Cooling Technology: Why and How utilized in Food Processing and allied Industries

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Module No 02

Lecture 07

Cooling Load Calculation Contd.

Good afternoon. Good afternoon, again we are in the class of Cooling Load Calculation right. So, this is a continuous class of the previous class that is Cooling Load Calculation. We have said, there are two types, one is unsteady, one is steady state, right. Now, when we are calculating, as it is shown in this figure that we have a, say 4 wall like this, right. This is of course, 2 dimensional, it can be also shown in 3 dimension and heat transfer is coming from all the sides, right and that is what we are saying that heat transfer rate through composite solid, you have to take care.

And also the heat transfer coefficient from outside by air through various surfaces under of course, various conditions. I give you again one example that couple of weeks or months back there were huge natural calamities and there, you have seen the air velocity was somewhere may be 100 or 80 kilo meters per hour, right. Of course, that was natural calamity, but that time it was also having some rain, it was also providing a little cooling. We are not talking about that I am just saying about your perception that during that period the air velocity was somewhere 80 to 100 or 120 kilo meters per hour.

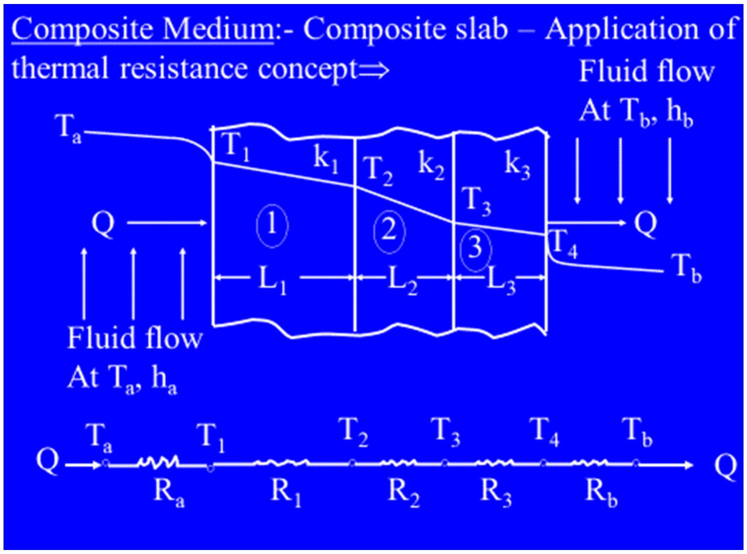
And suppose like today there is no such breeze it is almost steady. So the velocity could be somewhere 5 to 10 kilo meters per hour. So obviously, if you consider even say the sun, because in India we have plenty of sun. So if you consider that the heating from the sun, so considering the month of May or April and considering the month of November or December obviously, the situation is not different, is same, right. And another example of various surfaces here the one which we have given you that blue colored and it is of course, two dimensional.

Suppose the top one is the roof and the side one is the sidewalls, right. Now as I said that in the month of April May lot of air movement is there because of different reasons. So, there the velocities are very high. So the roof will have, that is a surface will have one kind of heat compared to that of the sidewalls. Because, sidewall's velocities will be interrupted whereas, the roof top that is free.

So there will be good breeze. So the resultant heat transfer coefficient also will differ. So that will give you some idea obviously, under which condition what could be tentative heat transfer coefficient to have the idea may not be exact, but to have the idea, right. So what we are doing? We are now calculating the heat load, right. So in this square, how much heat is being conducted or conveyed, right.

So generally conduction, convection and radiation these three are the mode of heat transfer. As we are talking about that this is a solid boundary, right. Inside we have the material to be stored, right. So leaving this material, if we assume that there is nothing, it is empty, right, then what we see, we see that the heat which is coming from the outside to the room or wall, which we have shown here is due to the resultant conductivity of the material and that we calculate through m dot C p delta T right. So m dot C p delta T is the heat and this C p is the resultant C p of the wholem here you have one heat transfer coefficient, here you have one conductivity, this side also you have one heat transfer coefficient.

So everything put together will make one U, as you know, so this U will be 1 by h 1 plus 1 by k by your area A x, right that heat transfer coefficient not heat transfer coefficient, your, the Fourier law, right, is dT dx A, right, q is equal to A into k into dT dx with a negative right. So, that, if we put here, so, that will be coming here and plus 1 by h 2 another. So all these different heat transfer equations can be utilized for finding out the cooling load right. So if we go to the next slide, if we go to the next slide, oh, I have to erase it, because surface remains. So this, it is saying that the unsteady state refrigeration load corresponds to the load of the product to be stored till it reaches a steady storage temperature, which I have been saying, right, from the beginning.



Both sensible and latent heat are to be considered and for the heat load calculation this latent heat and sensible heat are to be known. The heat of fusion of ice is 335 kilo joules per kg or as we have given 0.335 mega joules per kg. So when a change of phase is involved here there is some red marking when this change of phase is involved the latent heat of water must also be considered, right. So this is as far as unsteady load, right, and we have talked about the steady load also.

So that as we have already said, I have already said that depending on the surfaces the heat transfer coefficients are also different. In this case it is watt per meter square Kelvin, right, it is watt per meter square Kelvin. So that watt per meter square Kelvin should be known for different surfaces. Some examples we have, I have given, that is, if it is inside the wall, steel air in the room, where you are sitting, if there is no fan, no air conditioner, then the air can be asked or air can be can be assumed to be steel air. So there the heat transfer coefficient is very low, minimum, it is somewhere around 8.

