**Solar Engineering and Technology**
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**Lecture No. 25**
**Solar Air Heaters**

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Dear students, today we will be discussing about Testing of Solar Air Heater and Application of Solar Heaters in Drying and Electricity Generation.

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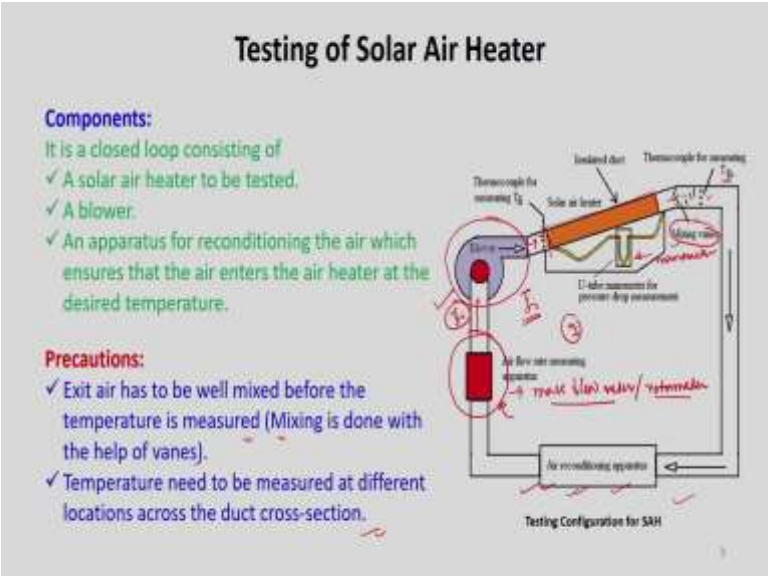


So, this figure, so the experimental setup by which solar air heater can be tested. So, it is a closed loop consisting of a solar air heater. This is the solar air heater. One blower is required to blow air, this is the blower. Of course, we need measurement instrument, so this is a Manometer, this is a manometer. And we need flow measuring device, maybe Mass Flow Meter or maybe Rotameter. So, I am talking about very sophisticated mass flow meter or maybe rotameter can be used for measurement of flow. And we need an air reconditioning apparatus, because we need to perform the experiment at constant $T_{fi}$.

As you can see, there are positions to measure the temperature. So, these are the thermocouple sensors position. So, we can average it out later on, so once we know the temperature at different locations. And also, here, we need to have some kind of Mixing Vanes, because this is air. So, at different locations temperature variation will be there. So, we need to use this kind of vanes to make uniform temperature, then only we can attach this thermocouple sensor for measurement of temperature.

So, as a whole here, this air inlet is here and outlet is here. And then this air again flow through the same circuit but conditioning has to be done, because this air will be passing through this tube at $T_{fi}$, that has to be fixed. That is why this air conditioning apparatus is installed here. And we need to vary this mass flow rate. So, we need to perform here at different mass flow rate means, these characteristics of this solar heater is to be performed at different mass flow rate. So, which is different than in case of Liquid Flat plate Collector.

And while doing the experiments, we need to do some kind of precautions. Say, for example, this exit air has to be well mixed before the temperature is measured. So, this mixing is done with the help of vanes, as I have shown here. And this temperature need to be measured at different locations across the duct cross-section, because of this non uniformity of the temperature. And this setup works in a closed system.

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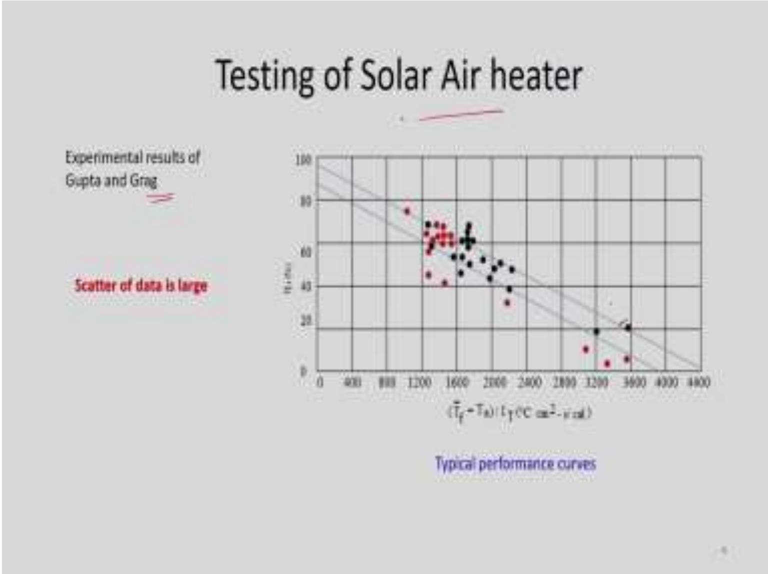


Now, if you see this typical performance curve of the solar air heater, you can see these two are at different mass flow rates. And this is the experimental results of Gupta and Grag. And as you can see, there is a scatter off data. And the scatter is very-very large. And in case of liquid flat plate collector, what we are doing, only single mass flow rate was giving the entire characteristics of the liquid flat plate collector. But in case of solar heater, this is not so. So, we have to perform the experiments at different mass flow rate. So, why this is so?

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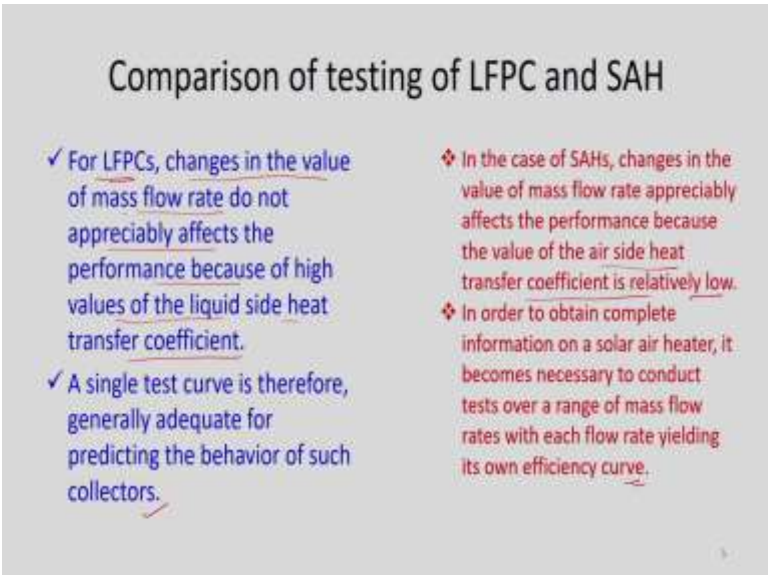


If we compare both liquid flat plate collector and solar air heater, so in case of liquid flat plate collectors, changes in the value of mass flow rate do not appreciably affect the performance because of high values of liquid side heat transfer coefficient. That is why a single test curve is therefore, generally adequate for predicting the behaviour of such collectors. But in case of solar air heaters, the changes in the value of mass flow rate appreciably affect the performance because the value of air side heat transfer coefficient is relatively low. This is the primary region.

So, in order to obtain complete information on a solar air heater, it becomes necessary to conduct test over a range of mass flow rates with each flow rate yielding its own efficiency curve. So, that is why we need to perform the test at different mass flow rate, keeping the inlet fluid temperature constant.

