

# HEATING LIQUIDS BY STEAM SPARGING

## ABSTRACT

Heating liquid by steam sparging. Steam is often used for heating liquids. The direct steam injection into the process is known as steam sparging. The sparge design and location affect the efficiency of the process. Keywords: boiling, heating water, temperature increase, injector, lance, boiler pressure, properties of steam.

## PROPERTIES OF STEAM

As water is heated it boils and some turns into a damp vapour called 'wet' steam. If heated further the water is all boiled away and at that point it is called saturated vapour. If heated still more it turns into super heated steam. In super heated steam the water molecules are at very high energy levels. This energy in steam can be used for heating.

Pressure also affects the amount of energy in steam. Water at sea level boils at 100 °C (212 °F) while on top of Mount Everest it boils at a lower temperature, and in a pressure cooker heated on a stove it boils at a higher temperature. A higher pressure allows higher temperature and energy.

If water is to be used to make steam at more than 100 °C on planet Earth it is done in a pressure vessel called a boiler.

At a given pressure steam takes up a specific volume per kilogram. The lower the pressure the larger the volume needed for the same amount of steam. One kilogram of saturated steam at sea level atmospheric conditions will be at 100 °C, 1 atmosphere pressure and require 1.7 cubic meters volume. The same kilogram at six times atmospheric pressure will be at 158 °C and squeezed to a volume of 0.3 cubic meters. At 100 times atmospheric pressure it will be at 311 °C and squeezed into a 0.018 cubic meter space.

If steam at 100 times atmospheric pressure were released at sea level it would expand instantly 95 times and lose 211 °C in temperature. You would see and hear a massive plume of vapour streaming out of the hole at very high velocities. The excess heat is radiated into the air around the plume.

## HEATING LIQUIDS WITH DIRECT STEAM INJECTION

Heat can be provided to a liquid either through a heat exchanger or by the direct injection of raw steam. Injecting steam directly into a liquid puts the molecules of high-energy water in direct contact with the liquid molecules. The energy is transferred from the hotter to the colder molecules and so the process liquid warms-up. As more steam is injected the liquid's temperature rises toward the steam's temperature.

The temperature rise one kilogram of steam can cause to one kilogram of liquid depends on the ability of the liquid to take in the energy. This ability to absorb energy is known as the liquid's specific energy. It is the energy needed to raise the temperature of one kilogram of the liquid by one degree centigrade. If we can find out how much specific energy is needed to heat one kilogram of a liquid one degree we can calculate how much steam, at a certain temperature and pressure, is needed to heat the liquid.

The time taken to heat the liquid depends on how fast the steam is introduced, how much hotter the steam is than the liquid and how well it is distributed through the liquid. If 1000 kilograms of liquid is to be heated 100 °C higher but only one kilogram of steam per hour could be supplied it will take an eternity to warm. Similarly if the steam was only 101 °C hotter than the liquid there would be an initial surge in the liquid temperature as it warmed but the final few degrees rise would take longer and longer. And unless the steam is evenly distributed in the liquid there would be pockets of hot liquid around the sparge, with the liquid further away getting progressively colder.

When heating liquids with a sparge insure there is a plentiful supply of steam at sufficiently high temperature and the steam and process liquid are well mixed together. Examples of some typical steam sparges are shown in Figure 1.

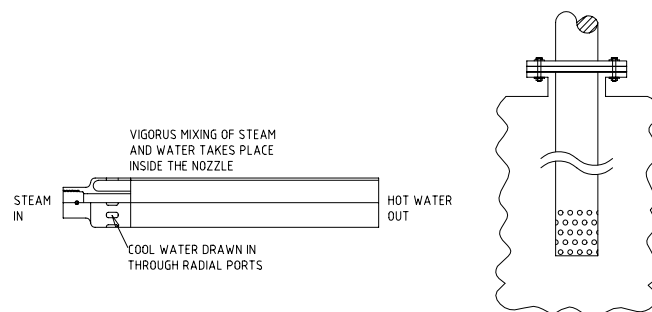


FIGURE 1 Two typical steam sparge designs

How fast the steam can be injected into the liquid depends on the steam pressure and the size of the hole through which the steam is squirted. With the specific energy of the process liquid and steam known it is only necessary to decide how quickly to heat up the liquid and then the size of the hole to provide the steam can be calculated.

