source and quality

S. No	Source of Waste Heat	Quality of Waste Heat
1	Heat in flue gases	The higher the temperature, the greater the potential value for heat recovery
2	Heat in vapour streams	As above but when condensed, latent heat also recoverable
3	Convective & radiant heat lost from exterior of equipment	Low grade – if collected may be used for space heating or air preheats
4	Heat losses in cooling water	Low grade – useful gains if heat is exchanged with incoming fresh water
5	Heat losses in providing chilled water or in the disposal of chilled water	1.High grade if it can be utilized to reduce demand for refrigeration 2.Low grade if refrigeration unit used as a form of Heat pump
6	Heat stored in products leaving the process	Quality depends upon temperature
7	Heat in gaseous & liquid effluents leaving process	Poor if heavily contaminated & thus requiring alloy heat exchanger

Introduction

High Temperature Heat Recovery

Table: Typical waste heat temperature at high temperature range from various sources

Types of Devices	*Temperature (^{0}C)*
Nickel refining furnace	1370 – 1650
Aluminium refining furnace	650 –760
Zinc refining furnace	760 – 1100
Copper refining furnace	760 – 815
Steel heating furnace	925 – 1050
Copper reverberatory furnace	900 – 1100
Open hearth furnace	650 – 700
Cement kiln (Dry process)	620 – 730
Glass melting furnace	1000 – 1550
Hydrogen plants	650 – 1000
Solid waste incinerators	650 – 1000
Fume incinerators	650 – 1450

Medium Temperature Heat Recovery

Table: Typical waste heat temperature at medium temperature range from various sources

Types of Devices	*Temperature (^{0}C)*
Steam boiler exhaust	**230 – 480**
Gas turbine exhaust	**370 – 540**
Reciprocating engine exhaust	**315 – 600**
Reciprocating engine exhaust (turbo charged)	**230 – 370**
Heat treatment furnace	**425 – 650**
Drying & baking ovens	**230 – 600**
Catalytic crackers	**425 – 650**
Annealing furnace cooling systems	**425 – 650**

Introduction

Low Temperature Heat Recovery

Source	*Temperature ⁰C*
Process steam condensate	55-88
Cooling water from: Furnace doors	32-55
Bearings	32-88
Welding machines	32-88
Injection molding machines	32-88
Annealing furnaces	66-230
Forming dies	27-88
Air compressors	27-50
Pumps	27-88
Internal combustion engines	66-120
Air conditioning and refrigeration condensers	32–43
Liquid still condensers	32-88
Drying, baking and curing ovens	93-230
Hot processed liquids	32-232
Hot processed solids	93-232

Table: Typical waste heat temperature at low temperature range from various sources

Waste

Introduction

Type of waste heat recovery

Performance evaluation

TYPE OF WASTE HEAT RECOVERY

Commercial Waste Heat Recovery

Recuperators

- Heat exchange between flue gases and the air through metallic/ceramic walls
- Ducts/tubes carry combustion air for preheating
- Waste heat stream on other side

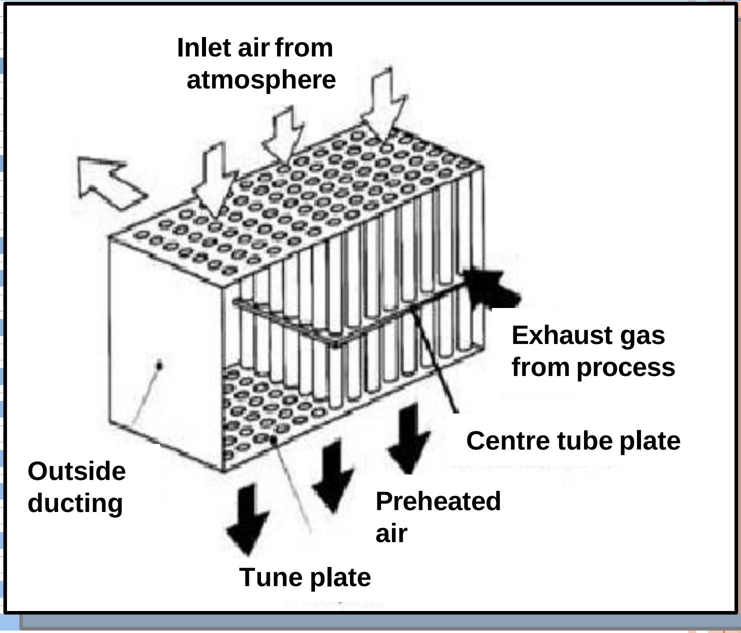


Figure 1 : Waste heat recovery using recuperator, Source: SEAV

Type of Waste Heat Recovery

Commercial Waste Heat Recovery

- **Metallic radiation recuperators**

- **Simplest recuperator**
- **Two metal tubes**
- **Less fuel is burned per furnace load**
- **Heat transfer mosly by radiation**