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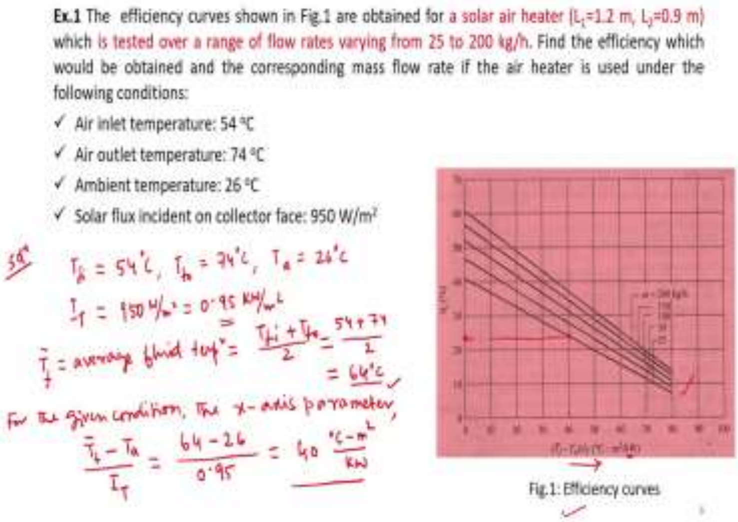


Now, let us take an example to calculate efficiency of a solar air heater and the corresponding mass flow rate under a given set of operating conditions. The example goes something like a solar air heater of length $L_1$ is equal to 1.2 meter and width $L_2$ is equal to 0.9 meter is tested under a range of flow rates varying from 25 to 200 kg/hr, and the efficiency curve so generated is shown in Figure 1.

So, we need to calculate the efficiency and the corresponding mass flow rate under the condition like air inlet temperature of 54 °C, air outlet temperature of 74 °C, ambient temperature of 26 °C. And the solar flux incident on solar collector face is equal to 950W/$m^2$. So, let us solve this problem to, solution, I will write. The figure what you have seen here, its efficiency curve which is plotted based on the absorber plate area. What you can see here, the variation of instantaneous efficiency with respect to this parameter $\frac{\bar{T}_f - T_a}{I_T}$. So, with increase in mass flow rate, how this efficiency curve changes that can be seen here.

Now, it is given that $T_{fi}$ is equal to 54 °C , then $T_{fo}$ is equal to 74 °C, ambient temperature Ta is 26 °C, and $I_T$ the amount of solar flux which is falling on the solar air heater which is given us 950 W/m$^2$, so which is equal to 0.95 kW/m$^2$. So, why we have converted to kW/m$^2$? Because if you see the horizontal axis of this efficiency curve, so this $I_T$ is in kW.

Now, let us calculate first the average fluid temperature. So, $\bar{T}_f$ which is nothing but average fluid temperature, and which can be represented by $\bar{T}_f = \frac{T_{fi} + T_{fo}}{2}$. So, if we substitute the value of $T_{fi}$, which is equal to 54 and then $T_{fo}$ 74 divided by 2, which is equal to 64 °C. So, for the given condition, the x-axis parameter, so I will write, for the given condition the x-axis or the horizontal axis parameter, which is nothing but $\frac{\bar{T}_f - T_a}{I_T}$, which will be equal to 64, $T_{fi}$, we have calculated to be 64 minus Ta is 26 and $I_T$ is in kilowatt, it will be 0.95. So, if we do the calculation it is found to be 40°C-m$^2$ /kW so unit will be something like this.

Now, what we need to do, we need to do a trial and error procedure in order to find out the required values of instantaneous efficiency and mass flow rate. So, if we see this 40 here, this parameter is calculated to be 40 in our case, and if we consider this mass flow rate, maybe 25 if we consider initially, then we have to find out that cross-section point here. So, 40 it will go here and it will cut here. So, if we draw a line, something like this, so we can find out the corresponding value of the instantaneous efficiency.

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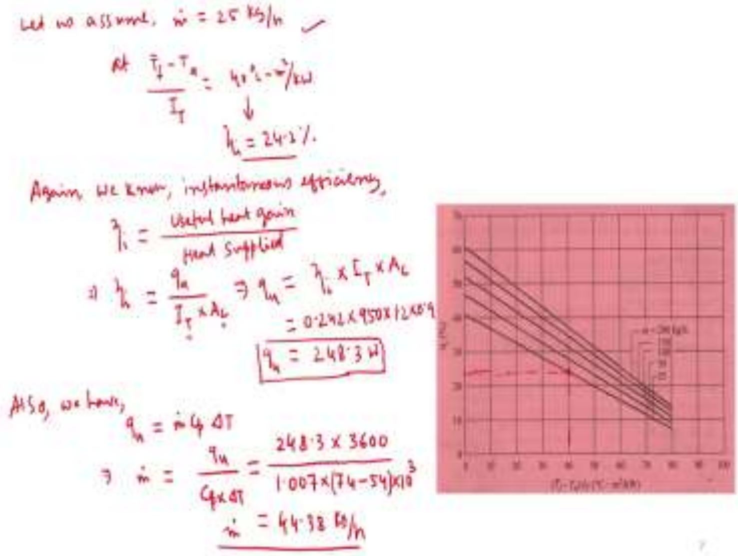

So, now, let us do the calculation. So first, let us assume m dot, which is mass flow rate equal to 25 kg/hr. So, from the efficiency curve, so we can find out the point, because this point is known by using this plot, as this is at 25 kg/hr first line followed by 50 then 100 150 and 200. So, know this value, and we have find out this cross-section point and then corresponding efficiency we need to find out. So, at that x-axis parameter $\frac{\overline{T}_f - T_a}{I_T}$, which is equal to 40°C-$m^2$/kW. So, this efficiency is found to be 24.2 %.

So, if you use a scale and take the point, then what we will get, $\eta_i$ is equal to 24.2 %. And this is nothing but the instantaneous efficiency at mass flow rate of 25 kg/hr. Again, we know instantaneous efficiency $\eta_i$, it can be defined as useful heat gain, useful heat gain to heat supplied. Then what we can write here, mathematically, $q_i$ by $q_u$ by, heat applied is nothing but I, $I_T$ multiplied by $A_C$. So, this I is nothing but solar radiation incident on the solar collector and $A_C$ is the collector area. So, if we are interested about $q_u$, then $q_u = \eta_i \times I_T \times A_c$.

Now, we know the value of instantaneous efficiency at 25 kg/hr, which is equal to 24.2 %, so we can write, 0.242. So, 24.2 divided by 100, it will be 0.242 multiplied by $I_T$ is 950 and area of the collector is $1.2 \times 0.9$. So, if we do the calculation, then $q_u$ is found to be about 248.3 watt. So, this is at mass flow rate of 25 kg/hr. Also, we know, we have $q_u = \dot{m} C_p \Delta T$. So, this is nothing but useful heat gain can be represented in terms of mass flow rate, specific heat and temperature difference.

So, from this, what we can calculate is the mass flow rate. So, which will be equal to $\frac{\dot{q}_u}{C_p \Delta T}$

So, if we substitute these values of $q_u$ $C_p$ and $\Delta T$, then we can find out what is $\dot{m}$. So, $q_u$ already we have calculated, which is equal to 248.3 divided by Cp is 1.007 multiplied by 74 minus 54. And we need to multiply this in $10^3$, because this is in kilojoule per kg per degree temperature.

So, again we need to multiply this, which is 3600, because we want $\dot{m}$ in kg/hr. So, this will be equal to 44.38 kg/hr. So, $\dot{m}$ is found to be now 44.38. But what we did? We initially assumed that mass flow rate is 25 kg/hr, but what we got it is 44.38, then we have to see what will be the appropriate mass flow rate. Now, let us assume this m is equal to 50 kg/hr, and let us do the calculation, what happens.

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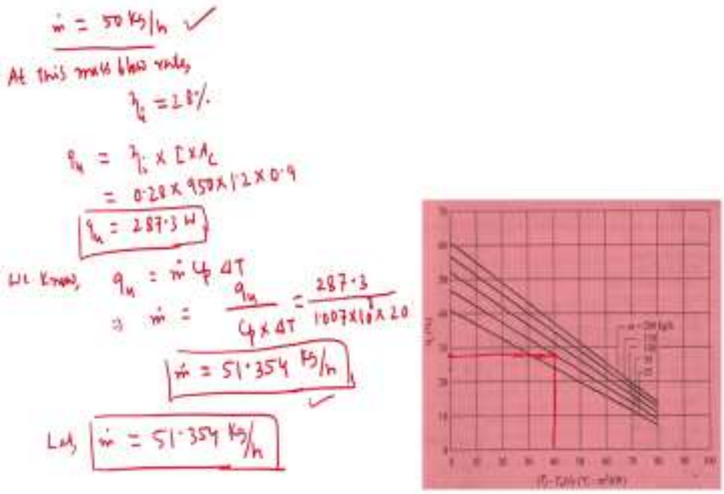


So, this m dot is now 50 kg/hr. So, this is the assumption we made. So, at this mass flow rate, we get the value of $\eta_i$ is equal to how much? So, here we have to extend this curve till here. So, this is the curve and then we have to extend this. So, if we do a very precise calculation, then this value is found to be about 28 %. So, of course, that has to be at 40°C-$m^2$/kW. And we know $q_u$ expression what we have used earlier, which is nothing but $q_u = \eta_i \times I \times A_c$.

