CONDENSERS AND CONDENSER COOLING SYSTEMS

INTRODUCTION

Conventional cooling methods of thermal power plants are extremely water intensive processes.

Once-through cooling needs large natural bodies of water (ocean, sea or major river) and disposing the waste heat into them causes thermal pollution.

Evaporative (wet) cooling towers require significant amounts of make-up water, emit vapor plumes with the related drawbacks, meanwhile discharge concentrated cooling water blow-down, which may pollute the surroundings.

The use of dry cooling systems completely eliminate the need for cooling tower make-up water. Emitting only warm and clean air, it has no adverse environmental effects, while freeing power plants from dependence on water sources.

CONDENSERS

The function of the condenser is to condense exhaust steam from the steam turbine by rejecting the heat of vaporisation to the cooling water passing through the condenser.

Once the steam has passed through the turbine, it enters the condenser where heat is removed until it condenses back into liquid water.

This is done by passing the wet steam around thousands of small cold water tubes.

The cold water is usually supplied from a nearby sea, lake, river, or from a cooling tower.

The condensed steam is collected at the bottom of the condenser and returned to the boiler using feedwater pumps, to begin the water-to-steam, steam-to-water cycle again.

The temperature of the condensate determines the pressure in the steam/condensate side of the condenser.

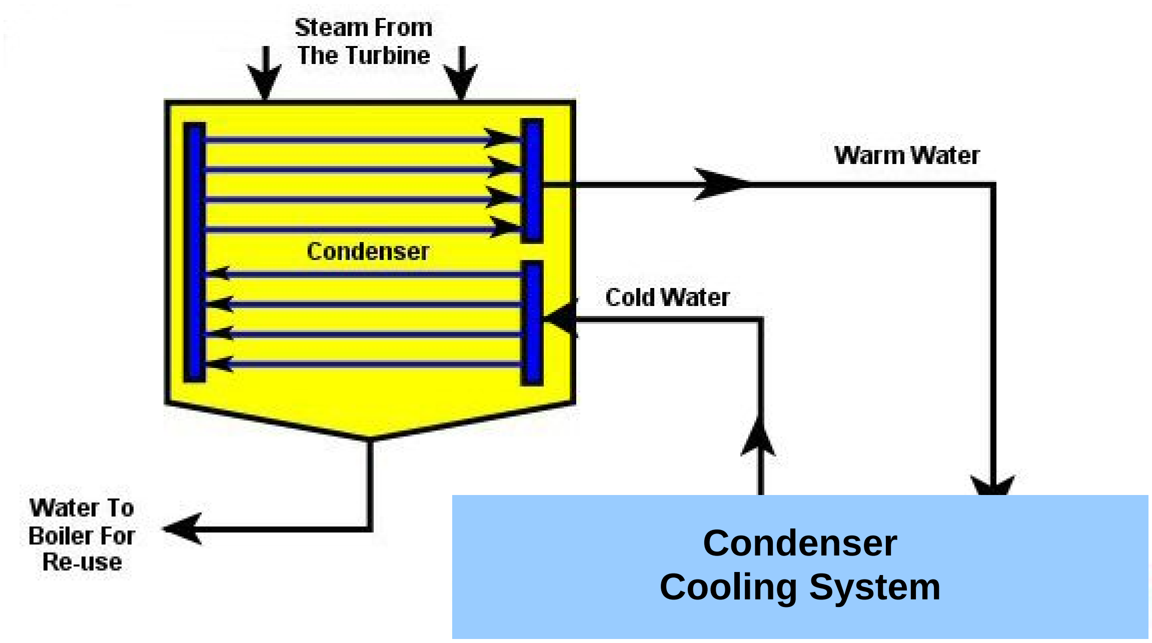
This pressure is called the turbine backpressure and is usually a vacuum.

Decreasing the condensate temperature will result in a lowering of the turbine backpressure and increasing turbine power output and efficiency.

The condenser also has the following secondary functions:

- The condensate is collected in the condenser hot well, from which the condensate pumps take their suction;
- Provide short-term storage of condensate;
- Provide a low-pressure collection point for condensate drains from other systems in the plant; and
- Provide for de-aeration of the collected condensate.

A typical power plant condenser has the following functional arrangement.