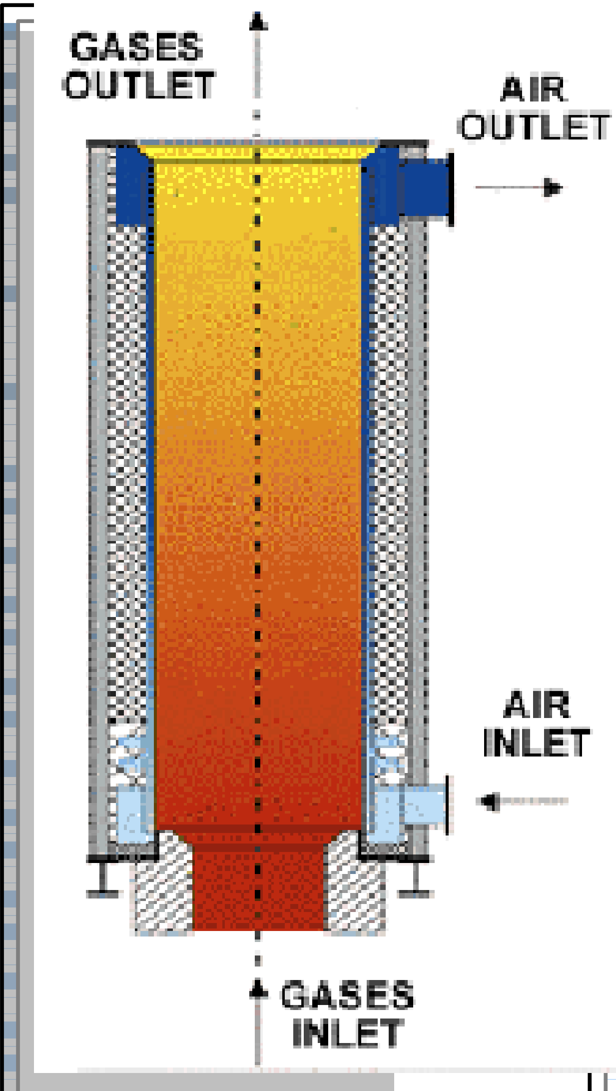


Figure 2. Metallic Radiation Recuperator (Hardtech Group)

Type of Waste Heat Recovery

- Commercial Waste Heat Recovery

Convective recuperators

- Hot gas through parallel small diameter tubes
- Tubes can be baffled to allow gas to pass over them again
- Baffling increases heat exchange but more expensive exchanger is needed

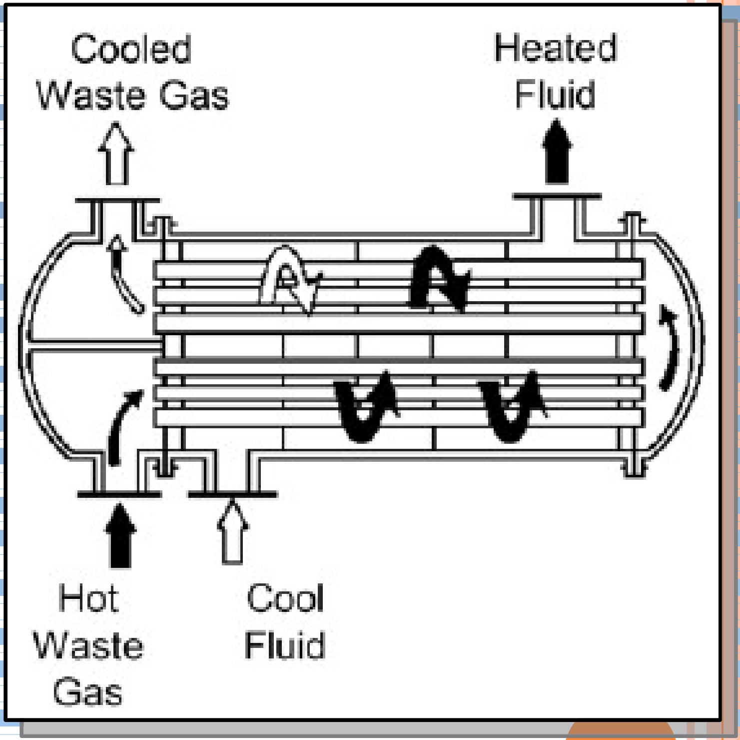


Figure 3. Convective

Type of Waste Heat Recovery

Commercial Waste Heat Recovery

Radiation/convective hybrid recuperators

- Combinations of radiation & convection
- More effective heat transfer
- More expensive but less bulky than simple metallic radiation recuperators