So, if we substitute the values of instantaneous efficiency, which is 0.28 multiplied by 950 and then $A_C$ is 1.2 meter by 0.9 meter. So, if you do the calculation, this $q_u$ is found to be

287.3 watt as per my calculation. So, $q_u$ is found to be this one. And also, we know $\dot{q}_u = \dot{m} C_p \Delta T$ . So, this $\dot{m}$ , we can calculate $\frac{\dot{q}_u}{C_p \Delta T}$ . So, this is, $C_p$ is the specific heat of air and this value is also known to us and $q_u$ is also known, which is equal to 280 7.3 divided by $C_p$ is $1.007 \times 10^3$ and $\Delta T$ is 20, straightway you can write, which is nothing but 74 minus 54.

So, if we do the calculation, then m dot is found to be 51.354 kg/hr. So, since the value of $\dot{m}$ calculated from the useful heat gain rate does not match, let us now assume a value say, $\dot{m}$ is equal to 51.354 kg/hr. So, we have initiated with 50 and we got 51.354, which is not exactly matching. Then let us try one more time by considering m dot is equal to 51.354 kg/hr.

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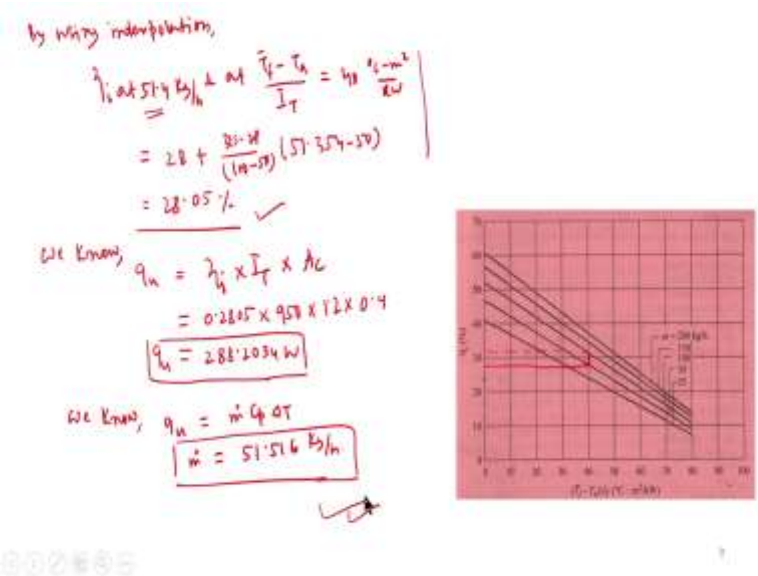


Now, let us do the calculation. If we see the efficiency curve again, now what happens, we are now interested about 51.354, so we will extend this curve, and this is for 50, and 51.354 is in between 50 and 100. Value will be somewhere here. So, we need to do the interpolation. So, how to calculate? By using interpolation, we can calculate a $\eta_i$ at 51.4 kg/hr, and at of course, x-axis parameter by $I_T$, which is equal to 40°C-m$^2$/kW.

So, at this condition, we need to find out this instantaneous efficiency. So, how we can calculate? See here, already we know this efficiency, which is equal to 28. So, we will use this. And than efficiency is increasing, we think is mass flow rate at that particular condition. So, we will see that difference here. So, if we consider here, maybe this condition, so interpolation, you can use it.

So, there is something like, you can use $\frac{30-28}{100-50}$, and here 51.354 minus 50. So, here, if we draw this line is, this is 100. So, this is somewhat higher. So, it will be this is for 25, 50, then we have 100, and that this will be about 31.5, something. So, if we do the calculation, so it is about 28.05. So, that much of instantaneous efficiency we will get.

And once we do this, then what we can calculate? We know $q_u = \eta_i \times I_T \times A_c$. And if we substitute the values of $\eta_i$, which is equal to 0.2805 multiplied by $I_T$, $I_T$ is about 950, then $A_C$ is about 1.2 and 0.9, which is equal to 288.2034, to be precise, so that much of watt we will get is qu. Now, we know $q_u = \dot{m} C_p \Delta T$, and from here you can calculate $\dot{m}$, which is found to be 51.516, which is in kg/hr. The m dot, assume the earlier, which is equal to 51.354, which is very close to this value. So, we can accept this value as the solution to that problem.

So, this is the procedure by which you can calculate the instantaneous efficiency and mass flow rate. So sometimes, if we can use a scale and all, then from that also you can calculate what is the instantaneous efficiency at this condition. And finally, we can use $q_u$, and once you know that $q_u$, then by using the expression $q_u = \dot{m} C_p \Delta T$. And from that, we can calculate what is mass flow rate. And in this case, it is found to be 51.516 which is very-very close to the assumed values. So, this maybe the solution to this problem.

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Now, let us discuss about solar drying of agricultural products. The use of solar radiation for drying is one of the oldest applications of solar energy. Solar drying has not yet been widely commercialized because of many issues. And these solar dryers are generally of small capacity. The design of solar dryers are based on primarily empirical and semi empirical data than in the theoretical design, as you can see many of the cases. The majority of the solar dryer designs are used mainly for drying of various crops, either for family use or for small scale industrial production.

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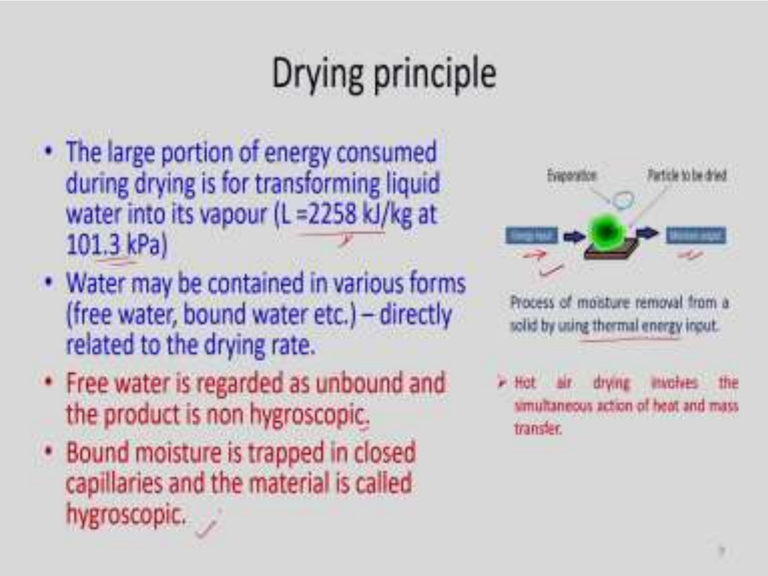


So, without delay, let us discuss about drying principles. So, as you can see in this figure, this figure shows the process of moisture removal from a solid by using thermal energy input. So, energy input is there, which is thermal and this is the product, which is to be dried and moisture has to be removed. So, during this phenomenon, hot air is applied and heat and mass transfers are involved throughout this drying process. The large portion of energy consumed during drying is for transforming liquid water into its vapour, because as we know it is latent heat of vaporization at this ambient, so that has to be removed.