Typical Arrangement of Steam Turbine Condenser

Large power plant condensers are usually 'shell and tube' heat exchangers.

These types of condensers are also classified:

- As single pressure or multi-pressure, depending on whether the cooling water flow path creates one or more turbine backpressures;
- By the number of shells (which is dependent on the number of low-pressure turbine casings); and
- As either single pass or two-pass, depending on the number of parallel water flow paths through each shell.

Other types of condensers are:

- Plate types consisting of a series of parallel plates that provide paths for the steam and the cooling water. Plate condensers are used mainly for smaller power plants; and
- Direct contact types where the cooling water is sprayed directly into the steam. This type of condenser is used in applications where the cooling water is the same quality as the steam condensate. Systems that have dry cooling sometime use direct contact condensers.

The parts of shell and tube condensers and plate condensers involved in the transfer of heat from the steam and condensate to the cooling water should have the following properties:

- Be resistant to corrosion from both the steam/condensate and the cooling water;
- Have a minimal resistance to the flow of heat from the steam/condensate through the material into the cooling water; and
- Provide mechanisms to remove organic and inorganic deposits on the heat transfer surfaces in contact with the cooling water.

TYPES OF COOLING SYSTEMS

The choice between evaporative and dry cooling systems is basically an economic one in regions of inadequate water supplies.

Some power plants have an open cycle (once through) cooling water system where water is taken from a body of water, such as a river, lake or ocean, pumped through the plant condenser and discharged back to the source.

Inland plants away from large water bodies prefer to use closed cycle wet cooling system with wet cooling towers.

Power plants in remote dry areas without economic water supplies use closed cycle dry cooling systems that do not require water for cooling.

Hybrid cooling systems are used in particular circumstances.

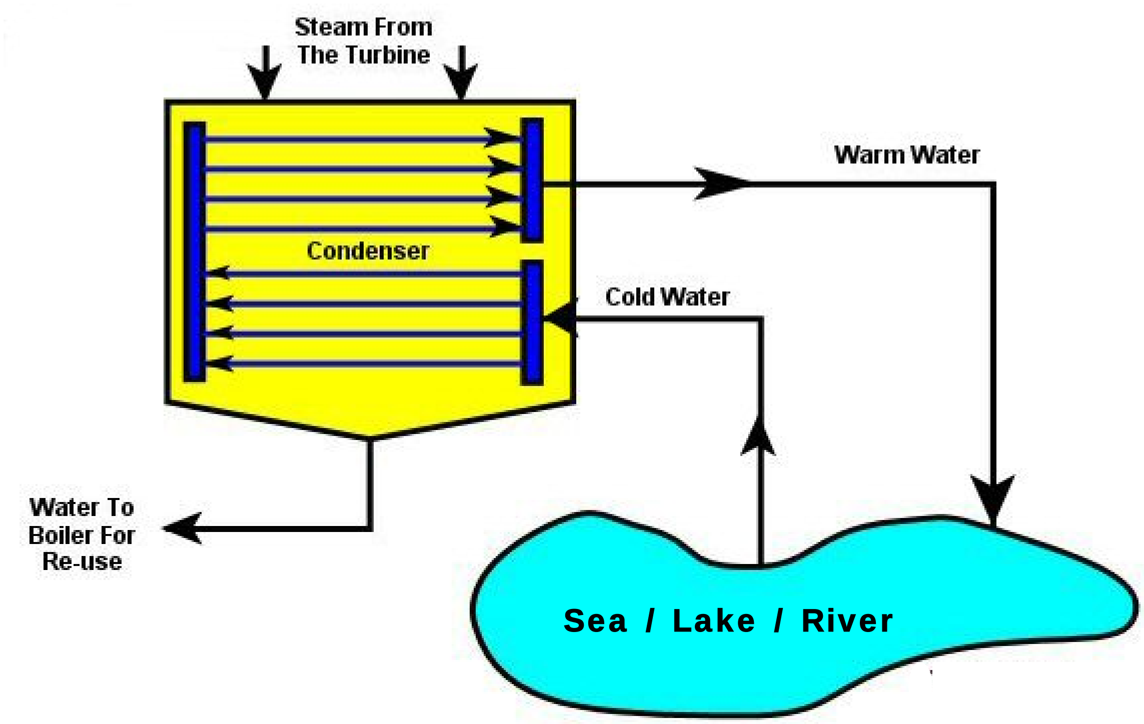
The type of cooling system used is therefore heavily influenced by the location of the plant and on the availability of water suitable for cooling purposes.

