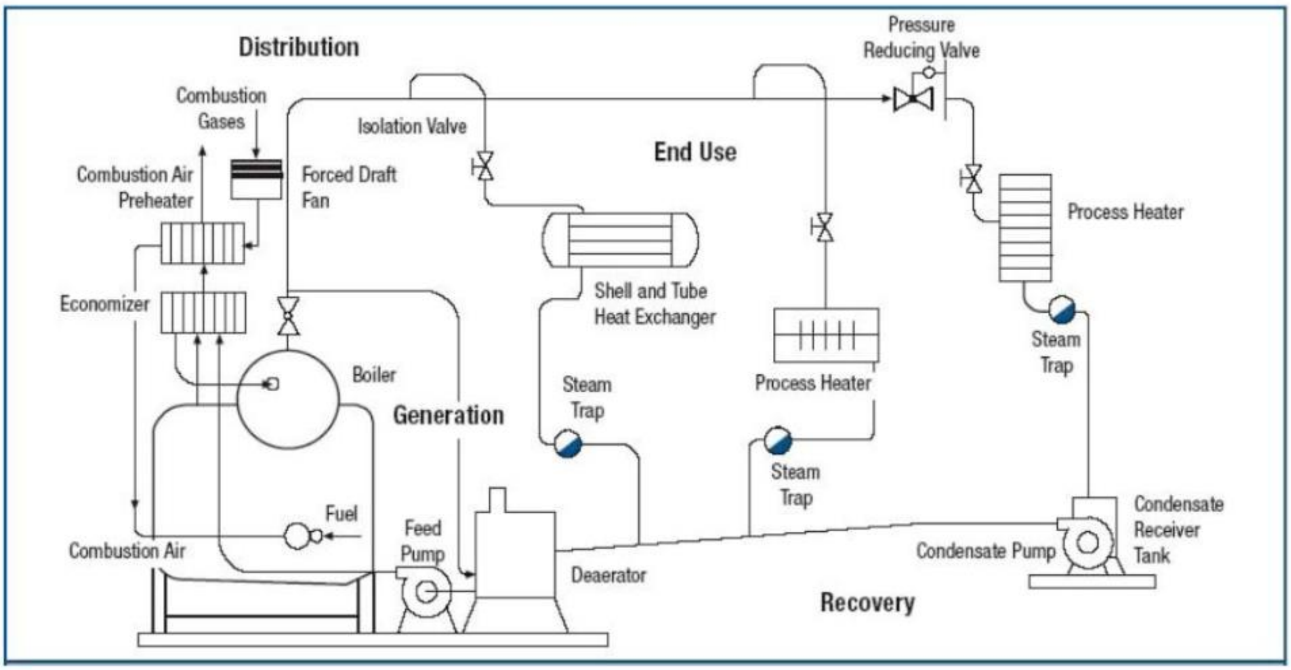
STEAM

STEAM GENERATION IN CHEMICAL PROCESS PLANTS

Steam is a principle energy source for chemical industrial processes. It provides energy for process heating, pressure control, mechanical drives, and component separation, and is also a source of water for many industrial operations and chemical reactions. The popularity of steam as an energy source stems from its many advantages, which include low toxicity, transportability, high efficiency, high heat capacity, and low production costs relative to other energy transport mediums. [Steam Source Document DOE]



A process steam system consists of the four categories listed below:

- generation
- distribution
- end use
- recovery

GENERATION

Steam is normally generated in a boiler or waste heat recovery device by transferring heat from hot combustion gases or other hot process streams to water. The water absorbs the heat, facilitating the phase change necessary to produce steam. The steam is then transferred under pressure from the boiler to the distribution system. In general, two types of boilers are used to generate steam.

• Firetube boilers—Combustion gases pass through tubes, transferring heat to boiler water flowing over the tubes on the shell side. Benefits of this type of boiler include low initial costs as well as efficiency and durability. The boilers are limited, however, to lower pressure steam production temperatures, generally not exceeding 300 psig, due to the steam being contained in the shell.

