ET3034TUx - 6.2.2 - Solar thermal energy 2 - Solar thermal heating

So far, we have covered the basic concepts of heat transfer and properties.

Now we are going to discuss the applications of these concepts to cover our heat consumption.

As shown in the first graph, the supply of heat represents nearly half of the world's energy demand.

Oil, coal and gas account for more than two-thirds of this demand.

Most of the heat demand is accounted for the industrial and residential sectors.

What we propose here is to cover at least part of this demand with solar energy.

For that purpose, we can use a solar water heater.

A solar water heater is a combination of a solar collector array, an energy transfer system and a storage tank.

The main part of a solar water heater is the collector array, which absorbs solar radiation and converts it into heat.

This heat is then absorbed by a heat transfer fluid that passes through the collector.

This heat can be stored or used directly.

The amount of hot water produced by a solar water heater depends on the type and size of the system, the amount of sunshine available at the site and the seasonal hot water demand pattern.

There are several ways to classify solar water heating systems.

The first way is by the fluid heated in the collector.

When the fluid used in the application is the same that is heated in the collector it is called a direct or open loop.

When the fluid heated in the collector goes to a heat exchanger to heat up the utility fluid, it is called an indirect or closed loop.

The second way to classify the systems is by the way the heat transfer fluid is transported.

This can either be passive, in which pumps are not needed, or by forced circulation, using a pump.

The passive solar water heating system, shown in the picture, uses natural convection to transport the fluid from the collector to the storage.

This happens because the density of the fluid drops when the temperature increases, so the fluid finds it easier to rise from the bottom to the top of the collector - this is the same as the principle of natural convection we discussed in the previous block.

The advantage of these systems is that they don't need pumps or controllers, so they are more reliable and last longer.

However, if the quality of the water is not very good, it can clog the pipes, considerably reducing the flows.

On the other hand, active systems need pumps to be able to circulate the fluid from the collector to the storage tank and the rest of the circuit.

They are usually more expensive and bulky, and less efficient than passive systems.

However, they have the advantage that the flow rates can be tuned more easily.

One of the most famous active solar water heating systems is heat pumps.

Heat pumps use mechanical energy to transfer thermal energy from a source at a lower temperature to a sink at a higher temperature.

The concept is that the working fluid of the pump evaporates in the collector, and the condenser of the pump is a heat exchanger wrapped around the storage tank.

Now we are going to look at a traditional solar thermal water heating system in a little bit more detail.

In the picture, the scheme of a general solar water heating system is shown.

First, we have the collector, in which the working fluid is heated by the solar radiation.

The collector determines how much of the incident light is used.

It usually consists of a black surface, called the absorber, and a transparent cover.

The absorber is able to absorb most of the incident energy from the sun (through the transparent cover), represented as Q_sun, raising its temperature and transferring that heat to a working fluid.

Thus, the absorber can be cooled and the heat can be transferred elsewhere.

Here, the output energy moving with the working fluid is represented by Q_col.

But not all the incident light is converted into heat.

A part of it, Q_refl, is lost as reflection either in the encapsulation or in the absorber itself.

Other losses are related to the heat exchanged with the surrounding air by the convection mechanism, represented by Q_conv.

Finally, there are also losses by radiation from the heated absorber.

All these quantities can be easily correlated by a simple energy balance.

The efficiency of the collector depends mainly on two factors: the extent to which the sunlight is converted into heat by the absorber and the heat losses to the surroundings.

It will therefore depend on the weather conditions and the characteristics of the collector itself.

To reduce losses, insulation from the surroundings is important, especially when the temperatures are high.

Collectors can be classified in three categories: uncovered, covered and vacuum.

Uncovered collectors don't have a transparent cover, so the sun strikes directly in the absorber surface, avoiding a good fraction of the reflection losses.

It is used only for small differences in temperature with respect to the ambient temperature, such as the ones in swimming pools.