The selection process is also influenced by the cooling system's environmental impacts.

OPEN CYCLE COOLING SYSTEMS

Open cycle (once through) cooling systems may be used for power plants sited beside large water bodies such as the sea, lakes or large rivers that have the ability to dissipate the waste heat from the steam cycle.

In the open system, water pumped from intakes on one side of the power plant passes through the condensers and is discharged at a point remote from the intake (to prevent recycling of the warm water discharge).

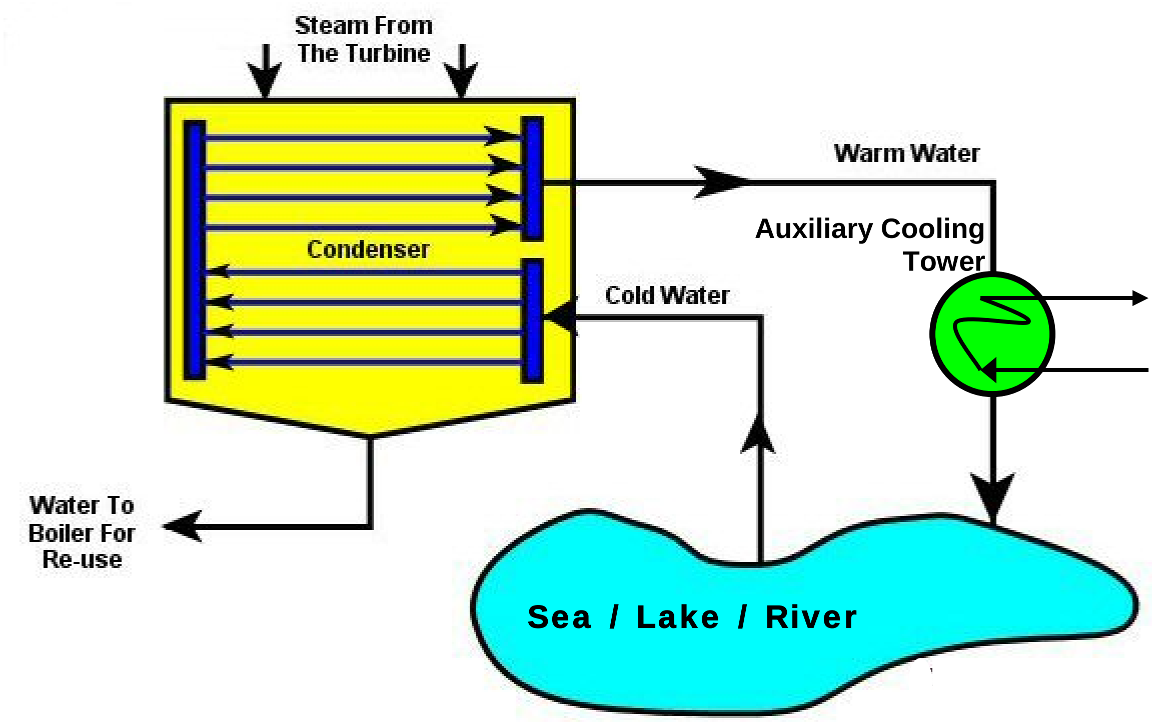


OPEN CYCLE COOLING SYSTEM

Environmental requirements have become more stringent on the allowable rise in temperature of the receiving waters, so that in many countries worldwide, often open cycle cooling systems are used only when sea water is available and for inland power plant installations, closed cooling systems are more commonly used.

OPEN CYCLE WITH AUXILIARY COOLING TOWER

In this system, cooling towers are installed on the discharge from open systems in order to remove part of the waste heat, so that the load on the receiving waters is contained within pre set limits.



OPEN-CYCLE WITH AUXILIARY COOLING TOWER

Systems with auxiliary cooling towers are common in Germany and France where cooling supplies are drawn from the large rivers.