• Water tube boilers—Boiler water passes through tubes while hot gases contained on the shell side circulate over the outside of the tubes, transferring heat. The fact that the steam is contained in the tubes and not the shell allows for much higher pressure steam production, on the order of up to 3000 psig is practical. For this reason, and due to their high efficiency, water tube boilers are ideal for applications that require saturated or superheated steam, especially those applications insisting on dry, high pressure, high heat energy steam. About 60% of the steam produced in the chemical industry lies in the range of 300 to 1000 psig. [Steam Assess DOE]

The two boiler types listed are both fuel-fired boilers; in addition, heat recovery devices such as waste heat recovery boilers (WHRB), heat recovery steam generators (HRSG), superheaters, and economizers are used in industry to generate steam.

DISTRIBUTION

The distribution system is critical because it carries the pressurized steam produced in the boilers to the end-use operations. Systems often have numerous take-off lines that operate at different steam pressures, which are achieved by using isolation valves, pressure regulating valves, and, in some cases, back pressure turbines to separate take-off lines from the original headers. The goal of any distribution system is to deliver to the end-user sufficient quantities of steam at a specified temperature and pressure. An efficient system requires proper pressure balance and regulation, good condensate drainage, and proper insulation. [Steam Source DOE] Typical steam distribution system components include:

• piping
• proper insulation
• valves or turbines
• steam separators, accumulators, and traps

END USE

Steam end-use equipment transfers steam energy into other useful forms of energy that can then be used further in process applications.

The most common operational end uses employed by chemical manufacturers include: [Steam Asses DOE]

- stripping
- fractionation
- power generation
- mechanical drive
- process heating
- quenching
- dilution
- vacuum draw
- pressure regulation
- injection
- source of process water

Stripping

Steam is often used to facilitate the separation of components. In stripping towers, steam pulls unwanted contaminants from a process fluid. The steam used in these applications is not directly returned because the effluent has too many unwanted substances.

Fractionation

In fractionation towers, steam is used to assist in the separation of chemical products that contain components with different boiling points. Steam is injected in the bottom of the towers along
with a feedstock. The steam helps carry the more volatile products up the tower where they condense on trays that are maintained at the condensation temperature of the desired products. The steam provides a mass transport medium, helps prevent deposition on hot surfaces, and provides favorable viscosity properties of the product within the tower.

Power Generation

In power generation, steam is often used to drive turbines, which, in turn, spin electric generators. Many chemical plants meet their electric power needs with a mixture of purchased power and on-site generation. The ratio between purchased power and self-generated power depends on several factors, including cost of electricity, availability, and capacity of on-sited power generation, anonymous on-sited demand for steam.

STEAM AND ITS PROPERTIES

Steam is the gaseous phase of water. It utilizes heat during the process and carries large quantities of heat later. Hence, it could be used as a working substance for heat engines. Steam is generated in boilers at constant pressure. Generally, steam may be obtained starting from ice or straight away from the water by adding heat to it. Steam exists in following states or types or conditions.

(i) Wet steam (saturated steam)

(ii) Dry steam (dry saturated steam)

(iii) Superheated steam

(iv) Supersaturated steam water, which is one of the Pure Substance, exists in three phases:
(i) Solid phase as ice (freezing of water)
(ii) Liquid phase as water (melting of ice)
(iii) Gaseous phase as steam (vaporization of water)
Water could be used as coolant and water vapor is used as a working fluid for the operation of Steam Engines and Steam Turbines.

Dryness Fraction of Saturated Steam (x or q)

It is a measure of quality of wet steam. It is the ratio of the mass of dry steam (mg) to the mass of total wet steam (mg +mf), where mf is the mass of water vapor.