The water may be contained in various forms, maybe free water or bound water, which directly related to the drying rate. This free water is regarded as unbound, and the product is non-hygroscopic. And this bound moisture is trapped in close capillaries in that material. And the material is called hygroscopic.

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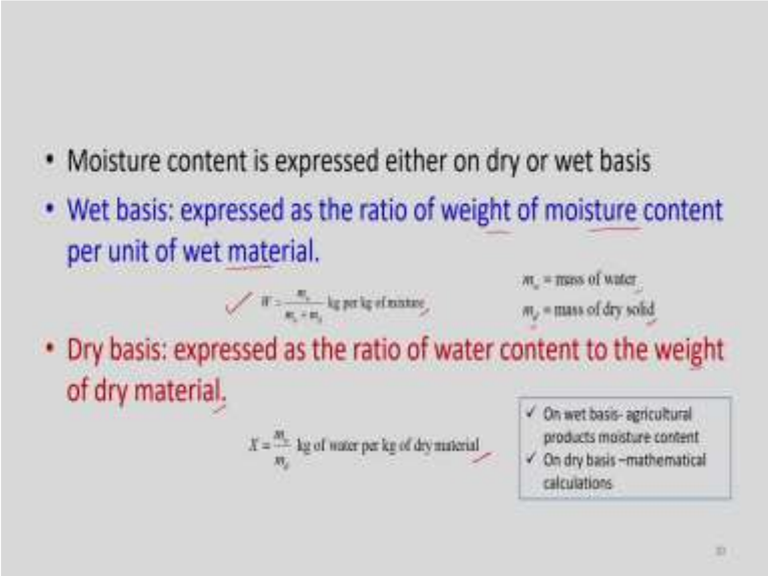


Now, this moisture content is expressed either on dry or wet basis. So, on dry basis, it is expressed as the ratio of weight of moisture content per unit of wet material. Mathematically, it can be expressed as $W = \frac{m_w}{m_w + m_d}$. That means kg per kg of mixture. So, $m_w$ is mass of water and $m_d$ is mass of dry solid. And if we are interested about dry basis, so on dry basis, it is expressed as the ratio of water content to the weight of the dry material.

Mathematically, it can be expressed as $X = \frac{m_w}{m_d}$, which is kg of water per kg of dry material.

Normally, agricultural products are analysed based on wet basis and when mathematical calculations are involved, then dry basis calculations are considered.

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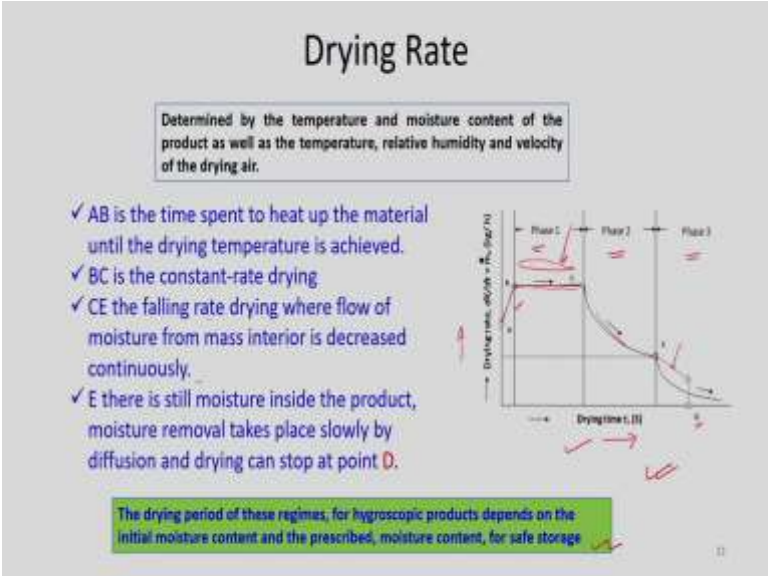


Now, let us discuss about Drying Rate, which is very-very important. And this determine by the temperature and moisture content of the product, as well as the temperature, relative humidity and velocity of the drying air. As you can see here, this is drying curve, so there are different regimes, AB then BC then CE and ED. So, this B to C, this Phase 1, C to E Phase 2, then E to D is Phase 3. So here, AB is the time spent to heat up the material until the drying temperature is achieved. So, this is first drying temperature has to achieve.

So, this is the time spent to heat up the material until the drying temperature is achieved. So, this may be the drying temperature. So here, horizontal axis is the drying time and vertical axis is the drying rate. Then BC is the constant-rate drying. So, this part is a constant-rate drying. So, it is, at constant temperature, drying takes place. So, this Phase 1 is nothing but constant-rate drying. Then CE is the falling rate drying, where flow of moisture from mass interior is decreased continuously.

So, when moisture is removed from the surface, then Phase 1 is applied. When this moisture has to be removed from the interior of the material, then this pattern follows, that is falling rate drying follows. And this point E, there is still moisture inside the product. And moisture removal takes place slowly by diffusion, and drying can stop at point D. So, this is the process of diffusion. So, even though this point achieved, further drying might be required in some cases to reach to this point D.

The drying period of these regimes, this Phase 1, Phase 2 and Phase 3, that is constant-rate drying, then falling rate drying and second falling rate drying for hygroscopic products depends on the initial moisture content and the prescribed moisture content for safe storage, which is very-very important. So, this drying rate curve is important to understand, how this drying is taking place if we consider any substance.

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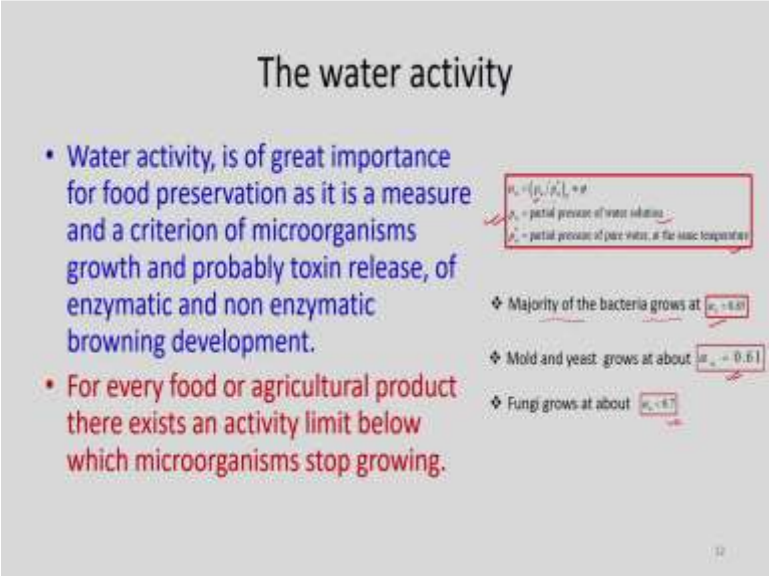


Now, we need to learn what is water activity, and why this is important. This water activity is of great importance for food preservation as it is a measure and a criterion of microorganisms growth and probably toxin release of enzymatic and non-enzymatic browning development. So, as you can see, this is the mathematical expression by which we can calculate what is water activity. So, pw is the partial pressure of water solution, then pw star is the partial pressure of pure water at the same temperature. And for every food or agricultural product, there exists an activity limit below which microorganisms stop growing.

So, for example or your informations, the majority of the bacteria grows at an activity of 0.85, and mold and yeast grows at about an activity of 0.61, and fungi grows at about an activity less than 0.7. So normally, in drying of many agricultural products, the activity is maintained below 0.6.