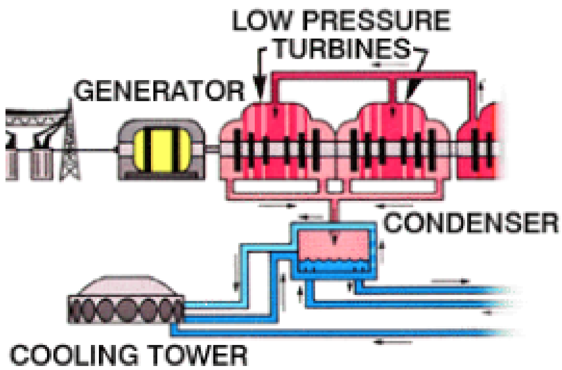
The auxiliary cooling towers are used in the warmer summer periods to limit the temperature of the discharged cooling water, usually to less than 30ºC.

Open cycle systems typically have high flow rates and relatively low temperature rises to limit the rise in temperature in the receiving waters. A typical 300 MW unit would have a flow of some 13m^3/second to 17m^3/second .

CLOSED CYCLE WET COOLING SYSTEMS

In closed cycle wet cooling systems, the waste energy that is rejected by the turbine is transferred to the cooling water system via the condenser.

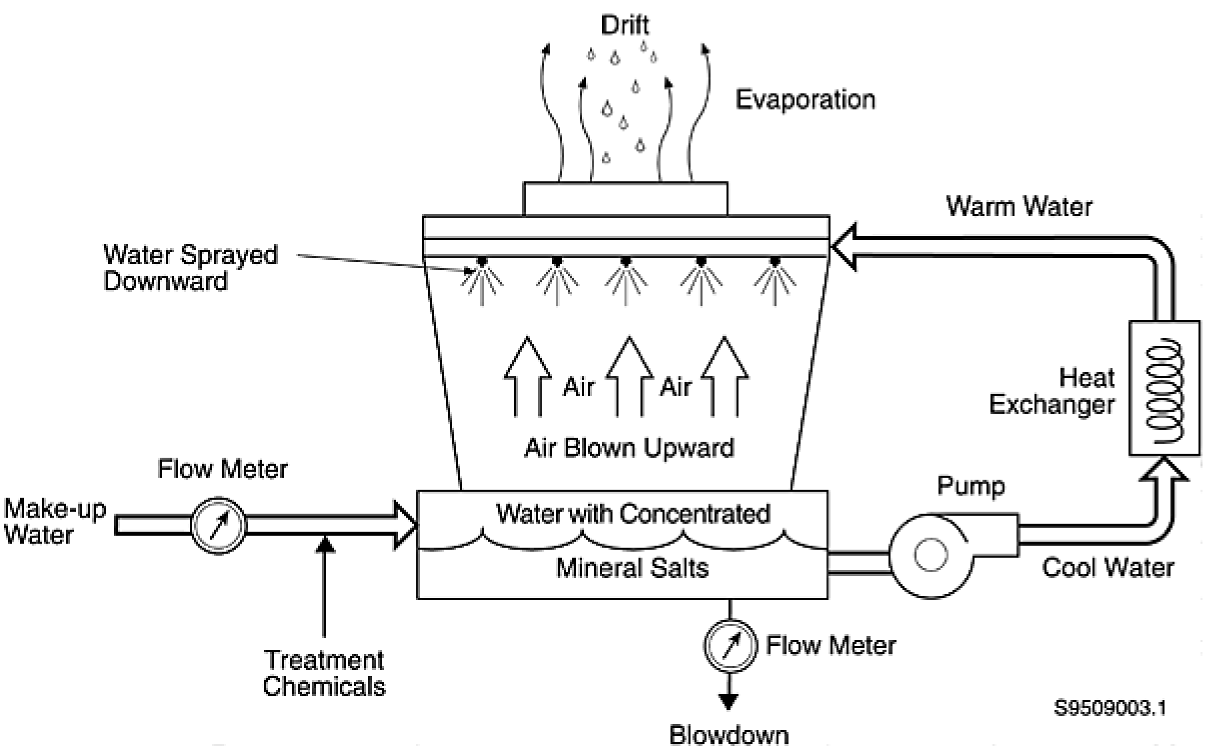
The waste heat in the cooling water is then discharged to the atmosphere by the cooling tower.