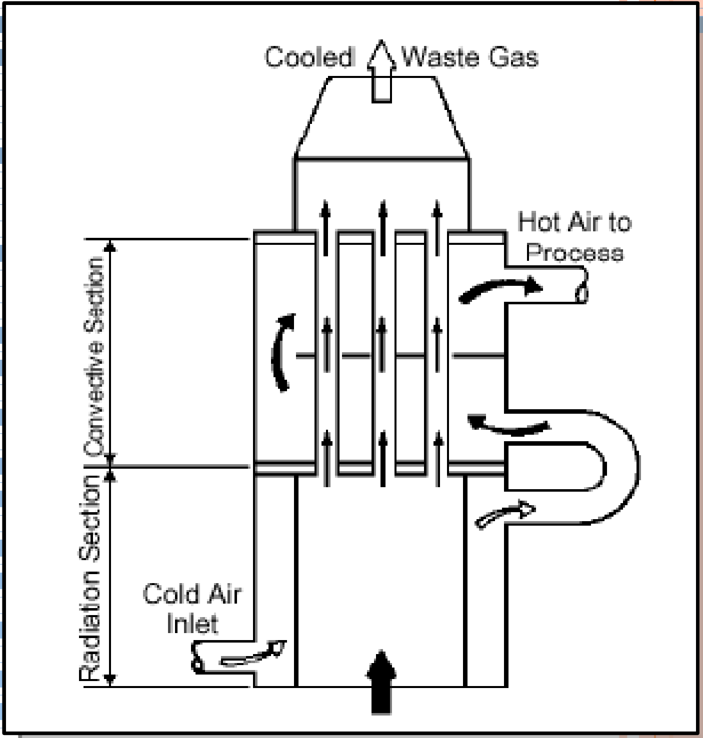


Figure 4. Hybrid Recuperator
(Reay, D.A., 1996)

Type of Waste Heat Recovery

- Commercial Waste Heat Recovery
- Ceramic recuperators
  - **Less temperature limitations:**
    - **Operation on gas side up to 1550 °C**
    - **Operation on preheated air side to 815 °C**
  - **New designs**
    - **Last two years**
    - **Air preheat temperatures <700° C**
    - **Lower leakage rates**

TYPE OF WASTE HEAT RECOVERY

Regenerator

- Large capacities
- Glass and steel melting furnaces
- Time between the reversals important to reduce costs
- Heat transfer in old regenerators reduced by
  - •Dust & slagging on surfaces
  - •heat losses from the walls

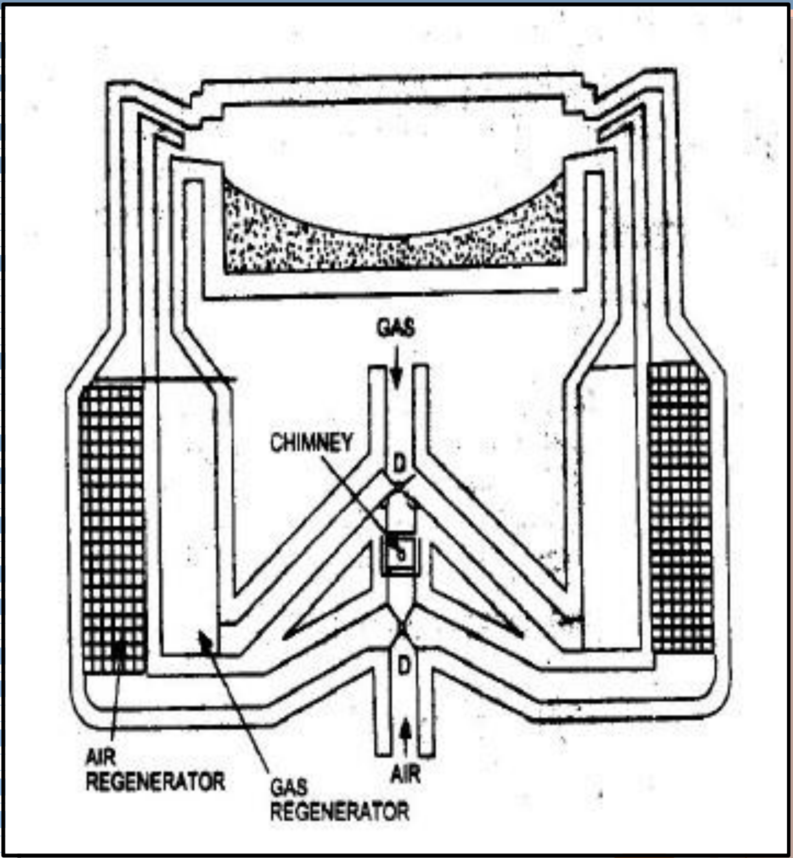


Figure 5. Regenerator
(Department of Coal, India, 1985)

Type of Waste Heat Recovery

Heat Wheels

- Porous disk rotating between two side-by-side ducts
- Low to medium temperature waste heat recovery systems
- Heat transfer efficiency up to 85 %