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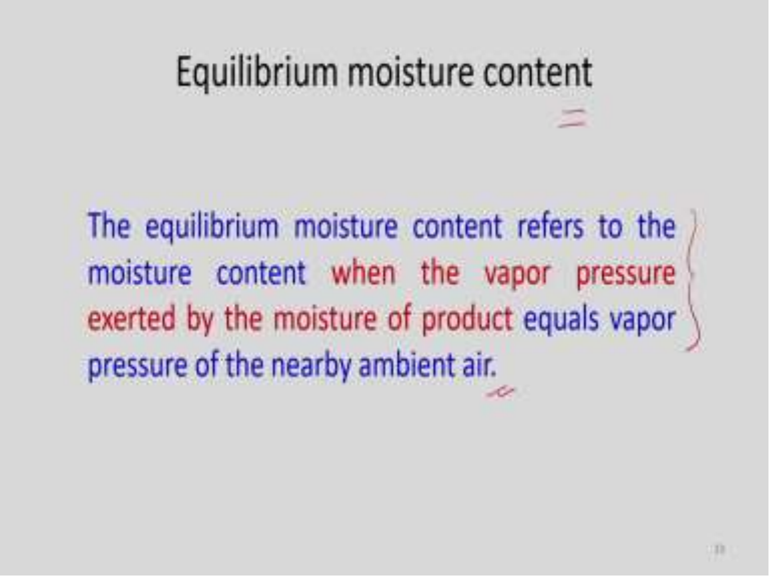


Also, we need to learn equilibrium moisture content, which is important to understand at what moisture content we need to maintain for a particular product. The equilibrium moisture content refers to the moisture content, when the vapor pressure exerted by the moisture of the product and equals vapor pressure of the nearby ambient air. So, this is very-very important to know this equilibrium moisture content.

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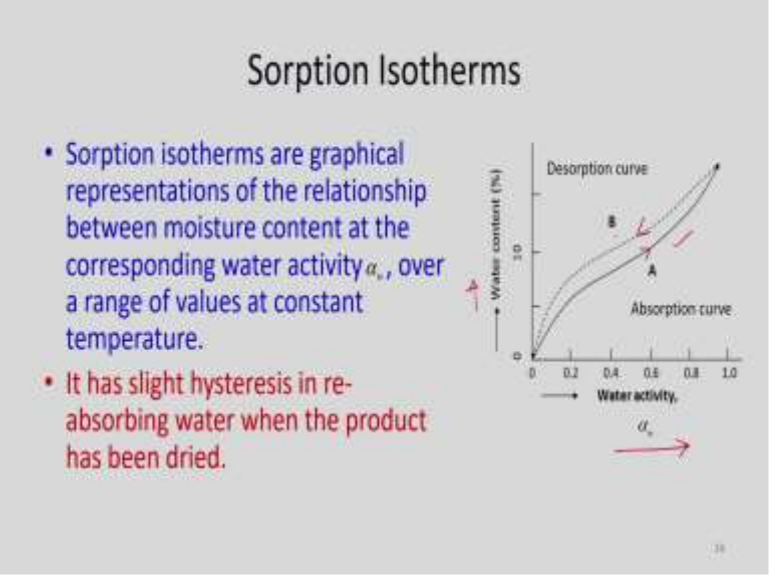


Also, sometimes we need to know Sorption Isotherms. These sorption isotherms are graphical representation of the relationship between the moisture content at the corresponding water activity over a range of values at constant temperature. So, as you can see here, this curve is for absorption curve and this B curve is for desorption curve. You can notice hysteresis between these two, because after drying completes, again some moisture absorption by the product has been observed, and because of that this hysteresis are observed.

So, in the horizontal axis, it shows water activity and in the vertical axis, it shows water content. So, what it shows primarily, it has slight hysteresis in reabsorbing water when the product has been dried. So, this is how we got different sorption curve.

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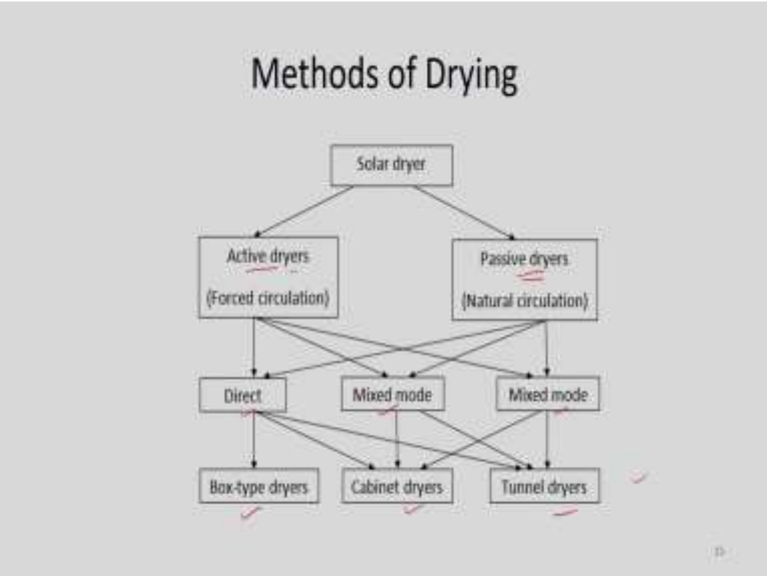


Let us discuss about the method of drying. So, there are different methods of drying. So, primarily it has got two-division, like Active Dryers and then Passive Dryers. So, as you can say, active dryer means, you need to supply some kind of forces externally. And passive devices are something like natural circulation. So, again these active dryers can be classified into many groups like Direct, Mixed Mode and again mixed mode with natural and forced. And again, natural circulations can be divided into many groups. And these direct dryers are something like Box-type Dryers, Cabinet Dryers, then Tunnel Dryers.

So, there are different kinds of dryers. So, this figure shows the different methods of drying. So, let us discuss some of the drying devices, which is used extensively historically.

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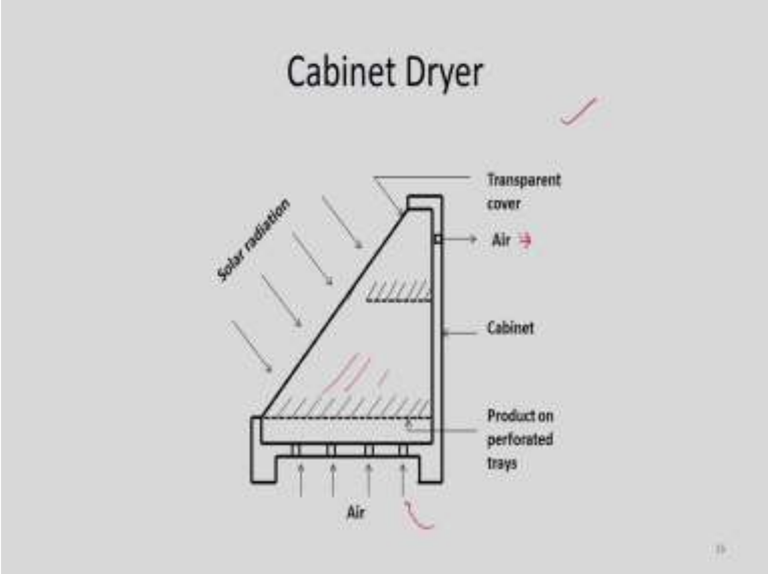


So, this is a cabinet dryer. So, solar radiation is falling, through this glass cover, and materials to be dried, we will keep here in these trays. So, these are trays, so long trays, so different stages are there for keeping the products, and air is supplied from the bottom. So, finally air has to be take out, so it will carry the moisture. And this can be taken out with time if we know the drying time for a particular material.