# COOLING WATER TOWER DESIGN, OPERATION & USE

## **ABSTRACT**

Cooling water towers. There are two types of cooling water towers: natural draft and mechanical draft. A cooling water tower is used to remove heat from incoming hot water and reduce it to a lower temperature. It does that by evaporating off some of the hot water. The evaporated water takes away the heat. Exactly the same process occurs when your body sweats to keep you cool. You cool off even faster if there is a breeze blowing. Keywords: forced air draft, evaporation rate, relative humidity, heat exchange.

## **Cooling Tower Design**

Natural draft towers are the huge concrete, vapour billowing, flower vase shaped towers usually seen at power stations. Mechanical draft cooling water towers (CWT's) use fans to force air through the circulated water. The fan can be at the top of the tower drawing air in (induced) or at the side of the top pushing air in (forced). These are the cooling towers usually used in the chemical process and air conditioning industries and will be the type discussed in this article.

In mechanical draft CWT's the hot water is piped to the top of the unit and then broken up into droplets by sprays or by falling through perforated (with holes) plates. The falling drops contact upward flowing air and are cooled. Large fans are used to create a forced draft of air to move through the tower. To increase the evaporation rate the water runs through packing or 'fill' within the tower. The fill looks like corrugated plastic sheets or it can be a collection of splash plates distributed through the middle part of the tower. The fill breaks the water up into smaller droplets and thin streams. The air drafts also flow through the fill. The fill causes the water to remain in contact with the cooling air for longer and maximises the contact time for cooling.

At the bottom of the tower is the sump where the cooled water collects. It is then drawn off by pumps and sent to the process. To reduce the loss of fine droplets blowing out of the tower (carry-over) another set of plates or fill is often used at the top of the tower as drift eliminators. Figure 1 shows two typical arrangements of mechanical draft CWT's.

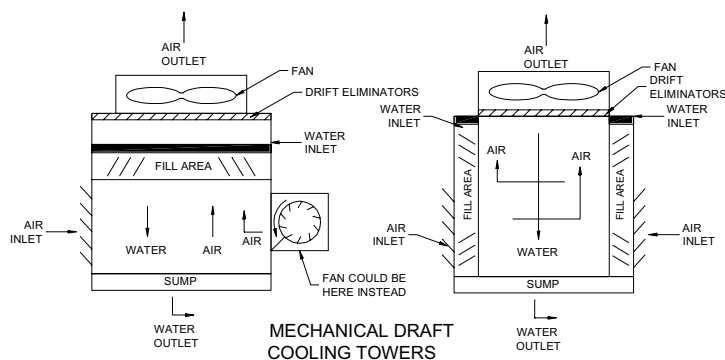


Figure No. 1. Cooling Water Tower Configurations

## **Evaporation Rate**

A CWT must be adequately sized if it is to provide sufficient cool water for the process. The air passing through the tower must cool the water low enough for it to be reused. The cooling effectiveness depends on several factors. The most important are:

- the flow rate of water (how much water to cool?).
- the flow rate of air (how much cooling is available?).
- the incoming water temperature (how hot is it to start with?).
- the difference between incoming air wet and dry bulb temperatures (how much vapour can the air carry?).

Wet bulb temperature is found by putting a wet cloth sleeve around the bottom bulb on a thermometer and letting the water evaporate. It is the lowest temperature to which water can be naturally cooled at that time. The dry bulb temperature is found by leaving a thermometer standing free without shrouding the bulb. It is the daytime temperature reported by the news services. If the temperature of a summer's day is reported to be 32°C it is the dry bulb temperature that has been measured. The wet bulb temperature on that day may have been as low as 20°C. This means that with evaporation you could get the temperature down to 20°C. The difference between the two temperatures is a measure of the evaporation effect available at that time. The greater the difference in dry and wet bulb temperatures, the greater the water vapour holding capacity of the air and the cooler the water can become.

