Bio Power Plants

Introduction:

Bio Power Plants (also known as Biomass Power Plants) are facilities that generate electricity or heat by converting organic materials (biomass) into energy. Biomass can include materials such as wood, agricultural residues, animal waste, or even organic waste from landfills.

Types of Bio Power Plants:

1. **Direct Combustion Power Plants:** These burn biomass directly to produce heat.
2. **Co-firing Power Plants:** These plants use biomass alongside coal or other fossil fuels, reducing the need for coal and lowering carbon emissions.
3. **Combined Heat and Power (CHP) Systems**: These systems generate both electricity and useful heat from biomass, improving overall efficiency.

Bio Power generation routes:

Biomass power generation refers to the process of producing electricity, heat, or biofuels from organic materials (biomass). There are several different biomass power generation routes based on the technology and conversion processes used to transform biomass into usable energy. The main routes are:

1. **Combustion:** Biomass is burned in a boiler to produce heat, which is then used to generate steam. The steam drives a turbine connected to a generator to produce electricity.
2. **Gasification:** Biomass is heated at high temperatures with limited oxygen, causing it to decompose into a mixture of gases (syngas). This syngas can be used to generate electricity or can be converted into biofuels.
3. **Anaerobic Digestion:** Organic waste materials, such as agricultural waste, food waste, and manure, are broken down by microorganisms in the absence of oxygen. This process produces biogas (primarily methane), which can be used for power generation.
4. **Pyrolysis:** Biomass is rapidly heated in the absence of oxygen to produce solid biochar, liquid bio-oil, and gaseous products. Bio-oil can be used as a fuel for power generation.

5. **Fermentation:** Biomass, such as crops like corn or sugarcane, is fermented to produce ethanol, which can be used in electricity generation through combustion or in transportation as a biofuel.
6. **Biochemical Conversion:** Biomass, particularly lignocellulosic materials (like wood), is broken down by enzymes to produce sugars. These sugars can then be fermented into ethanol or other biofuels
7. **Algal Biofuel Production**: Algae are cultivated to produce oils that can be converted into biodiesel. These oils can be used to generate electricity or power vehicles.
8. **Co-firing with Coal**: Biomass is mixed with coal in traditional coal-fired power plants to reduce coal consumption and greenhouse gas emissions.

Brayton cycle :

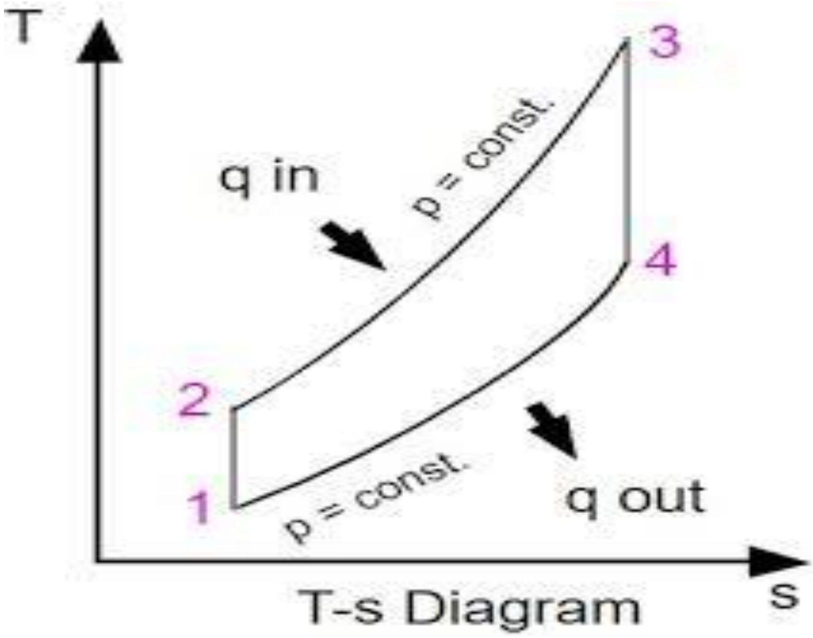
The Brayton cycle is a thermodynamic cycle that describes the operation of gas turbines and jet engines. It involves the compression of air, its subsequent heating (via combustion), expansion through a turbine, and exhaust. This cycle is used in biomass gasification (for biomass power plants), natural gas, and other turbine-driven systems. Block and T-s diagram is shown in Figure.