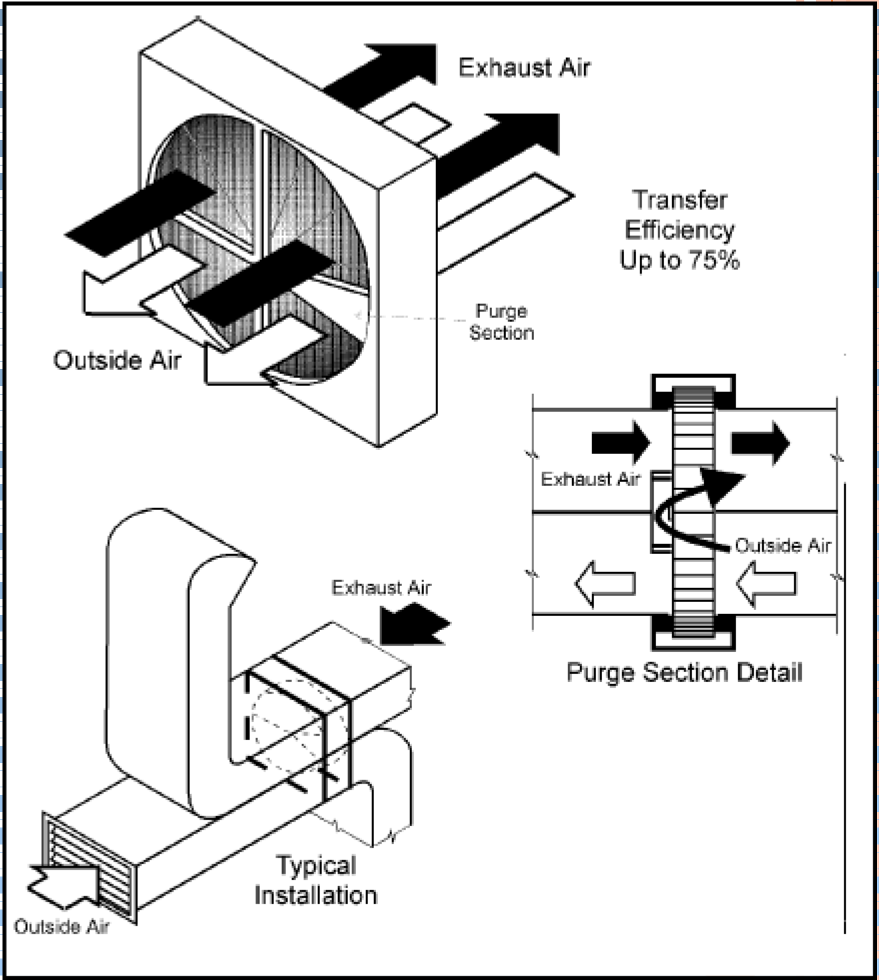


Figure 6. Heat Wheel
(SADC, 1999)

TYPE OF WASTE HEAT RECOVERY

Heat Pipe

- **Transfer up to 100 times more thermal energy than copper**
- **Three elements:**
  - sealed container
  - capillary wick structure -
  working fluid
- **Works with evaporation and condensation**

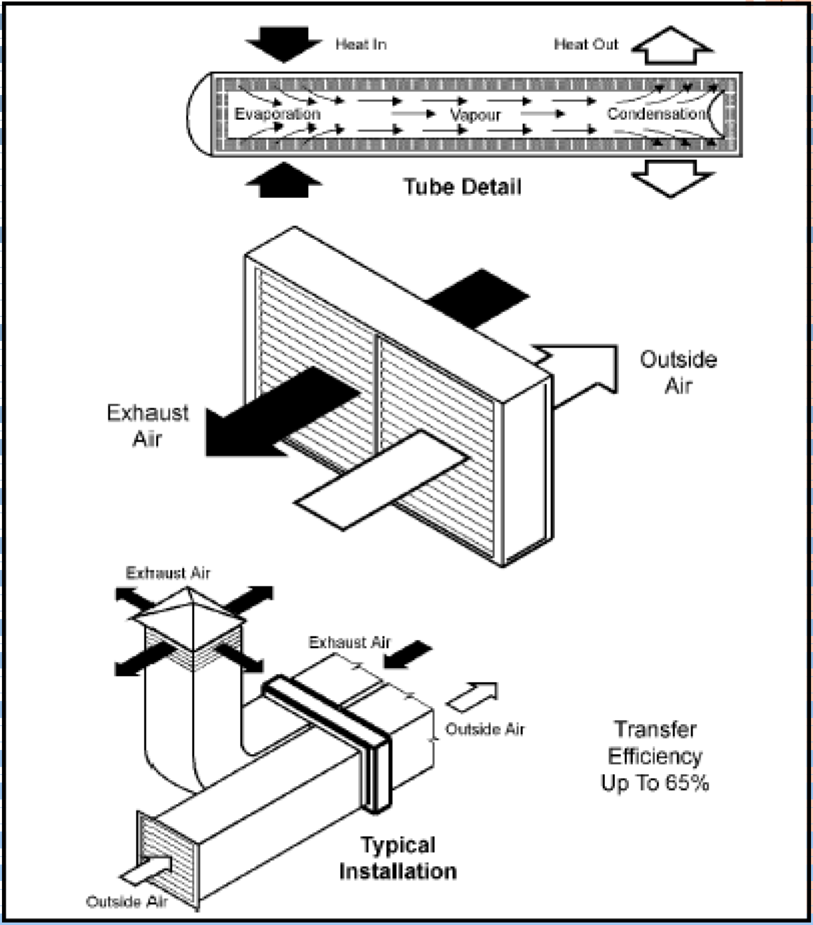


Figure 7. Heat Pipe
(SADC, 1999)