TYPICAL ARRANGEMENT OF STEAM TURBINE WITH COOLING TOWER

In the cooling tower, heat is removed from the falling water and transferred to the rising air by the evaporative cooling process.

The falling water is broken up into droplets or films by the extended surfaces of the tower 'fill'. This 'fill' is very often manufactured from plastic.



TYPICAL ARRANGEMENT OF WET COOLING TOWER

Some of the warm water, typically 1% to 1.5% of the cooling water flow, is transferred to the rising air, and this is visible in the plume of water vapour above towers in times of high humidity.

The evaporation rates of typical cooling systems are in range 1.8 litres of water per kWh of power generated.

Natural Draught Towers

The major components of a closed cycle wet cooling water system are:

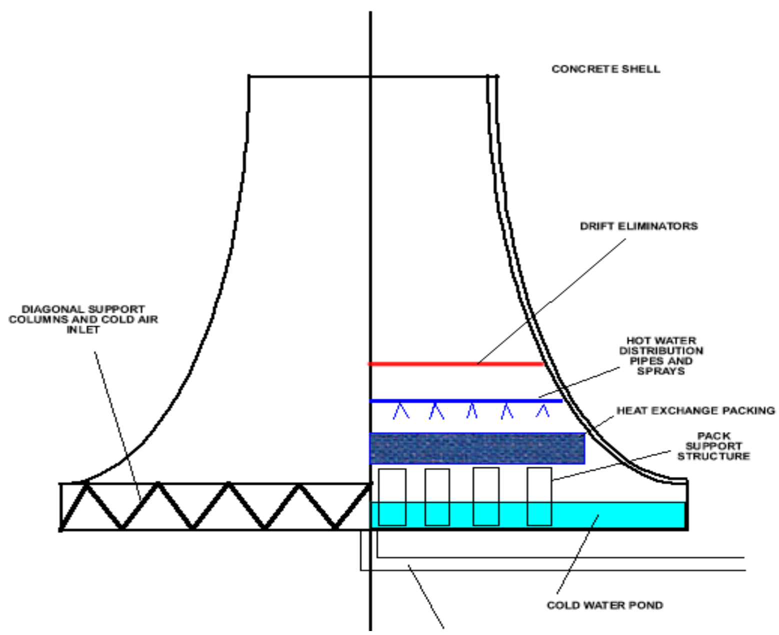
- Cooling towers - two types are commonly used, concrete natural draught towers and mechanical draught towers; and
- Pumps and pipes.

Concrete natural draught towers have a large concrete shell.

The heat exchange 'fill' is in a layer above the cold air inlet at the base of the shell as shown in the tower sectional view.

The warm air rises up through the shell by the 'chimney effect', creating the natural draught to provide airflow and operate the tower.

These towers therefore do not require fans and have low operating costs.



Natural Draft Counter-Flow Cooling Tower

The cooling towers have two basic configurations for the directions of the flow of air in relation to the falling water through the tower fill:

- The counter-flow tower where the air travels vertically up through the fill (a diagram of this type of tower is shown below); and
- The cross-flow tower where the air travels horizontally through the fill.

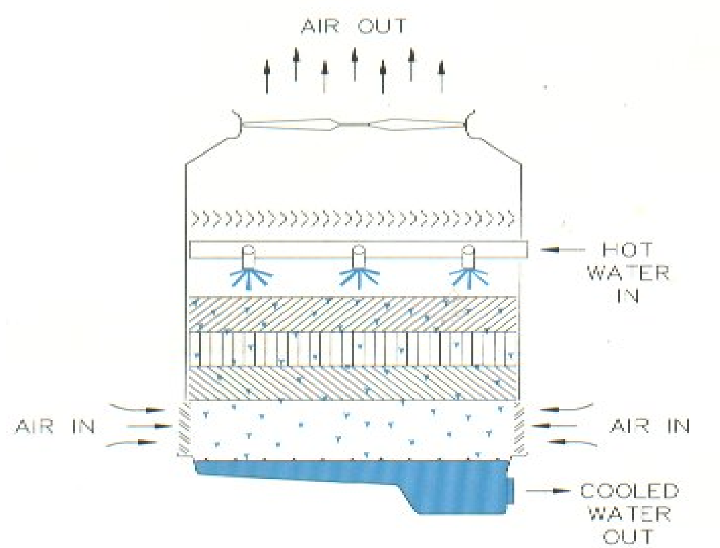
Natural draught towers are only economic in large sizes, which justifies the cost of the large concrete shell.