## **Energy Transfers**

The majority of cooling in a CWT is done by the rejection of heat through the creation of water vapour. A lesser amount of cooling occurs by direct contact of cool air with the water.

Evaporation requires the transfer of energy from the warmer water to the cooler air until all is at equilibrium. The energy in the water is removed by converting the liquid to vapour. The vapour is a higher energy state than the liquid and to get to the

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# HEAT EXCHANGER DESIGN AND USE

## **ABSTRACT**

Heat exchanger design and use. The article introduces readers to heat transfer in heat exchangers. It explains the concepts of temperature gradients across walls and parallel-current and counter-current flows. Both shell-and-tube and plate heat exchanges are discussed along with their common operational problems and remedies. Keywords: recuperative, flooding, temperature rise, heating, cooling, fouling, condensation, boiling.

Shell-and-tube and plate heat exchangers (HXCH's) are recuperative type devices, meaning that flowing fluids exchange heat through a dividing wall. The exchange of heat occurs from the hotter liquid to the cooler one. The hotter liquid is at a higher energy level than the colder liquid and the energy flows from hot to cold in an attempt to reach a steady equilibrium state at an intermediate temperature.

## **TEMPERATURE GRADIENTS ACROSS WALLS**

HXCH's cool or heat fluids (both liquids and gasses are used). Because a wall separates the two fluids a temperature difference exists from one side to the other. This temperature gradient, from hot to cold, forces energy to be transferred through the wall into the cooler fluid. As the cooler fluid absorbs energy, the hotter fluid loses energy. If it is necessary to cool a fluid to a required temperature then a colder fluid must be used on the other side of the wall. Conversely if a fluid must be heated to a required temperature then a hotter fluid must be used so an energy transfer can occur. Figure No. 1 shows a temperature gradient through the walls of a fouled plate HXCH.

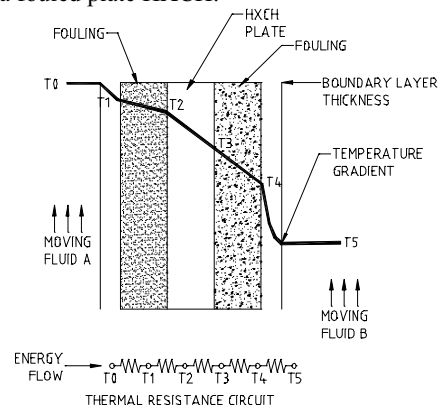


Figure No. 1. Temperature Gradient across a Fouled Plate Heat Exchanger Wall

The amount of heat transferred through the wall from one fluid to the other depends on the thermal resistance properties of the wall materials. All materials transfer heat through them at different rates. You will get a burn if you touch an uninsulated steam pipe. But when the insulation is installed, the surface of the insulation is safe to touch. The presence of the insulation has increased the thermal resistance and reduced the amount of heat transfer. The same effect occurs when HXCH walls are fouled. The fouling introduces extra thermal resistance to the transfer of heat.

When designing HXCH's formulas are used that allow for the thermal resistance properties of the materials used and for the presence of a minor amount of fouling. Once fouling exceeds the design allowance the heat exchange may not be sufficient to meet process requirements. The 'hook' shape in the temperature gradient of Figure No. 1 just before the first solid surfaces is the resistance effect of the relatively still boundary layer at the wall.

Turbulence is another factor affecting the rate of heat transfer. If a still fluid is heated the heat has to be conducted atom-by-atom from one end to the other. This is a slow process. If instead the fluid is turbulent and jostling about then new atoms are continually making contact with hot surfaces and hotter atoms and the heat is transferred faster. Flows in HXCH's need to be turbulent.

## **PARALLEL AND COUNTER CURRENT FLOW EFFECTS**

The rate of heat transfer decreases as the temperature difference between the fluids decrease. If you want rapid heating or cooling there must be a big temperature difference between the fluids to cause large heat transfer rates.