Type of Waste Heat Recovery

Heat Pipe

- **Performance and advantage**

•Lightweight and compact

•No need for mechanical maintenance, input power, cooling water and lubrication systems

•Lowers the fan horsepower requirement and increases the overall thermal efficiency of the system

•Can operate at 315 ◦C with 60% to 80% heat recovery

Type of Waste Heat Recovery

Heat Pipe

- **Typical application**
  - **Process to space heating**
    - **-Transfers thermal energy from process exhaust for building heating**
  - **Process to process**
    - **-Transfers recovered waste thermal energy from the process to the incoming process air**
  - **HVAC applications**
    - **- Cooling and heating by recovering thermal energy**

Type of Waste Heat Recovery

Economizer

- Utilize the flue gas heat for pre-heating the boiler feed water
- 1% fuel savings if
  - •60 ◦C rise of feed water
  - •200 ◦C rise in combustion air temp

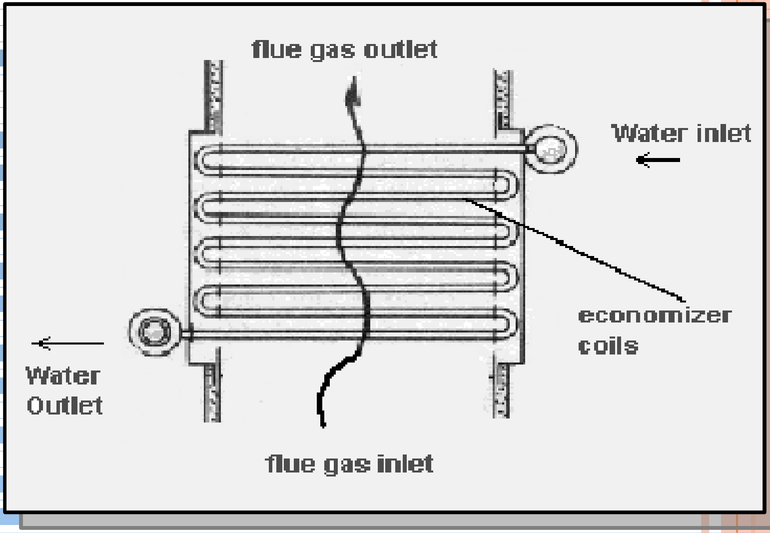


Figure 8. Economizer
(Bureau of Energy Efficiency, 2004)

Type of Waste Heat Recovery

Economizer

Shell and tube heat exchanger

- Used when the medium containing waste heat is a liquid or a vapor that heats another liquid

•Shell contains the tube bundle, and usually internal baffles to direct the fluid

•Vapor contained within the shell

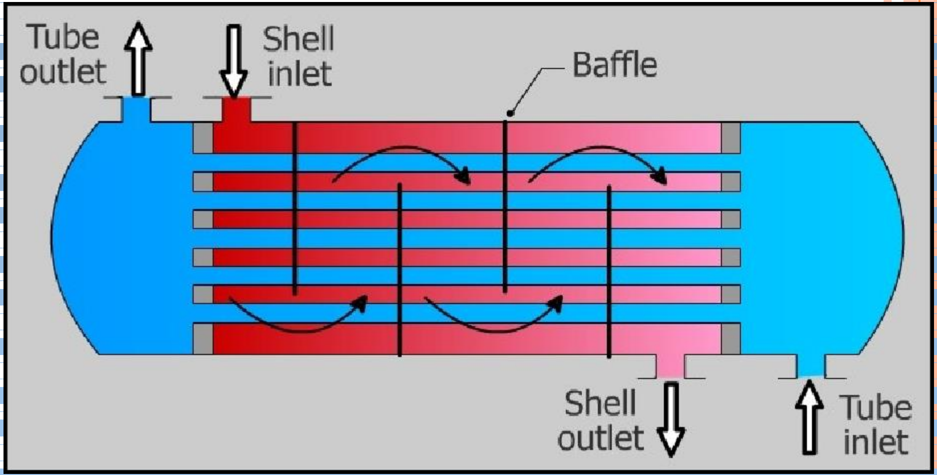


Figure 9. Shell & Tube Heat Exchanger
(King Fahad University of Petroleum & Minerals, 2003)

Type of Waste Heat Recovery

Plate Heat Exchanger

- Parallel plates forming a thin flow pass
- Avoids high cost of heat exchange surfaces