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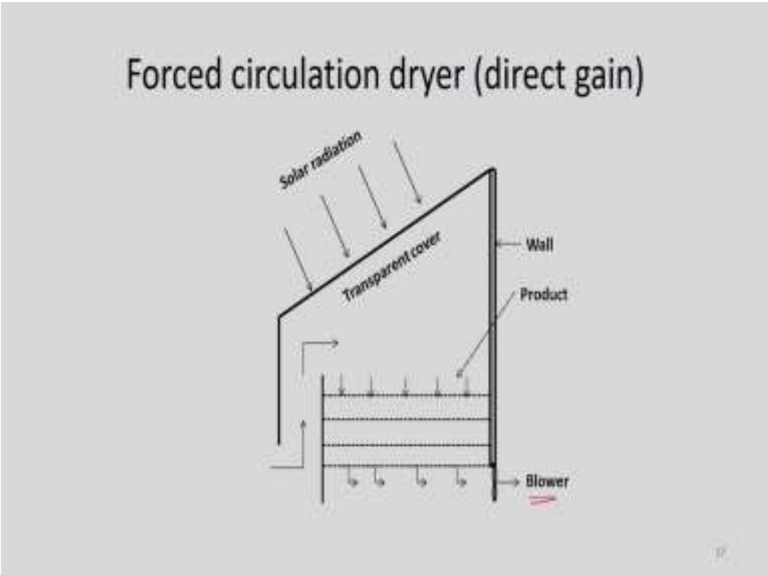


So, Forced Circulation Dryers are something like this, they have glass cover, solar radiation is falling through this glass cover, and materials to be dried, we will keep in these trays, and blower is employed here to suck the air, because it is a active device, so external unit has to be employed to suck the air. So, drying is performed by using this sucking effect of this air.

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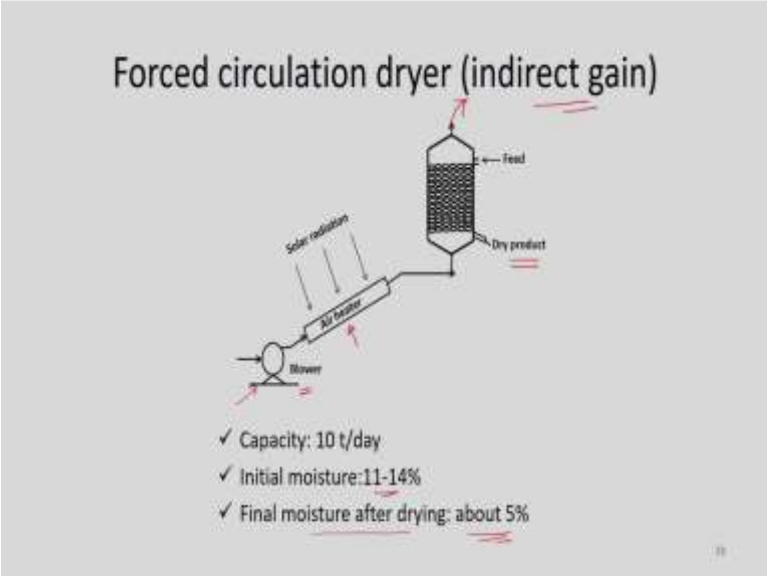


And this is one more forced circulation dryer, which is indirect gain. So, this is solar air heater, and blower is installed here. Blower blows the air, so of course we need to apply some kind of electricity to run this blower. So, air will flow through this air heater and then it will introduce here in this bed. And feeding will be done here, and then drying flow rate can be collected from the bottom of this vessel, and air can be ejected from the top.

Normally, its capacity varies from 10 tonne to 15 tonne per day, and initial moisture varies from 11 to 14 %, and final moisture after drying is about 5 % is achieved for this kind of arrangement.

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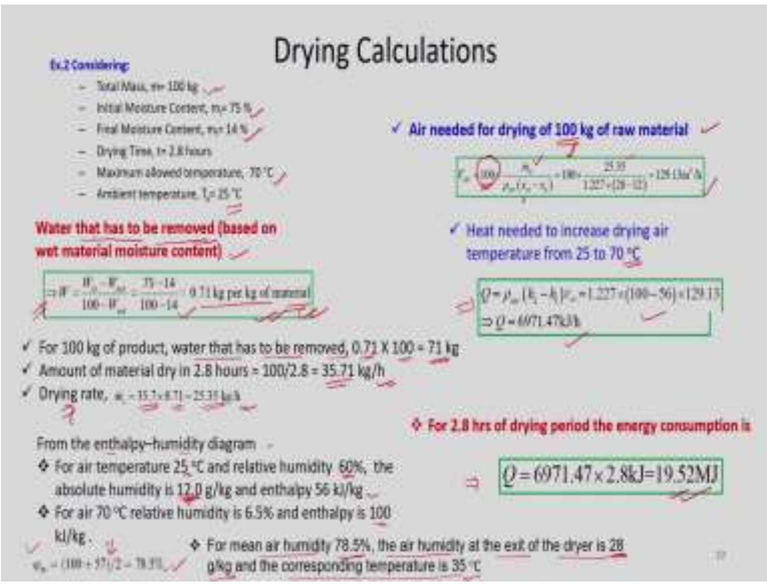

So, let us do a calculation. How this drying calculation can be carried out, which is very-very important? Once we are comfortable about this, then we can do any of the calculations. So, let us consider a problem. Say, we need to dry a product, say, agricultural product, maybe grapes or maybe other products. Say, let us consider the mass of the product is 100 kg and initial moisture content is 75 % and final moisture content is 14 %, and we need to dry this product in 2.8 hours, and maximum allowed temperature is 70 °C and ambient temperature is 25 °C.

So now, first step is to calculate the water removal. So, water there has to be removed that is based on the wet material moisture content. So, which is known by us. This $W = \frac{W_{in} - W_{out}}{100 - W_{out}}$ is something like this, 0.71 kg per kg of material. So, that is the water that has to be removed. So, that much amount of water has to be removed. So, for 100 kg of product, so, this is for single kg, the water that has to be removed is 0.71× 100, it will be 71 kg for this problem.

The amount of material to be dried in 2.8 hours will be 100 divided by 2.8, it will be 35.72 kg/hr. Now, we need to calculate what is the drying rate, if we need to calculate then what we need to do, we need to multiply with this 0.71. So, what we get now 35.35 kg/hr is the drying rate. So now, we need to use this enthalpy-humidity diagram or psychometric chart. So, for air at 25 °C and relative humidity of 60 %, absolute humidity is found to be 12 gm/kg, and enthalpy is 56 kJ/kg. And for 70 °C, relative humidity of 6.5, enthalpy is about 100 kJ/kg, and also, we need to find out this equivalent humidity.

So, because activity is about 0.57 in our case, so it will be equivalent, the humidity will be $\frac{100+57}{2}$, it will be 78.5. So, for mean humidity of this value, the air humidity at the exit of the dryer is 28 gm/kg, and the corresponding temperature is 35 °C. So, we need to use those values for calculation of air needed for drying off 100 kg of raw material. So, if we have to calculate for 100 kg, then we have to multiply with 100. So, $V_{air}$, which is nothing but air needed for drying of raw material, so since it is 100 kg, so we need to multiply by 100. Then

$V_{air} = 100 \times \frac{\dot{m}}{\rho_{air}\left(x_m - x_a\right)}$, which are known to us now, this 12 is known and then we have 28.

This 28 minus 12, and these values are known. So, once we do the calculation it is found to be 129.13 $m^3$/hr. Now, this heat needed to increase the drying air temperature from 25 to 70, that also we can calculate very easily. So, this can be calculated by using the values what we have now. So, Q is found to be this. For 2.8 hours, the drying period, the energy consumption is, Q is about 19.52 MJ. So that much of heat is required to remove the moisture content from 75 to 14 % if we consider 100 kg of this raw agricultural product.