X= mg

mg + mf

Quality of Steam

It is the representation of dryness fraction in percentage: Quality of Steam = x X 100

Wetness Fraction

It is another measure of quality of wet steam. It is the ratio of the mass of water vapor (mf) to the mass of total wet steam

(mg +mf)

Wetness fraction in mf = (1-x)

mg +mf

Priming

It is the representation of wetness fraction in percentage.

Priming = (I - x) 100

Note: Quality + Priming = 100%

Density of Steam (p), kg/m3

It is the mass of steam per unit of volume of steam at the given pressure and temperature. It is the reciprocal of the specific volume.

P= 1/v

Internal (True) Latent Heat (internal Energy of Steam) (U), kj/kg

It is the energy required to change the phase. Hence, it is the actual heat energy stored in the steam above O'C. It may be calculated by subtracting the external work of evaporation from the enthalpy. U=h-E

External Work of Evaporation (E), kj/kg

It is the fraction of the latent heat of vaporization which does an external work in moving the piston at constant pressure due to increase in volume.

Enthalpy (h), kj/kg

It is the total amount of heat received by 1 kg of water from O"C at constant pressure to convert it to desired form of steam. It is the sum of the internal energy and work done at constant pressure process, which is equal to change in enthalpy.

Let U Internal energy, dU = Change in internal energy

h Enthalpy (heat received), A = Change in enthalpy

Q Heat supplied, dQ = Change in heat supplied

P Pressure, dP = Change in pressure

v Volume, du = Change in volume

Then by definition Enthalpy Internal energy + Work done

$h = U + PV$

From 1st Law of thermodynamics, $dQ = dU + d(Pv)$

$= dU + V\,dP + P\,dv$

$= dU + d(Pv) - v\,dP$

$= d\,(U + Pu) - v\,dP$

since, for a constant pressure process, $dP = 0$

$dQ = d(U + Pv)$

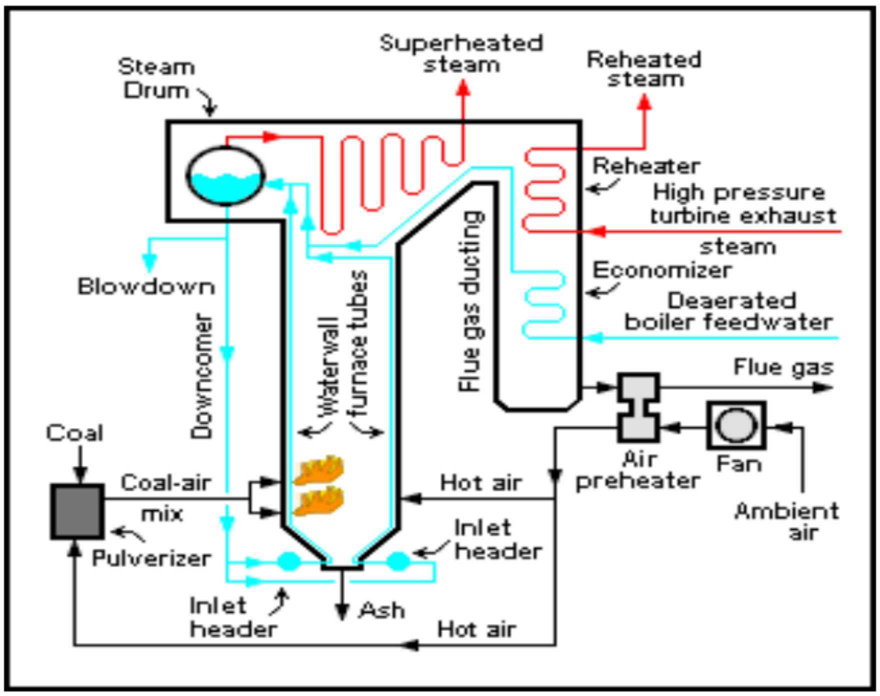
BOILERS AND POWER GENERATION EQUIPMENTS

A **boiler** or **steam generator** is a device used to create steam by applying heat energy to water. Although the definitions are somewhat flexible, it can be said that older steam generators were commonly termed *boilers* and worked at low to medium pressure (1–300 psi or 6.895–2,068.427 kPa) but, at pressures above this, it is more usual to speak of a *steam generator*.