- Corrugated plates to improve heat transfer
- When directions of hot and cold fluids are opposite, the arrangement is counter current

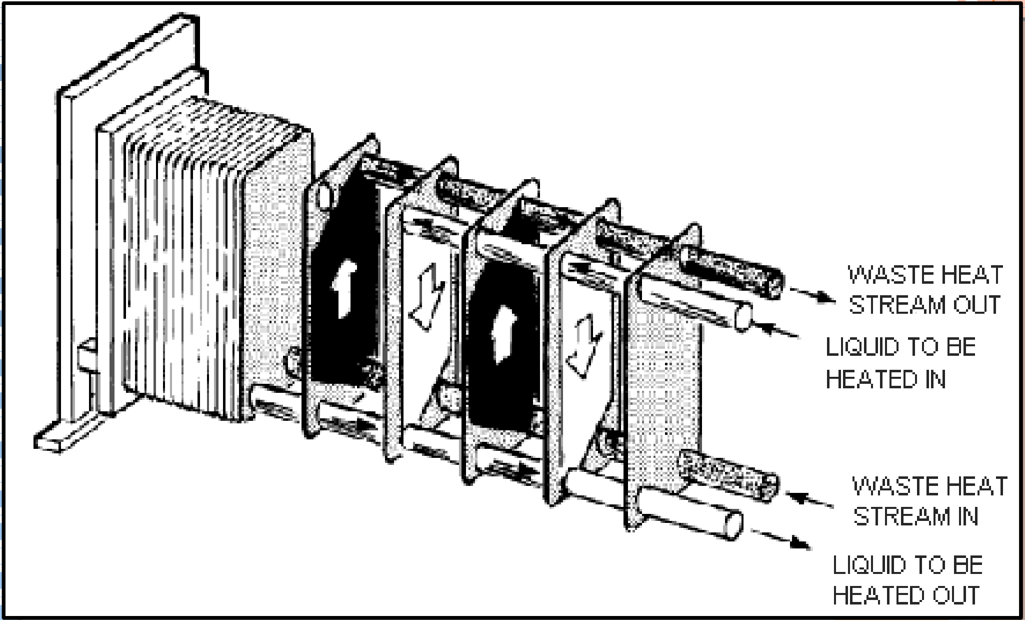


Figure 10. Plate Heat Exchanger
(Canada Agriculture and Agri-Food)

TYPE OF WASTE HEAT RECOVERY

Plate Heat Exchanger

Run around coil exchanger

- **Heat transfer from hot to colder fluid via *heat transfer fluid***
- **One coil in hot stream**
- **One coil in cold stream**

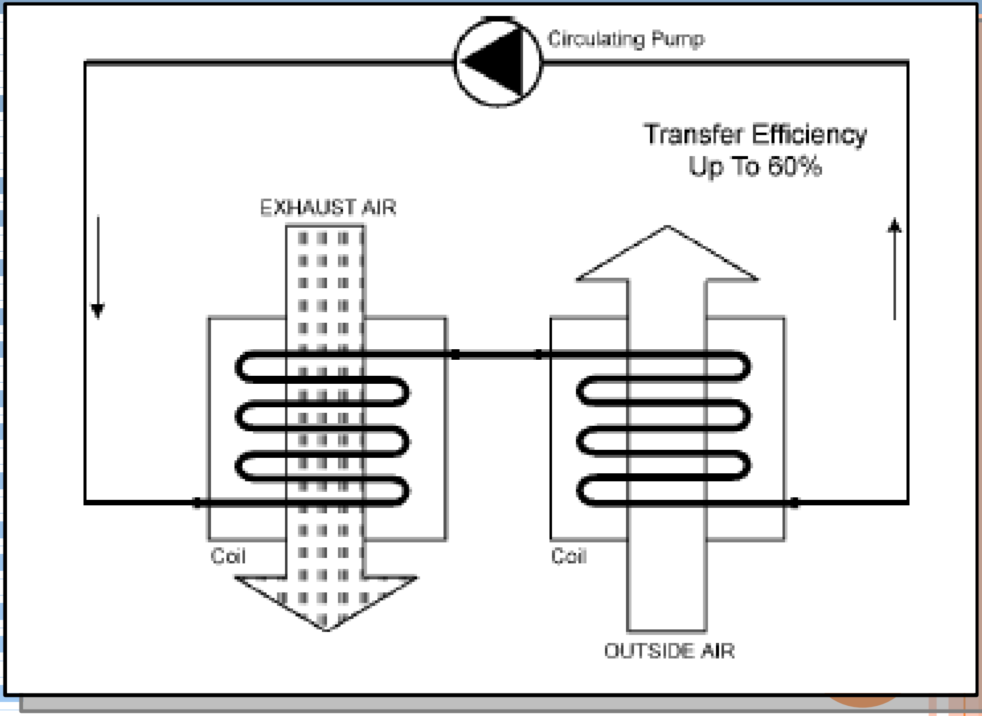


Figure 11. Run Around Coil Exchanger (SADC , 1999)