Covered collectors, on the other hand, are covered by a transparent material, providing extra insulation but also increasing reflection losses.

These collectors are used for temperatures of 100 degrees Celsius.

Finally, in vacuum collectors, the absorber is encapsulated in a vacuum space.

In that case, little heat is lost to the surroundings.

The manufacturing process of these collectors is more complicated and expensive, but the collectors can be used for relatively high temperature applications since the convection losses to the surroundings are considerably lower than for the other types.

Other way to classify collectors is by their shape.

In that case, we can consider flat-plate collectors and concentrating collectors.

Flat-plate collectors, as indicated by the name, consist of flat absorbers oriented towards the sun.

They can deliver moderate temperatures, around 100 degrees Celsius.

They use both direct and diffused solar radiation, so they don't require tracking systems.

The main applications are solar water heating, building heating air conditioning and industrial processes heat.

The other shape that collectors can adopt is in the form of concentrating collectors.

These collectors are for applications that need temperatures higher than those possible with flat-plate collectors.

Temperatures can be increased by decreasing the area of heat loss.

This is done by interposing an optical device between the source of radiation and the energy absorbing surface.

The small absorber will have smaller heat losses compared to a flat-plate collector at the same absorber temperature.

This configuration requires a tracking system to maximize the incident radiation at all times.

Even though these configurations reduce the losses, they have extra costs and problems due to the tracking systems, both during the design and the maintenance processes.

Most commercial and industrial systems require a large number of collectors to satisfy the heating demand.

Therefore, a combination of collectors in series and in parallel should be created.

Parallel flow is more frequent because it is inherently balanced and minimizes the pressure drop.

In any case, the choice of series or parallel arrangement depends ultimately on the temperature required for the system.

Connecting collectors in parallel means that all collectors have as input the same temperature, whereas if the series connection is used the outlet temperature from one collector is the input of the next.

The next element that we are going to consider in the solar water heating system is the storage.

Energy storage has an enormous influence on the overall system cost, performance and reliability.

Its design affects other basic elements such as the collector or the thermal distribution system.

That is why it is very important to choose the correct energy storage.

Storage has mainly two functions: improvement of the utilization of the collected solar energy providing thermal capacitance to minimize the load mismatch, and improvement of the system efficiency by preventing the array heat transfer fluid from quickly reaching high temperatures.

There are several storage technologies that can be used, and some of them can even be combined to cover daily and seasonal fluctuations.

Generally, solar energy can be stored in liquids, solids or phase-change materials, abbreviated as PCM.

Water is the most frequently used storage medium for liquid systems, because it is inexpensive, non-toxic, and it has a high storage capacity.

In addition, the energy can be transported by the storage water itself, without the need for extra heat exchangers.

The usable energy stored in a water tank can be calculated with the formula shown, where V is the volume in the tank, rho is the density of the water in the tank, C_p is the specific heat capacity of the fluid and delta T is the temperature range of operation.

The temperature range for operation is limited at the lower extreme for most applications by the requirements of the process.

The upper limit may be determined by the process, the vapor pressure of the liquid or the heat loss.

The heat loss of the tank, Q_loss, can be determined by the following expression, where A is the outside area of the tank and U is the global heat exchange coefficient.

The value of U gives the quality of the insulation, and usually varies between 2 and 10 W/K.

This U is also a function of the different media between which the heat exchange takes place.

The same principles can be applied to smaller or bigger systems.

Small water energy storage can cover daily fluctuations and is usually in the form of tanks.

On the other hand, bigger systems can be used as seasonal storage, typically in underground reservoirs.

Other type of energy storage is the so-called packed bed.

It is based on heat storage in solids.

It uses the heat capacity of a bed of loosely packed particulate material to store energy.

A fluid, usually air, is circulated through the bed to add or remove energy.

A variety of solids can be used, rock being the most widely used.

In operation, flow is maintained through the bed in one direction during addition of heat and in the opposite direction during removal.