5 watt per meter square Kelvin, right. So if it is outside wall or roof when wind is also blowing, here we have given at the rate of say 24 kilometer per hour. If it is 24 kilometer per hour, it is a reasonable figure because it is not like the storm as we gave example of 80, 100, 120 kilometers, but 24, 25, 20 kilometers per hour is a normal one. So there, in that case, and you see, over the roof, that means, you have a plane over which the air is blowing right and it is 33.5 watt per meter square Kelvin.

Whereas, outside the wall or roof, when wind is blowing around 12 kilometer per hour, as we said that when there is no breeze, it is 7, 8, 10. So 12 kilo meter per hour is the air velocity and it is also being considered for the roof only. Then the heat transfer coefficient is around 22.7 kilowatt rather watt per meter square Kelvin. Other cases could be like horizontal surface and you have still air, and upward heat flow, surface is horizontal and you are saying that you have still air and the heat flow is from bottom to top.

That means, top is cold and from bottom the hot air is going to the top. In that case the heat transfer coefficient is 9.7 watt per meter square Kelvin. And lastly, another one example is horizontal surface still air, but downward heat flow, right. So instead of this is the horizontal surface, inside is still air and it is flowing, it is flowing downward.

In that case it is even lower, 6.25, right. So, it is even lower 6.25. So, whatever be we have given some example, because we want that you should have some idea about the numbers that heat transfer coefficient numbers, as at the moment you have seen it is 8.

5, 33.5, 22.7, 9.7, 9.6.25 like that, right. There are many other examples also where the heat transfer coefficients are even much higher, right. Like if you have, say liquid nitrogen which is again another coolant, there the latent heat is around 200 kilo joules per kg and the heat transfer coefficient, depending on the condition, is around 170 watts per meter square Kelvin, right.

So, it all depends. So, what we need, we need to know the surface and the heat transfer coefficient. Then I would like to explain that we said, that composite medium, right, that composite medium meaning as you can see that here we have given 1, 2, 3 right. So, there may be n number such insulations or some other right. So, they, if you add them up you can find out the resultant conductivity. How, this is called thermal resistance concept.

Like electrical resistance if you have one voltage, here another voltage, here, there is a resistance in the electrical resistance and you can find out how much voltage or current is going on. Here also instead of that this is called thermal, this is here one temperature, here another temperature and you have a resistance, you can have one or n number, as here you are seeing we have 1, 2, 3, 4, 5 right, 5 numbers of resistances and we can have different situations. In this case, on this side we are having, some fluid is flowing at a temperature of T a and h a and here another fluid is flowing at a temperature of T b and h b right. So, the quantity of heat flowing is q through them, it is flowing according to their resistances and ultimately it is coming out as q, right. So, we have taken for the first one is, temperature at the surface is T 1 it's conductivity is k 1 and it's thickness is l 1, since it is only one dimensional heat transfer.

Similarly the second one temperature at the surface is T 2 conductivity is k 2 and the length or thickness of the material is l 2 and third one the temperature at the surface is T 3 it's conductivity is k 3 and the thickness is l 3 coming to the surface at T 4 and then it is dissipating q to the ambient where your ambient condition is T b and h b, temperature is T b and heat transfer coefficient is h b right. So, in this situation, if we look at now, what we are doing, that the q quantity of heat is flowing and the resistances are, you know any flow is function of the driving force and the resistance, it is directly proportional to the driving force and inversely proportional to the resistance. So, if q is the flowing quantity in terms of heat then the driving forces are for the first one, it is T a minus T 1 and the resistance is R a that must be equal, because the same q is flowing, it is not that you have in slab 1 1 q in slab 2 another q that is not, you have the same q which is flowing throughout. So, what we are doing, we are doing that q quantity of heat is flowing through first resistance was T a minus T 1 over R a, if you remember that we had, we had this type of 1 then 2 then 3 like this. So, here we are telling that T a minus T 1 by R a is equal to T 1 minus T 2 by R 2 is equal to T 2 minus T 3 by R 3 is equal to T 3 minus T 4 by R 4 and that whole is equal to T 4 minus T b by R b, right.

So, this 5 q's are same, right, this is called the thermal resistance concept and based on the thermal resistance, it is done, right and we have to find out the individual resistances. So, individual resistance is R a, right and that is equals to 1 by h a into A is equal to and then R 1 is L by A k right, R 1 is L by A k, then R 2 is L 2 by A k, R 1 is L 1 by A k 1 R 2 is L 2 by A k 2 and R a is L 3 by L 3 right then the last one R b is 1 by A h b then the total resistance is R if we look at q that is equal to the total temperature difference, that is T a minus T b divided by R and these are as you have seen that they were in series right, they were in series. So, this is the flow, so these were in series. So, that is why the R is added R is equal to R 1 plus R 2 plus R 3 plus R 4, has many R, right. So, then we find out what is the q, from there we can also find out what is the, if you know the q, what is the resultant k, right this is how the k or equivalent conductivity is also found out.

$$Q = \frac{T_a - T_1}{R_a} = \frac{T_1 - T_2}{R_1} = \frac{T_2 - T_3}{R_2} = \frac{T_3 - T_4}{R_3} = \frac{T_4 - T_b}{R_b}$$

where thermal resistances are defined as

$$R_a = \frac{1}{Ah_a} \quad R_1 = \frac{L_1}{Ak_1} \quad R_2 = \frac{L_2}{Ak_2} \quad R_3 = \frac{L_3}{Ak_3} \quad and,\ R_b = \frac{1}{Ah_b}$$

$$\therefore \quad Q = \frac{T_a - T_b}{R}\ W$$

$$where, \quad R = R_a + R_1 + R_2 + R_3 + R_b$$

Thank you.