Type of Waste Heat Recovery

Plate Heat Exchanger

Waste heat boiler

- Water tube boiler: hot exhaust gases pass over parallel tubes with water
- Capacities: 25 m3 to 30,000 m3 /min of exhaust gas

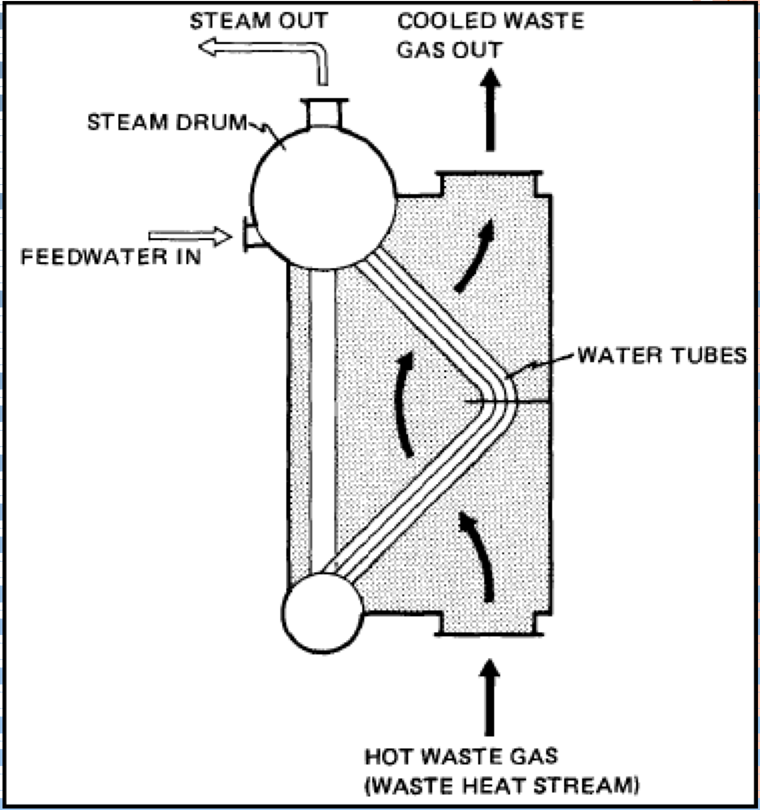


Figure 12. Two-Pass Water Tube Waste Heat Recovery Boiler
(Canada Agriculture and Agri-Food)