A boiler or steam generator is used wherever a source of steam is required. The form and size depends on the application: mobile steam engines such as steam locomotives, portable engines and steam-powered road vehicles typically use a smaller boiler that forms an integral part of the vehicle; stationary steam engines, industrial installations and power stations will usually have a larger separate steam generating facility connected to the point-of-use by piping. A notable exception is the steam-powered fireless locomotive, where separately-generated steam is transferred to a receiver (tank) on the locomotive.

Steam generator (component of prime mover)

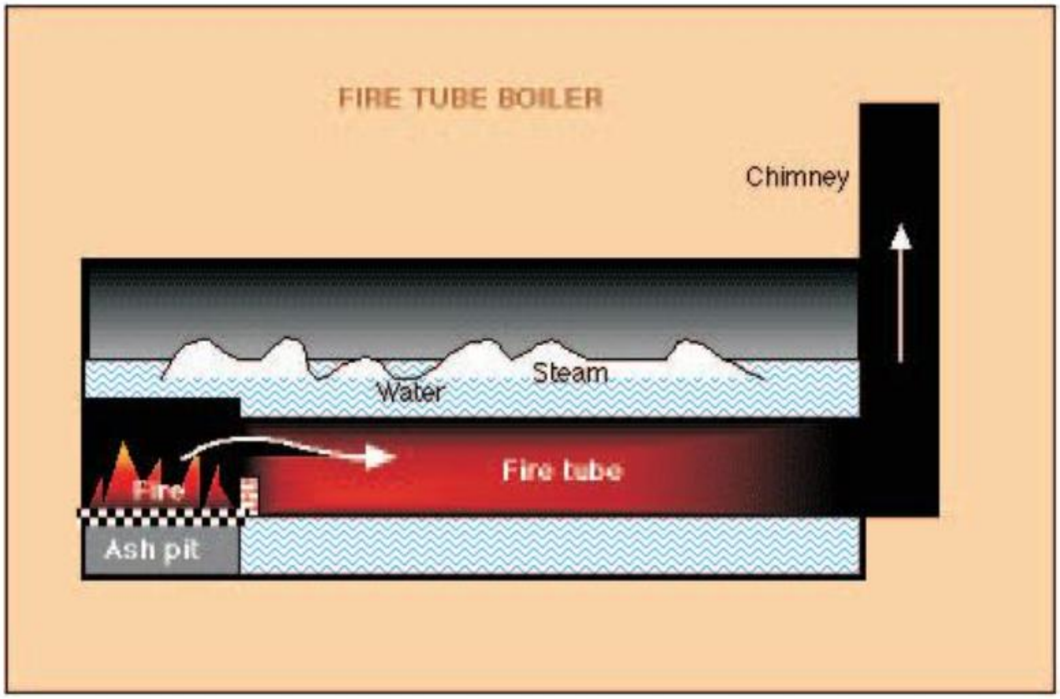
The steam generator or boiler is an integral component of a steam engine when considered as a prime mover. However it needs be treated separately, as to some extent a variety of generator types can be combined with a variety of engine units. A boiler incorporates a firebox or furnace in order to burn the fuel and generate heat. The generated heat is transferred to water to make steam, the process of boiling. This produces saturated steam at a rate which can vary according to the pressure above the boiling water. The higher the furnace temperature, the faster the steam production. The saturated steam thus produced can then either be used immediately to produce power via a turbine and alternator, or else may be further superheated to a higher temperature; this notably reduces suspended water content making a given volume of steam produce more work and creates a greater temperature gradient, which helps reduce the potential to form condensation. Any remaining heat in the combustion gases can then either be evacuated or made to pass through an economiser, the role of which is to warm the feed water before it reaches the boiler.