Fluids can be introduced into a heat exchanger from two directions. One with the fluids on either side of the wall flowing in opposite directions (counter) while the other has fluids flowing in the same direction (parallel). Figure No. 2 shows a graph of the temperatures for liquids in both flow configurations. Figure No. 3 shows a counter-flow shell and tube HXCH with the corresponding points at which the temperatures are taken for the relevant graph in Figure No. 1. If condensing steam (or gas) or a boiling liquid were on one side of the HXCH then the temperature on that side stays constant and the line on the graphs would be straight. Condensation and boiling occur at a specific temperature for a specific pressure. For example water boils at sea level at 100°C. Similarly steam escaping into the atmosphere condenses at sea level at 100°C. Water can never be hotter

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$$Q = \frac{k \cdot A \cdot (t_1 - t_2)}{x} \text{ Watt}$$

The equation shows that as either thermal conductivity, or the surface area, or the temperature difference between two positions increases, then the heat transferred also rises. However as the distance between two points increases the heat transfer between the two positions drops.

### **Convection in more detail.**

#### **Heat Transfer from a Solid to a Fluid.**

A hot surface will transfer heat to a fluid (liquid or gas). In order to boil water for a cup of tea or coffee, the energy from a kettle's heating element must be transferred to the water. The water nearest the element touches the surface and gets hot by contact (conduction). Natural convection causes the hot water to rise and new, cooler water touches the element and gets heated.

The heat transfer rate depends on a property of the fluid called its heat transfer coefficient 'h' in  $W/m^2 \text{ } ^\circ C$ . The higher the heat transfer coefficient the easier it is for heat to flow through the fluid.

The heat transfer from a solid of surface area 'A' at a particular temperature, to a fluid at a different temperature touching it, is given by the equation below:

$$Q = h \cdot A \cdot (T_{\text{surface}} - T_{\text{fluid}}) \text{ Watt}$$

The equation tells us that convection heat transfer can be increased by having more surface area in contact with the fluid, or by increasing the heat transfer coefficient or by having a higher temperature difference between the surface and the fluid.

Convection can also be by mechanical means (known as forced convection) such as pumping through heat exchangers, using static mixers inside tubes to make the flow turbulent and putting agitators in steam jacketed tanks. Forced convection is used because the fluid is forced into contact with the hot surface many times during its passage around the heat transfer equipment. This increases the heat input and warms the fluid faster.

### **Heat Loss Minimisation.**

Where heat loss is to be reduced it becomes necessary to:

- reduce heat transfer coefficients,
- reduce thermal conductivity (or increase thermal resistance),
- use low emissive surfaces,
- increase the thickness of the walls,
- keep surface areas small,
- block the direct radiation, conduction or convective paths between the two substances,
- minimise the temperatures of surfaces,
- minimise temperature difference with the surroundings.

Radiated heat whose escape is to be minimised (like the flame in a boiler) is usually 'boxed-in' with thick walls made of low conducting materials like refractory bricks. These are then insulated on the outer side with low conducting, low emissive materials like fiberglass blankets. This sandwich construction offers high resistance to heat transfers (i.e. low conductivity). For example, the flame temperatures in a boiler maybe  $1000 \text{ } ^\circ C$  ( $1832 \text{ } ^\circ F$ ) but the outside wall can be touched by hand.

An example of the use of multiple materials to create a thermal resistance is shown in Figure No. 1. It is a cross-section through a furnace wall showing the temperature of the various surfaces that make-up the wall (the temperature gradient). Note that the air gap stops conduction as the main heat transfer mode and makes radiation the dominant mode. If fiberglass batts could be used to fill the air gap, or aluminium metal sheeting hung between the walls, radiation would have greatly reduced and the outside wall temperature would be even lower.

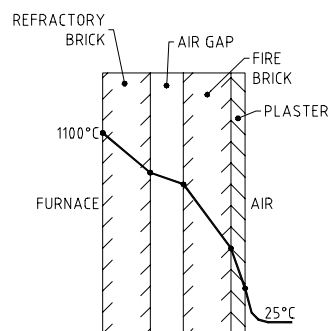


Figure No. 1. Heat loss through a composite wall.

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