Basic Steps of the Brayton Cycle:

1. **Compression (Isentropic Compression)**:
   Air is compressed adiabatically (no heat exchange) in the compressor. This increases the pressure and temperature of the air. The temperature and pressure increase as the air is compressed, but entropy remains constant (isentropic process).
2. **Heat Addition (Constant Pressure Combustion)**:
   The compressed air is then heated at constant pressure by burning fuel (e.g., biomass-derived syngas, natural gas). The heat added increases the temperature and internal energy of the air. The air is heated at constant pressure, causing a large increase in both temperature and entropy.
3. **Expansion (Isentropic Expansion)**:
   The high-pressure, high-temperature air expands through a turbine. The expansion produces mechanical work, which drives the compressor and generates electricity through a generator. The high-temperature air expands in the turbine,

decreasing in temperature and pressure. This is an isentropic expansion, and the entropy increases as work is done by the turbine.

4. **Heat Rejection (Constant Pressure Exhaust)**:
   The exhaust gases exit the turbine at a lower temperature and pressure. This stage completes the cycle, and the exhaust gases are expelled. The exhaust gases exit the turbine, losing energy at constant pressure.



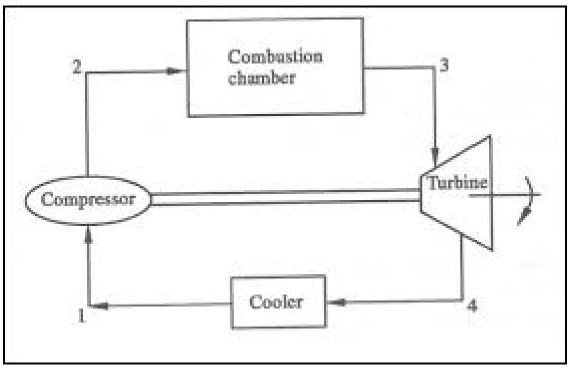


Fig: Brayton cycle block diagram

Rankine cycle: The Rankine cycle is a fundamental thermodynamic cycle used in power plants, to convert heat energy into mechanical work. It is a steam-based cycle that involves the conversion of water into steam, the expansion of steam to do work in a turbine, and the condensation of steam back into water to repeat the process.

Components of the Rankine Cycle:

1. Boiler: Burns biomass to generate heat, turning water into high-pressure steam.

2. Turbine: Expands the high-pressure steam, which spins a turbine to generate electricity.

3. Condenser: Cools the exhaust steam from the turbine and converts it back into water.

4. Pump: Increases the pressure of the condensed water, returning it to the boiler

Working: There are four processes in the Rankine Cycle

1. **Isentropic Compression (Process 1-2: Pumping Water):** The process starts by pumping the liquid water (at low pressure and temperature) from the condenser to the boiler at high pressure. In this stage, the water is compressed in a pump. The pump does work on the water, increasing its pressure from low-pressure conditions to high-pressure conditions. This compression process is considered isentropic, meaning that the entropy (a measure of disorder) remains constant during the compression (in an ideal case). On the Temperature-Entropy (T-S) diagram, this process is represented by a nearly vertical line moving upward because the pressure increases with little change in temperature.

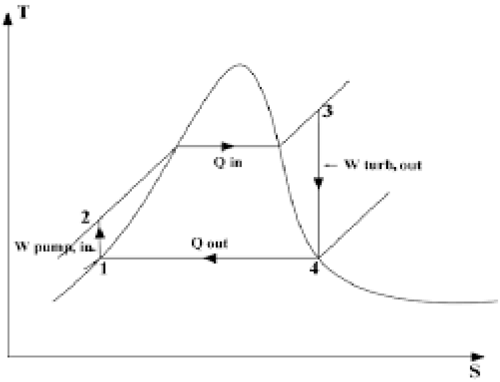
2. **Isobaric Heat Addition (Process 2-3: Boiler or Heater):**

   The high-pressure water is then sent to the boiler or heater, where it is heated at constant pressure. Biomass combustion in the furnace or boiler generates the heat required to raise the water's temperature. The water undergoes a phase change from liquid to steam as it absorbs heat. The temperature of the steam rises from the boiling point (at the given pressure) to its maximum temperature, typically between 400°C and 600°C. On the T-S diagram, this process appears as a horizontal line where the temperature increases as heat is added at constant pressure.