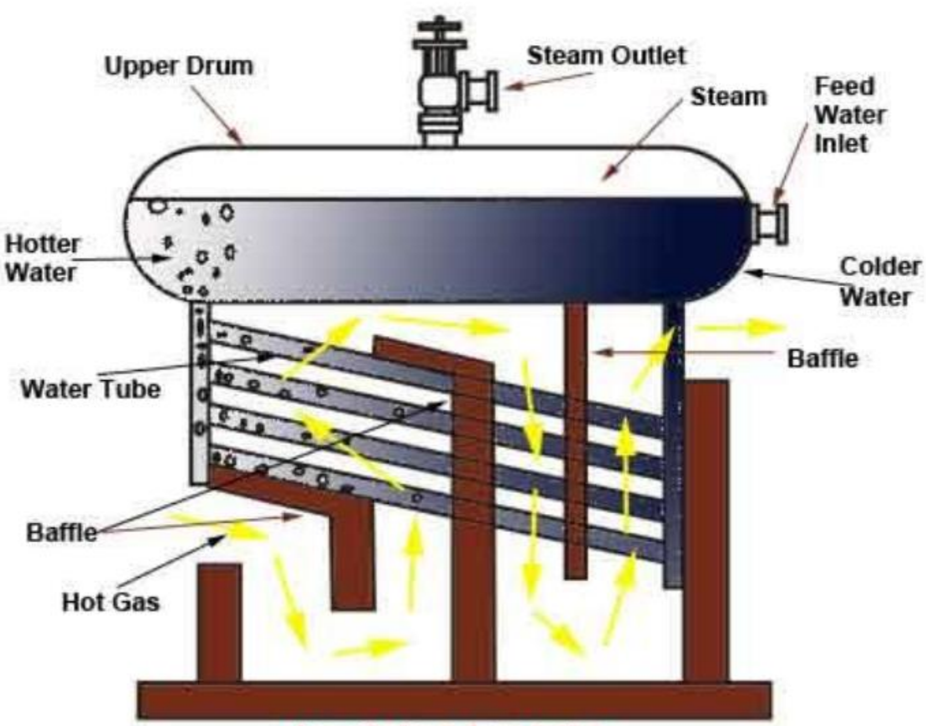
Type of **steam generator** unit used in coal-fired power plants

There are virtually infinite numbers of boiler designs but generally they fit into one of two categories:

Fire tube or "fire in tube" boilers; contain long steel tubes through which the hot gasses from a furnace pass and around which the water to be converted to steam circulates. Fire tube boilers, typically have a lower initial cost, are more fuel efficient and easier to operate, but they are limited generally to capacities of 25 tons/hr and pressures of 17.5 kg/cm^2.



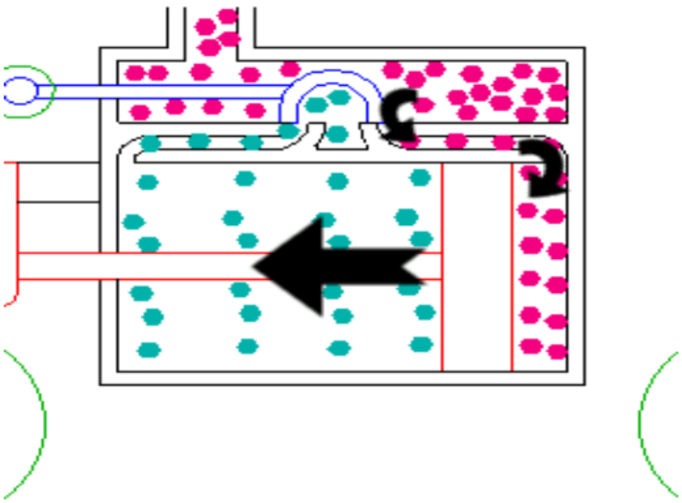
Water tube or "water in tube" boilers in which the conditions are reversed with the water passing through the tubes and the hot gasses passing outside the tubes . These boilers can be of single- or multiple-drum type. These boilers can be built to any steam capacities and pressures, and have higher efficiencies than fire tube boilers.