A packed bed in a solar heating system does not normally operate with constant inlet temperature.

During the day, the variable solar radiation, ambient temperature, collector inlet temperature, load requirements and the other time-dependent conditions result in a variable collector outlet temperature.

The bed is in general heated during the day with air from the collector and energy is removed during the evening and night by air temperatures near 20ºC flowing upward.

Other way to store energy in solids is when thermal energy is provided in the walls and roofs of the buildings for storage.

A case of particular interest is the collector-storage wall, which is arranged so that the solar radiation is transmitted through a glazing and absorber in one side of the wall, the temperature of the wall then increases and that energy is transferred from the wall to the room by radiation and convection.

Some of these walls are vented to facilitate natural convection even more.

Finally, the last way to store heat that we will discuss is by phase-change materials.

In this method, the heat is stored as latent heat instead of sensible heat.

Latent heat is the heat used for a phase change, without any change in the material temperature.

The materials used for energy storage via phase change must have high latent heat, so that a large amount of energy can be stored.

In addition, the phase change must be reversible, being able to withstand many cycles.

Then, the heat that can be stored in the material can be calculated with the formula displayed here.

In this case, we consider the specific heat capacity of the solid, C_s, from the initial temperature T1 up to the phase-change temperature T*, the latent heat of the material, lambda, and the specific heat capacity of the liquid C_l from the phase-change temperature T* up to the final temperature T2.

The materials commonly used for this purpose are molten salts, such as Na_2SO_4, $CaCl_2$ or $MgCl_2$.

This storage is used generally for high temperature applications.

Some systems include a boiler as a backup.

Its main function is to provide the necessary energy when the solar power is not sufficient.

It is basically a normal heater that adds the remaining heat needed to achieve the desired temperature.

The boilers normally use either natural gas or oil to function.

We have discussed how to collect and store the energy, but we also have to transport it.

How do we do that?

Using a collector circuit.

The collector circuit usually transports heat using either a liquid or a gas.

The optimum medium should not freeze or boil at the operational temperatures, it should have a large specific heat capacity and low viscosity, and it should be non-toxic, cheap and abundant.

The most common fluids then are water, oils or air.

The flux can either be caused naturally by the temperature gradients, forced by a pump, or by a heat pipe, in which the fluid is allowed to boil and condense again.

The best choice will depend on the specific system considered.

Also, it must be taken into account that if the pipelines are very long, the losses here can be considerable.

So pipeline length would have to be minimized.

The system also has a controller in the circuit that regulates the fluxes of fluid through the collector, the storage and the boiler, to assure the desired temperature.

They take action when they sense over or under temperature.

The most common application for these solar water heater systems is to produce warm water and space heating for households, industry, recreational activities or agriculture.

The total energy demand of a typical household in the United States is shown here.

You can see that the space heating and water heating represent 43% of the total energy consumption and that can easily be covered by solar water heating instead of spending high quality energy such as electricity or fuels.

Another interesting application is solar cooling.

This may seem as a bit contradictory, cooling with heat?

Well, it can be accomplished by four types of systems.

The first one will be solar absorption cooling, in which, similar to conventional gas and steam fire units, energy is produced by a generator in the solar collector and used for air conditioning or intermittent absorption cooling for refrigeration.

Other option is to use combined solar heating and cooling, in which the air conditioning will be done in conjunction with heating, with the same collector, storage and auxiliary energy system serving both functions.

Another interesting approach is the solar desiccant cooling, in which the system takes outside air, dehumidifies it with a desiccant, cool it in a heat exchanger and use it.

The desiccant is then regenerated with solar energy.

Finally, a solar-mechanical cooling system combines a solar-powered Rankine cycle engine with a conventional air conditioning system.

The engine is powered by the heat in the storage tank.

In this block we have looked at converting solar energy into heat.

In the next block, we will convert this heat again into electricity.

See you in the next block!