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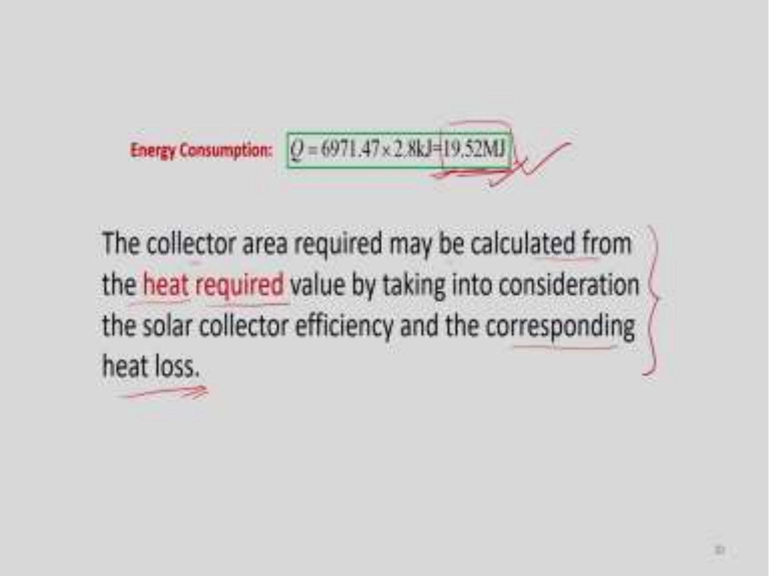


So, this energy consumption is 19.52 MJ. So, this collector area required may be calculated from the heat required value. So, this value, so once we know this value, then from that we can calculate the area required for drying the required amount. So, this collector area required may be calculated from the heat required value by taking into consideration the solar collector efficiency and corresponding heat loss. So, this is very-very important. Once we know this, then we can size the kind of solar air heater required and what capacity. How to connect those solar air heaters for meeting the requirement?

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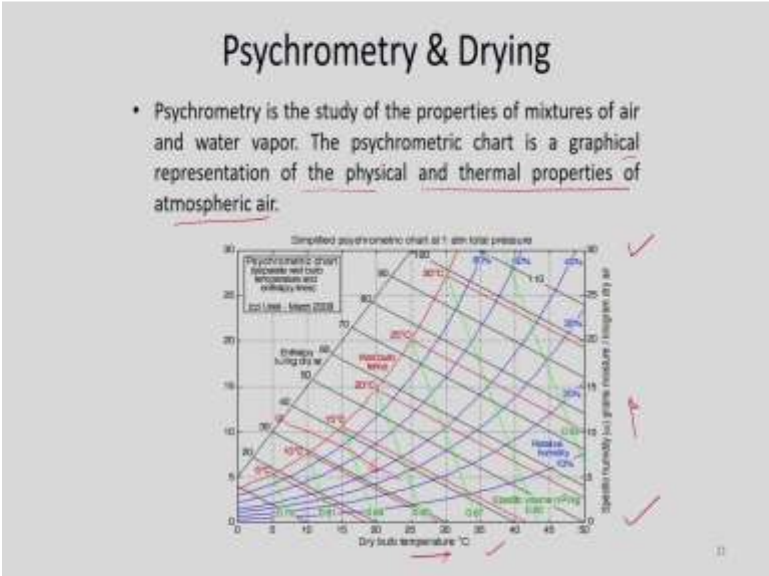


Now, you can see this is a psychometry and drying curve. So, since psychrometry is the study of the property of mixture of air and water vapor, the psychrometric chart is a graphical representation of the physical and thermal properties of the atmospheric air. So, this axisshows the dry bulb temperature, this is the specific humidity, and we will have enthalpy is here, and all the parameters, these are the relative humidity lines. Specific volume is also here.

So, at particular temperature, say, 20 degree, what will be relative humidity, if we know that relative humidity say, 40, so we can find out the coordinate. And if we have to know the enthalpy, then we have to go to here, then we can get the enthalpy. So, these charts are used for this kind of drying calculations and then psychometric calculation.

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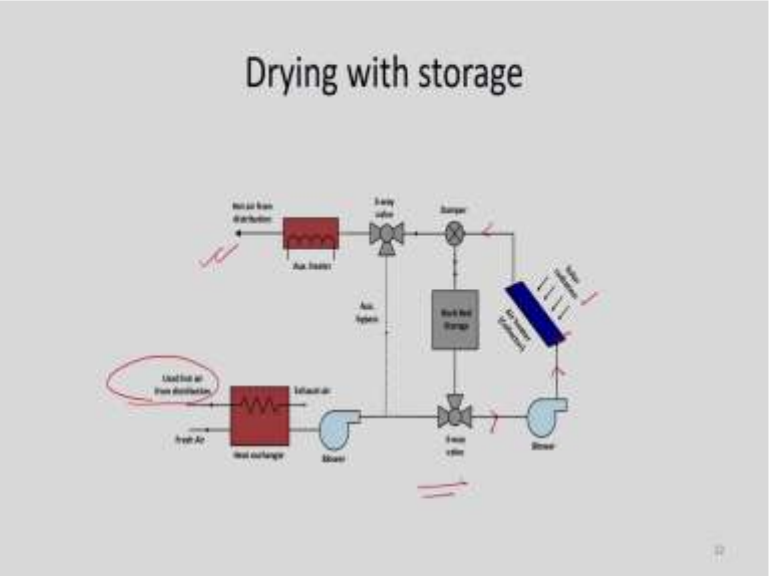


Let us now discuss how this solar air heater can be applied for process heat industries or say which requires process heat, and we can store energy by using this solar heater. So, this slides shows the use of solar heater for process heat industries. So, this is a solar collector, the solar collector. Solar radiation is falling on the collector, and blower is used. So, blower forces the air, and it goes to the dumper and then we can store, if we have generated more than the required air, then we can store it by using a Rock Bed Storage or some other devices.

And whenever required, that can be used for process heat applications. So, sometimes we can use the exhaust of engine to harvest those waste heat for drying of some other agricultural products. At the same time, we can connect that system with the solar air heating arrangement. So, when solar is not there, at the time also this facility can be employed for generating hot air.

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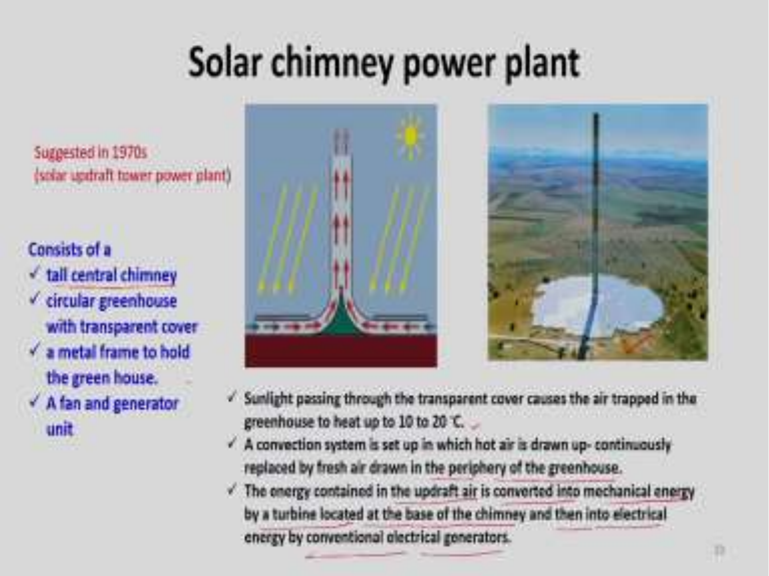


And this is something called Solar Chimney Power Plant. As you can see, this is a very tall chimney and this is one turbine and these are greenhouse. So, solar radiation is falling on the greenhouse and then there is a draft. And then this turbine is rotating and electricity can be generated. So, actually installation is seen something like this. So, this was suggested in 1970s. And it was also known as Solar Updraft Tower Power Plant. And it consists of a tall central chimney, this is the chimney, then circular greenhouse with transparent cover.

So, this is the greenhouse and it is a very-very transparent to the solar radiation. A metal frame to hold the green house, so here some kind of frame is required to hold the structure. And the fan and generator in it, so this is not shown, this is a fan, but it needs to be taken out, generator part has to be taken out and then the electricity can be generated. So, this sunlight passing through the transparent cover causes the air trapped in the greenhouse to heat up to 10 to 20 degree C.

A convection system is set up in which hot air is drawn up and continuously replaced by fresh air drawn in the periphery of the greenhouse. The energy contained in the updraft air is converted into mechanical energy by a turbine located at the base of the chimney, so this is the turbine, and then into electrical energy by conventional electrical generator. So, we can generate electricity from the solar energy.