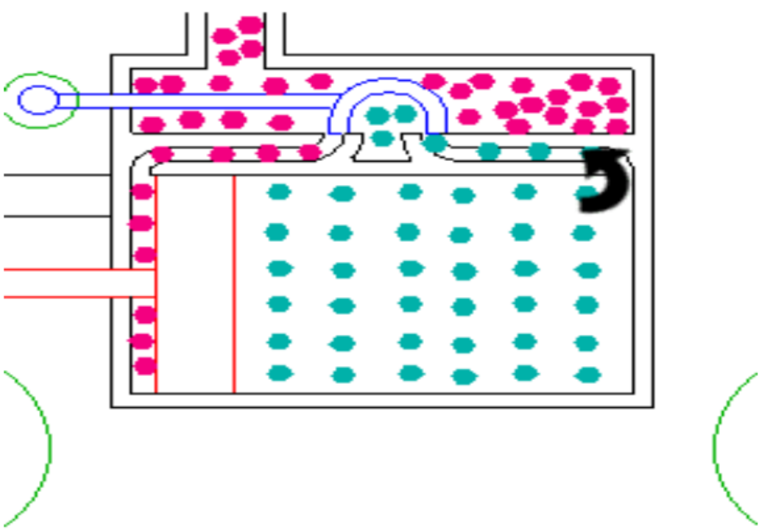
Longitudinal drum boiler

STEAM ENGINE

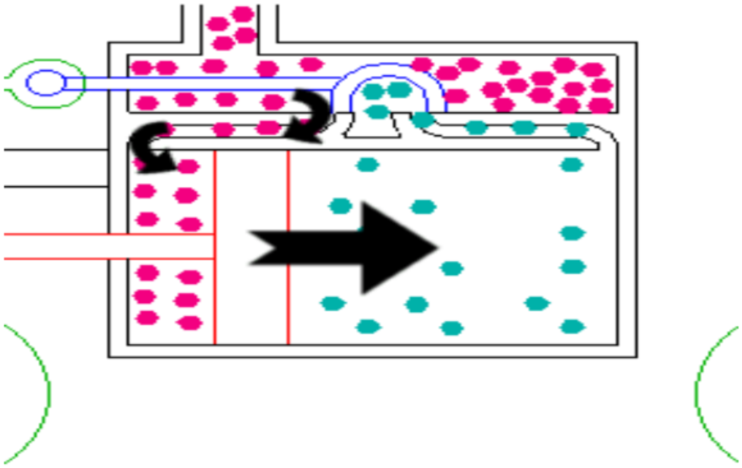
Steam from the boiler enters the *steam chest* and is admitted to the front end of the cylinder by the valve slide (illustrated in blue). The high pressure steam presses the piston backward, driving the engine wheels around one half turn