Type of Waste Heat Recovery

Heat Pump

The vapour compression cycle

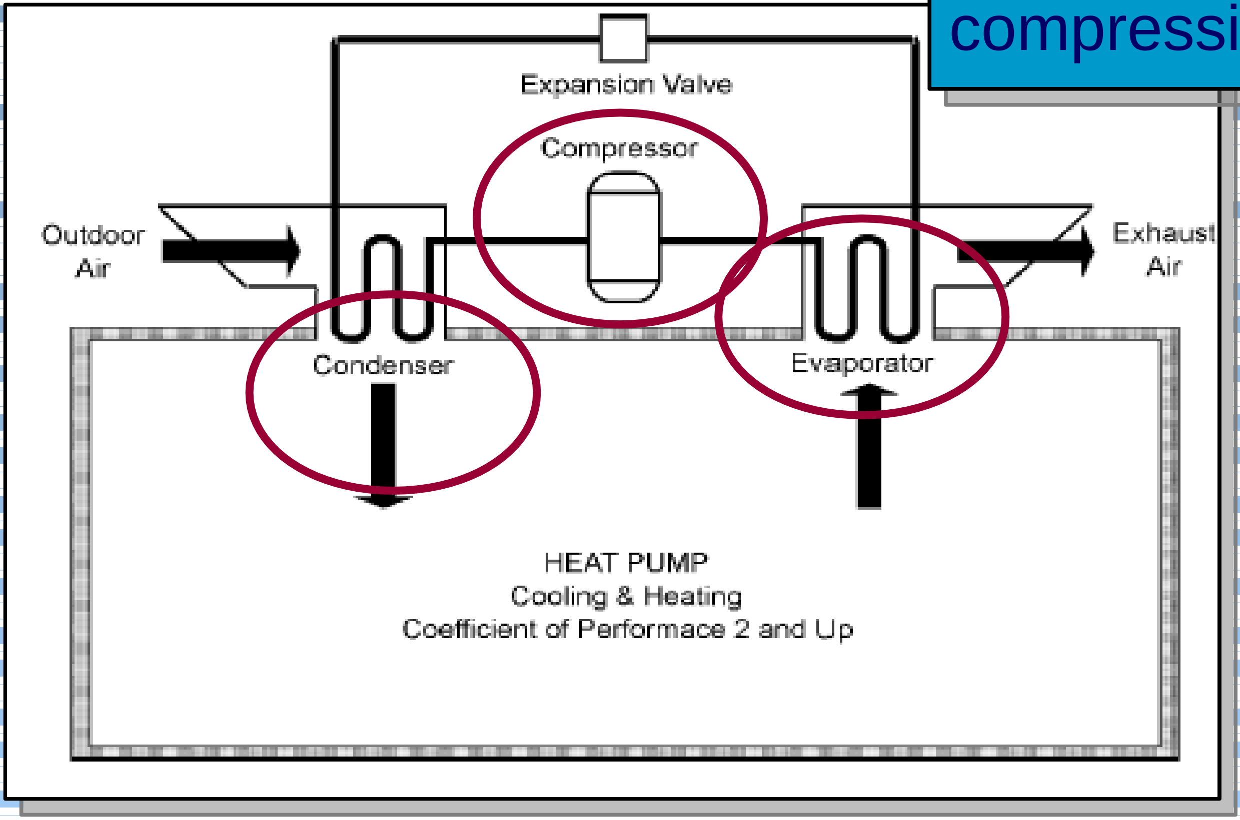


Figure 13. Heat Pump Arrangement
(SADC, 1999)

Type of Waste Heat Recovery

Heat Pump

- Developed as a space heating system
- Can upgrade heat >2X the energy consumed by the device
- Most promising when heating and cooling capabilities are combined

Type of Waste Heat Recovery

Heat Pump

Thermo compressor

- Compress low-pressure steam by very high-pressure steam and reuse as medium pressure steam
- Nozzle for acceleration of HP steam to a high velocity fluid.

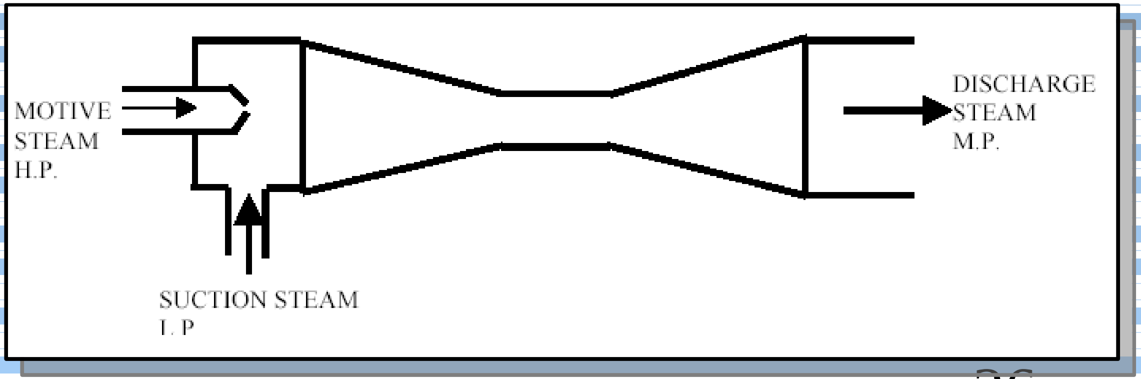


Figure: Thermo compressor

Waste

Introduction

Type of waste heat recovery

Assessment of waste heat recovery

Assessment of waste heat recovery

Heat Losses

Quality:

- **Higher temperatures = Higher quality = Lower heat recovery costs**

Quantity:

- **The amount of recoverable heat can be calculated as:**

$$Q = V \times \rho \times Cp \times \Delta T$$

Q = heat content in kCal

V = the flow rate of the substance in m^3/hr

ρ = density of the flue gas in kg/m^3

Cp = the specific heat of the substance in kCal/kg ^oC

Δ T = the temperature difference in ^oC

Cp (Specific heat of flue gas) = 0.24 kCal/kg/^oC

Assessment of waste heat recovery

Heat Saving Calculation Example

Saving money by recovering heat from hot waste water:

- **Discharge of the waste water is 10000 kg/hr at 75◦C**
- **Preheat 10000 kg/hr of cold inlet water of 20◦C**
- **A heat recovery factor of 58%**
- **An operation of 5000 hours per year**

The annual heat saving (Q) is:

$$Q = m \times Cp \times \Delta T \times \eta$$

Assessment of waste heat recovery

Heat Saving Calculation Example

m = 1000 kg/hr = 10000 x 5000 kg/yr = 50000000 kg/year

Cp = 1 kCal/kg ◦C

ΔT = (75 – 20) ◦C = 55 ◦C

η = Heat Recovery Factor = 58% or 0.58

⇒ Q = 50000000 x 1 x 55 x 0.58
= 1595000000 kCal/year

GCV of Oil = 10,200 kCal/kg

Equivalent Oil Savings = 159500000 / 10200 = 156372 L

Cost of Oil = 0.35 USD/L

Monetary Savings = 54730 USD/Annum

Assignment

Q 1. Write a note on type of waste heat recovery.