Natural draught towers are the most common towers for large generating units in Europe, South Africa and eastern United States of America.

They are not used in the drier areas of western United States of America, as their performance is better suited to cooler and more humid areas.

MECHANICAL DRAUGHT COOLING TOWERS

In mechanical draught cooling towers, large axial flow fans provide the airflow. While fans have the disadvantage of requiring auxiliary power, typically 1.0MW to 1.5MW for a 300MW steam turbine-generator unit, but they have the advantage of being able to provide lower water temperatures than natural draught towers, particularly on hot dry days.



FORCED DRAFT COUNTER-FLOW COOLING TOWER

Mechanical draught towers are used exclusively in central and western United States of America, in Canada, Europe and part of norther Asia as their climate can vary from freezing to hot with low humidity, and the mechanical towers can provide a more controlled performance over this wide range of conditions.

The most common materials used in large mechanical draught cooling towers are timber for the framing and plastic for the cladding and internals.

Dry Cooling Systems

For completely arid inland areas, if a power plant incorporating steam cycle is needed, there is no other practical choice than dry cooling, opening new territories for plant sites.

It is also important to note that, since areas of coal and lignite deposits are often short of water, this freedom of plant location opens up new possibilities for use of important and cheap fuel reserves by setting up mine-mouth generating plants.

There are dry cooled power plants in more than 30 countries worldwide, most of them operating in semi-arid or in arid sites.

There are power plants operating under diverse ambient air temperature conditions ranging from -50°C to +50°C.

These references provide excellent experience both, technically and economically to develop the adequate system for any unit rating or climatic conditions.

However, dry cooling systems are the least used systems as they have a much higher capital cost, higher operating temperatures, and lower efficiency than wet cooling systems.

In the dry cooling system, heat transfer is by air to finned tubes. The minimum temperature that can be theoretically provided is that of the dry air, which can be regularly over 30ºC and up to 40ºC.

Compare this to wet cooling towers, which cool towards the wet bulb temperature, which is typically 20ºC on summer afternoons.

The steam condensing pressures and temperatures of a dry cooled unit are significantly higher than a wet cooled unit, due to the low transfer rates of dry cooling and operation at the dry bulb temperature.

There are two basic types of dry cooling systems:

- The direct dry cooling system; and
- The indirect dry cooling system.

Variations on the full dry and full wet systems are hybrid systems, which may be wet with some dry or dry with part wet.

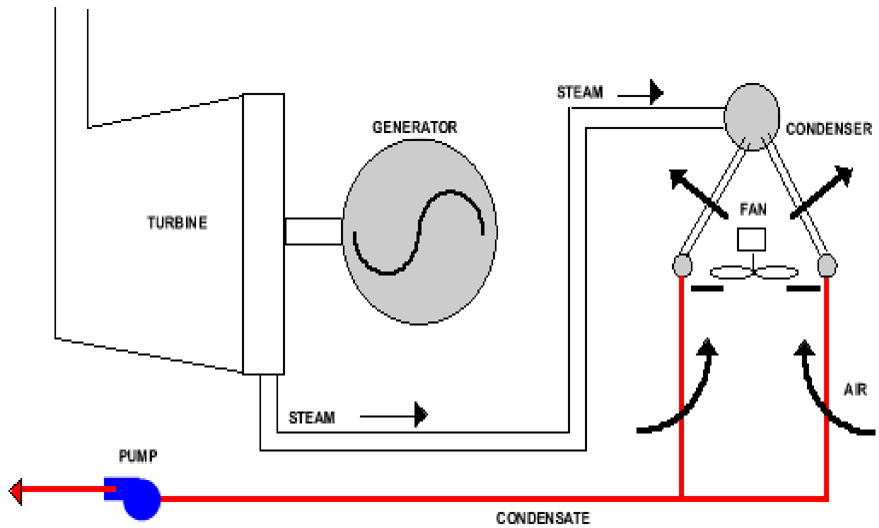
Direct Dry Cooling System

In the direct dry system, the turbine exhaust steam is piped directly to the air-cooled, finned tube, condenser. The finned tubes are usually arranged in the form of an 'A' frame or delta over a forced draught fan to reduce the land area.