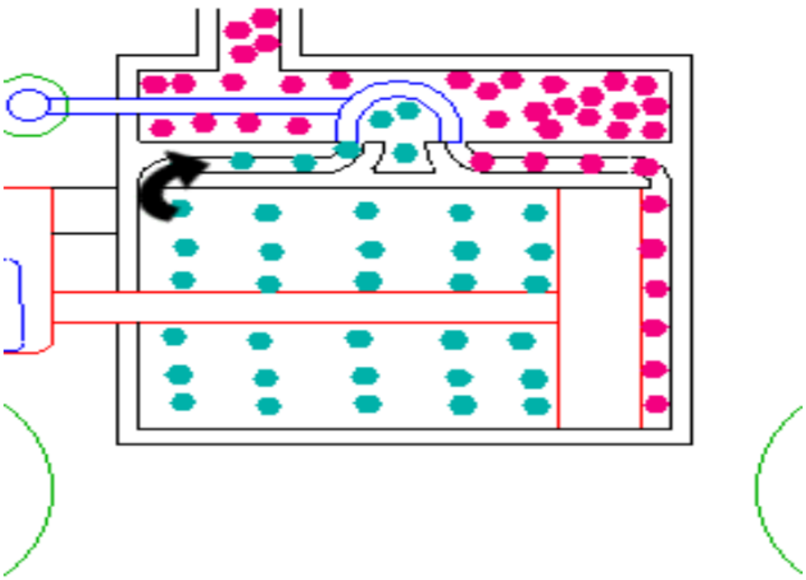
At the end of the piston stroke the valve shifts, allowing the expended steam to escape through the exhaust port (underneath the blue valve slide).



At the same time, the valve slide begins admitting high pressure steam to the back end of the cylinder. This presses the piston forward, pulling the engine wheels around another half turn.