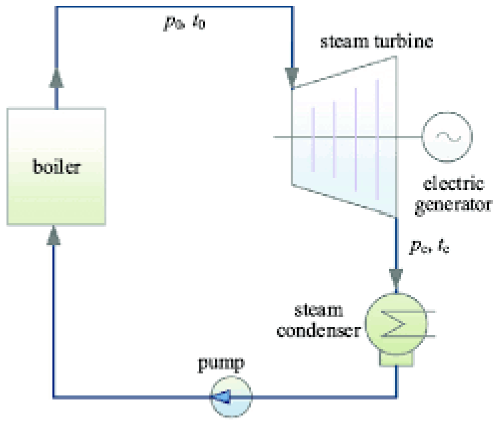
3. **Isentropic Expansion (Process 3-4: Turbine Expansion)**:
   The high-pressure, high-temperature steam enters the turbine, where it expands and does mechanical work by spinning the turbine blades. As the steam expands in the turbine, its pressure and temperature drop, and it undergoes an isentropic expansion (entropy increases during this process, but ideally, the expansion is adiabatic with no heat exchange). The turbine converts the steam's thermal energy into mechanical energy, which is used to drive a generator to produce electricity. On the T-S diagram, this process appears as a downward curve, as the steam expands (pressure and temperature decrease) while doing work.

4. **Isobaric Heat Rejection (Process 4-1: Condensation)**:

After the steam expands in the turbine, it enters the condenser, where it is cooled and condensed back into liquid water at constant pressure. The exhaust steam from the turbine is cooled by a cooling medium (such as water or air) and is condensed back into liquid water. This process removes heat from the system, lowering the steam's temperature and pressure. The condensed water is now at low pressure and temperature and is ready to be pumped back to the boiler to repeat the cycle. On the T-S diagram, this process is represented as a horizontal line moving to the left, as heat is rejected at constant pressure, and the steam's temperature and entropy decrease.



T-s diagram



Block diagram

Co-generation cycle:

In biomass power plants, the co-generation cycle is an important process that simultaneously generates both electricity and useful heat. This is achieved by capturing the waste heat from the Rankine cycle (which generates electricity) and using it for heating purposes, improving the overall efficiency of the system.

Co-generation, also known as combined heat and power (CHP), is widely used in biomass plants because it allows the plant to make use of both the electricity and the thermal energy produced by the combustion of biomass, such as wood pellets, agricultural residues, or waste materials. By utilizing this waste heat, biomass cogeneration systems can operate more efficiently, reducing fuel consumption and minimizing environmental impact.

The basic concept behind a co-generation cycle in a biomass power plant is that the biomass is burned to generate heat. This heat is then used in a Rankine cycle to generate electricity. After the steam passes through the turbine to generate electricity, the remaining thermal energy from the steam is captured and used for heating applications (such as district heating, industrial processes, or drying biomass fuel).

Processes in the Co-generation Cycle:(working):

The co-generation cycle in a biomass power plant typically follows a Rankine cycle, but with additional components to capture and use waste heat. Here are the key processes:

1. **Biomass Combustion:**

   Biomass fuel is burned in a boiler to produce heat. The combustion of biomass generates high-temperature, high-pressure steam**.** The heat from combustion drives the Rankine cycle, producing steam that powers a turbine to generate electricity.

2. **Electricity Generation (Rankine Cycle):**

   The high-pressure steam from the boiler enters the turbine and expands to generate mechanical energy, which is then converted to electrical energy by a generator. After passing through the turbine, the steam is cooled in the condenser, which converts the steam back into liquid water.

3. **Heat Recovery:**

   After the steam has passed through the turbine and the exhaust steam is condensed in the condenser, the remaining thermal energy can be recovered and used for heating.The heat recovery system captures this thermal energy from the exhaust steam and directs it to an external system, such as district heating (providing heat to nearby buildings), industrial heating (for processing materials), or drying biomass. In some systems, a portion of the heat from the exhaust steam is also used to preheat the feedwater before it enters the boiler, improving the overall efficiency.

4. **Water Pumping:**

   After condensation, the cooled water is pumped back into the boiler to begin the cycle again. The pump raises the pressure of the water before it enters the boiler for re-heating.

RANKINE WITH COGENERATION