The steam trunk main has a large diameter and is as short as possible to reduce pressure losses, so that the cooling banks are usually as close as possible to the turbine.

The direct system is the most commonly used as it has the lowest capital cost, but significantly higher operating costs.

The power required to operate the fans of this system is several times that required for wet towers, being typically 3.0MW to 3.5MW for a 300MW steam turbine-generator unit.



DIRECT AIR COOLING SYSTEM

INDIRECT DRY COOLING SYSTEM

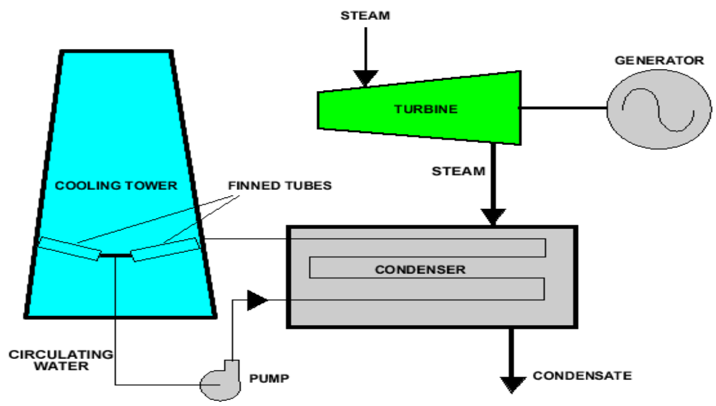
With indirect dry cooling, known as HELLER System, cooled water from the cooling tower flows through recovery hydraulic turbines connected in parallel and is used in preferably a direct contact (DC) jet condenser to condense steam from the steam turbine.

The condensation takes place practically at the temperature corresponding to the turbine backpressure - the terminal temperature difference is not more than 0.3°C, as opposed to approx. 3°C with a surface condenser.

Furthermore, a DC condenser is simpler and less costly than a surface condenser and practically maintenance-free. The mixed cooling water and condensate are then extracted from the bottom (hot-well) of the condenser by circulating water pumps.

Around 2-3% of this flow - corresponding to the amount of steam condensed - is fed to the boiler feed water system by condensate booster pumps.

The major part of the flow, discharged by the circulating water pumps, is returned to the tower for cooling. The cooling deltas (water-to-air heat exchangers) dissipate the heat from the cycle. Since in case of indirect dry cooling, there is an intermediate heat transfer medium, water between the steam and the air, it is not sensitive to the distance of air coolers from the turbine exhaust.



INDIRECT AIR COOLING SYSTEM

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HYBRID SYSTEMS

There are two common hybrid systems, which have been developed to overcome some of the disadvantages of the full wet and full dry systems.

WET WITH PART DRY

One of the problems with wet towers is that in cold and humid climates the towers plume, can create fog. In the part dry or plume abatement tower, a dry section above the wet zone provides some dry cooling to the exhaust plume to remove the condensing water vapour.

These towers are common in Germany and England where environmental problems with mechanical towers have arisen.

DRY WITH PART WET

Problems with full dry towers are centred on loss of performance in hot weather. With the part wet towers, there is provision for water sprays to evaporatively cool the finned tubes for short periods of extreme temperature.

ENVIRONMENTAL EFFECTS OF COOLING SYSTEMS

All the heat transferred from the exhaust steam to the cooling system eventually finds its way into the earth's atmosphere.

In the once-through cooling water system, heat is removed from the steam turbine and transferred to the source body of water. The heat is then gradually transferred to the atmosphere by evaporation, convection and radiation.

However, this waste heat transfer process may negatively affect the body of water buy increasing the temperature of the water.

In a re-circulating cooling system, the cooling water carries waste heat removed from the steam turbine exhaust to the cooling tower, which rejects the heat directly to the atmosphere.

Because of this direct path to the atmosphere, surrounding water bodies typically do not suffer adverse thermal effects. Some water is discharged from the cooling water system to maintain the concentration of chemicals in the cooling water below licensed limits. This water is often discharged to surrounding watercourses.

In dry cooling systems, the waste heat is transferred directly to the atmosphere.