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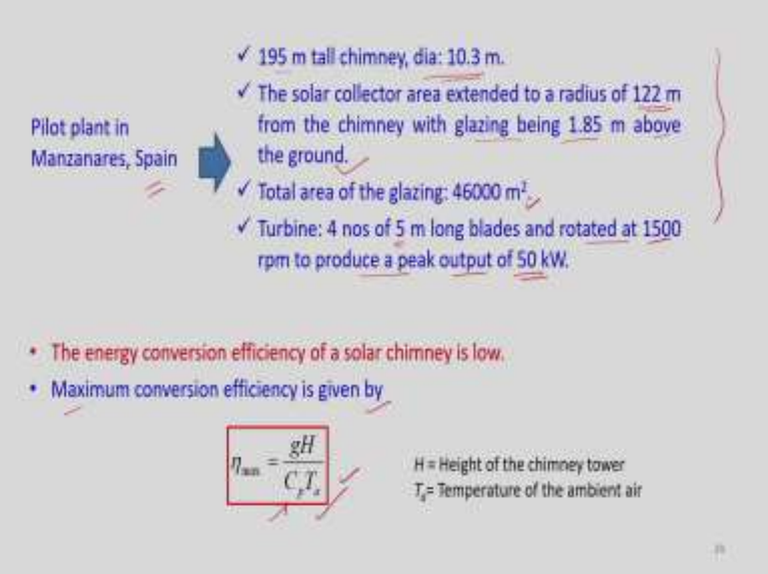


So, let us take an example. So, this data is for an installation done at Spain. This is a pilot plant solar air electricity generating unit. So, its chimney is about 195 meter tall and diameter is about 10.3 meter. The solar collector area extended to a radius of 122 meter, it is a huge from the chimney, with glazing being 1.85 meter above the ground, the clearance is about 2 meter. Total area of the glazing is 46000 meter square, it is a huge area. And as far as turbine is concerned, there are 4 numbers of blade of length 5 meters and rotated at a speed of 1500 rpm to produce a peak output of 50 kW.

The energy conversion efficiency of this kind of solar chimney is really low. And this maximum conversion efficiency can be calculated by using this expression once you know the height of the chimney. And then ambient temperature of course, specific heat is known to us, and g is known to us. So, by using that we can calculate what will be the maximum conversion efficiency of the solar chimney.

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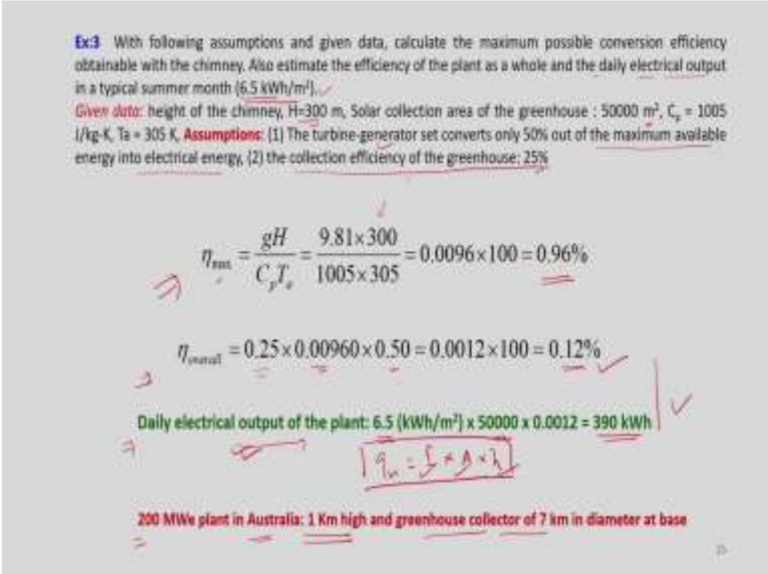


So, we can solve this numerical. So, this numerical goes something like, with following assumptions and given data, calculate the maximum possible conversion efficiency obtainable with the chimney. Also estimate the efficiency of the plant as a whole and the daily electrical output in a typical summer month of solar radiation about 6.5 $kWh/m^2$. So, height of the chimney is given us 300 meter, solar collection area of the greenhouse is 50000 $m^2$, so area is known now. $C_p$ value is always known, $T_a$ is known.

And assumptions are something like, the turbine generator get converted only 50 % out of the maximum available energy into the electrical energy. And second assumption is the collection efficiency of the greenhouse is 25 %. So, $\eta_{\max} = \frac{gH}{C_p T_a}$, we can substitute straightaway and what we get maximum efficiency is point 0.96 %, which is very-very less. And if we are interested about overall efficiency, which includes turbine generator and then collector efficiency, that has to multiply with this, what we got here now. So, 0.25 is the turbine generator, is the greenhouse efficiency.

And then turbine generator efficiency is 50 %, so it will be 59, and this mixing efficiency is 0.96. So, there is multiply then finally what we got about 0.12 % is the efficiency, which is very-very less compared to others solar conversion devices. So, this daily electrical output, you can calculate now. So, which is nothing but 6.5, which is given to us, this value is given to us, solar radiation, then multiplied by area. So, this is something like I×A and then you have efficiency. So, this is like output, so now something like $q_u$, so that can, we can resemble.

So, if we know this efficiency, then area is known, then intensity is known. So, we can calculate what is the daily electrical output of the plant, which is nothing but $6.5 \times 50000 \times 0.0012$ is equal to 390 kW. There are other installations as well in other countries, like in Australia they have a plant of capacity 200 MW electrical and its height was 1 kilometre and greenhouse collector area is about 7 kilometres in diameter. So, it is a huge structure. So, even though efficiency is very-very low, but there are certain conditions at which we can go for this kind of installation.

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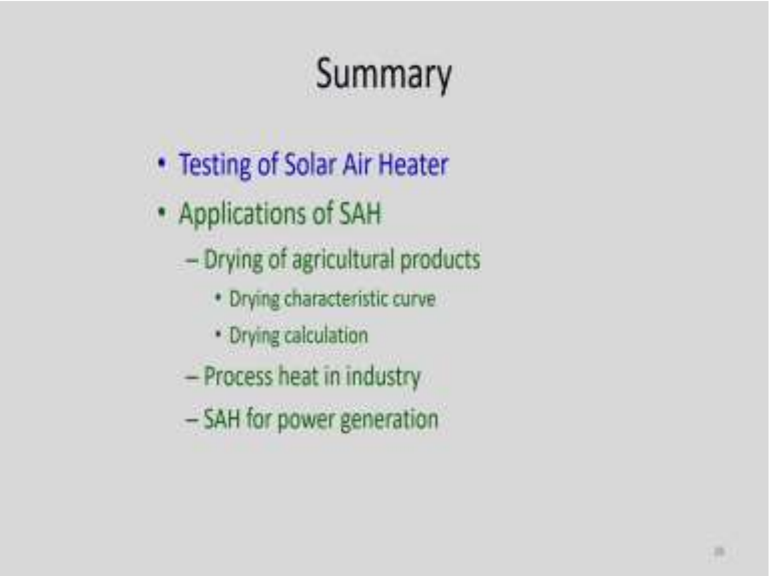


Now, let us summarize what we have discussed today. So, primarily we have discussed about the testing of solar air heaters, what are different instrument use and how this testing is done. So, this testing is done at different mass flow rates and at fixed air inlet temperature. Also, we have learned what are different instruments. Like for flow measurement, we need to use rotameter or maybe sophisticated mass flow meter.

For temperature measurement, we need thermocouples, so we need to measure a different thermocouples for inlet and outlet temperature. And of course, we need to have some kind of mixing vanes to regulate or to minimize the fluctuations of the temperature variations goes out from the solar heaters and then reconditioning unit. And also we have studied the application of solid air heaters in drying of agricultural products.

And also, we have studied drying characteristics curve, drying calculations by considering 100 kg of raw materials to be dried from 74 % to 14 %. So, we have understood the amount of heat required for doing so. And also, we have studied the use of solar air heater for process heat generation or process heat in industry. And finally, we have studied solar air heater for power generation. So, I hope that you have enjoyed this video. Thank you very much for watching.