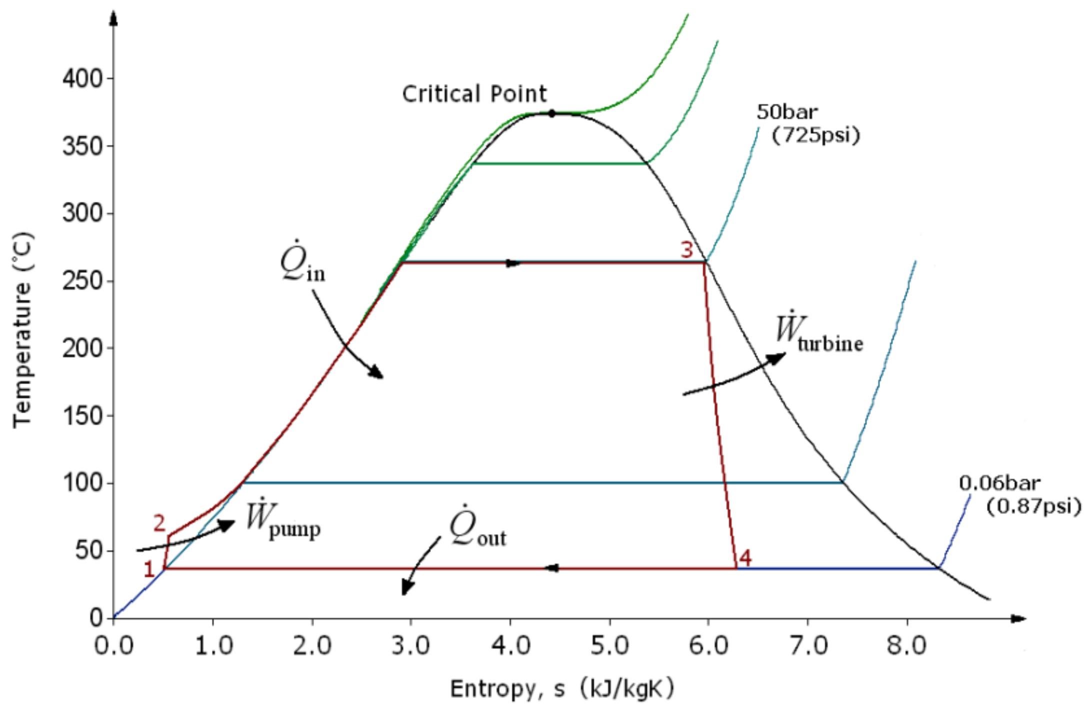


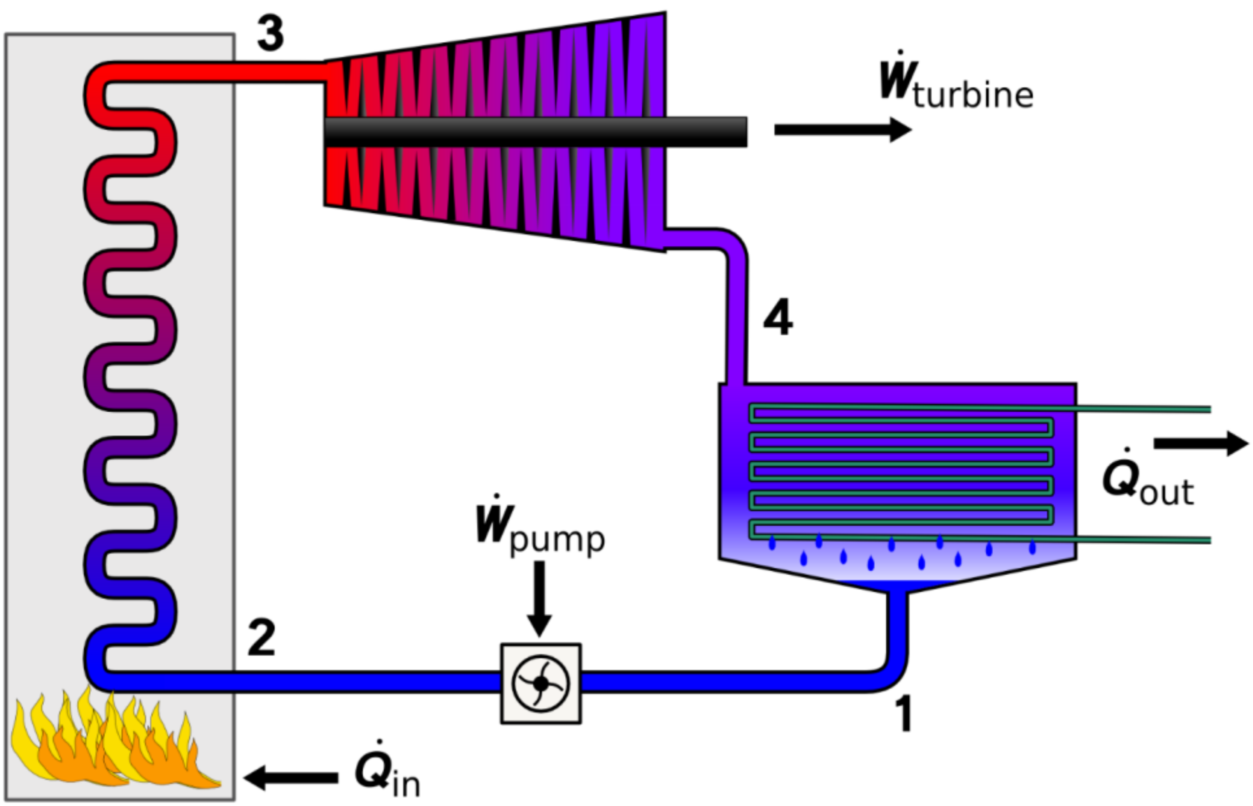
At the end of the forward stroke, the steam is released from the rear portion of the cylinder



Rankine Cycle

- **Process 1-2**: The working fluid is pumped from low to high pressure, as the fluid is a liquid at this stage the pump requires little input energy.
- **Process 2-3**: The high pressure liquid enters a boiler where it is heated at constant pressure by an external heat source to become a dry saturated vapor.
- **Process 3-4**: The dry saturated vapor expands through a turbine, generating power. This decreases the temperature and pressure of the vapor, and some condensation may occur.
- **Process 4-1**: The wet vapor then enters a condenser where it is condensed at a constant pressure and temperature to become a saturated liquid. The pressure and temperature of the condenser is fixed by the temperature of the cooling coils as the fluid is undergoing a phase-change.





Rankine Cycle