Thermal Operations in Food Process Engineering: Theory and Applications
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Lecture - 27
Heat Transfer by Convection

Good afternoon, my students. We have completed conduction heat transfer. Of course, in that we have also looked into a part of the convection also little the thing is that we have when completed this graphs, that is the Heisler chart. So, Heisler chart you have seen there you need both Fourier number alpha t by l square and you need Biot number that is hL/k. So, there also wherever h is also there so, there is a part of convection

However we have not covered the basics of convection. So, today we shall start that in our lecture number 27, 'right'; so, Heat Transfer by Convection.

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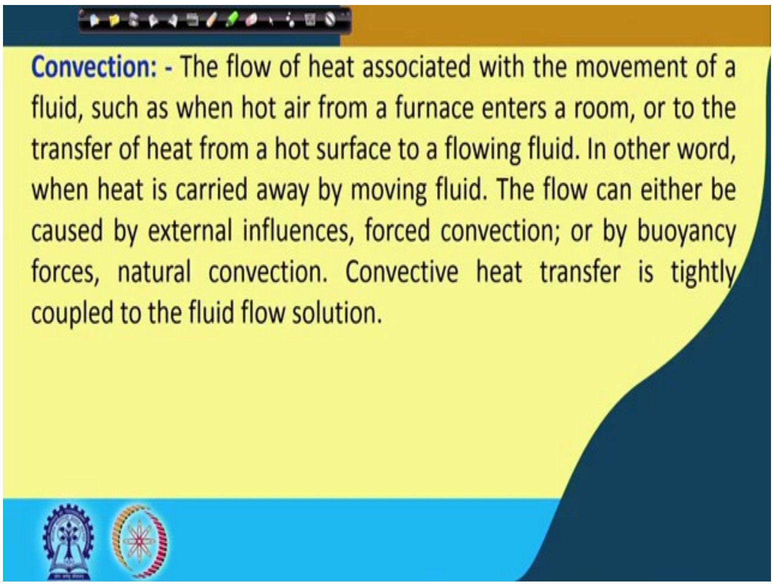

Now, convection that is the flow of heat associated with the movement of a fluid such as when hot air from a furnace enters a room, or to the transfer of heat from a hot surface to a flowing fluid. In other word, when heat is carried away by moving forced convection by we when heat is carried away by moving fluid. The fluid the flow can either be caused by external influences, forced convection or by conveyance forces natural convection. Convective heat transfer is tightly coupled to the fluid flow solution.

In this regard let me tell you that this is your everyday experience that you have seen your mummy and others, they are keeping in the household refrigerator food materials and may be cooked or precooked or raw vegetable, fruits they are keeping in different shelves of the refrigerator.

Now, in that refrigerator you have seen that on the top there is a cabinet where there is a cooling coil down below the cabinet. Now, this cooling coil is around minus 10ºC whereas, the shelves where the food materials are kept the temperature there are at different levels the upper stair or upper shelf may have lower temperature of to the tune of 3 to 4 degree. Then as you go down the freeze the temperature goes up and it may be to the tune of even 6 to 8 ºC depending on the loading depending on the condition of the freezer etcetera.

Now, the question is in the refrigerator there is no fan, if you have noticed that there is no fan. Then the question comes when the hot material hot to the respect that room temperature hot food materials or fruits and vegetables they are kept inside how the heat is being transferred from there to the material or to the cooling coil. This is a question which you should answer and also like in this room is fully air conditioned, but there is no fan, 'right'.

So, how this is happening that this whole room is getting cold there whereas, there is no fan, 'right' the answer to this both are that there is a convection current in both the refrigerator as well as the room such that hot gas or hot air in both the cases that goes up and the cold air being heavier that comes down. Just now we said that by buoyancy forces. So, that buoyancy force is being applied into these cases. These cases are that that because of the density difference there is a convective current generated that is by nature and that is why it is called though without any fan that is why it is called convective heat transfer, 'right'.

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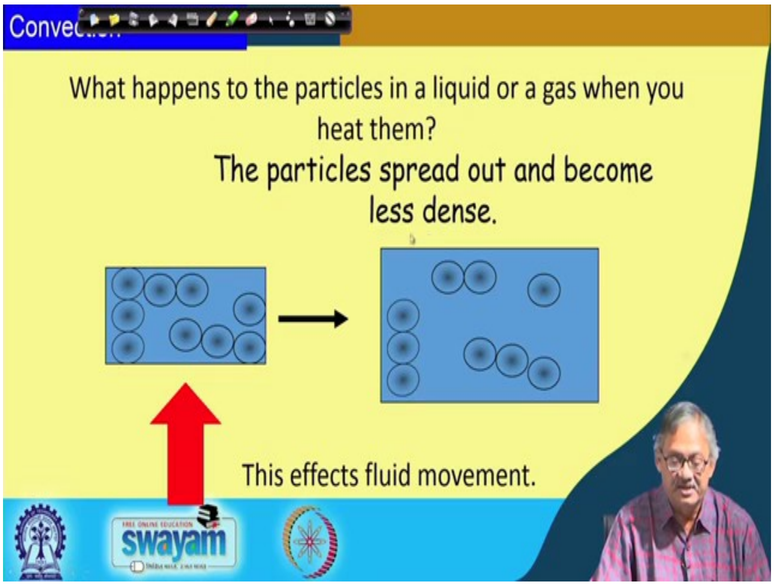

So, let us look into some more that what happens to the particles in a liquid or a gas when you heat them? Again, a part of heat will come under boiling that when we will go to the boiling that time you will see. But, again that mummy is preparing your tea in the early morning, 'right'. So, she has put water in a container and put on the oven now when it was being heated that time if you have ever noticed that initially there are some few droplets bubbles they are getting generated from the hot surface.

Then gradually the rate of this bubble formation is getting increased, 'right', and after sometime there are lots of bubbles are happening from the lower part of the container or hot surface and they are gradually in to coming to the surface and it is like a bubble which are dancing on the whole liquid, 'right'. The whole liquid there is turbulence and that condition we call it to be that it is boiling, 'right'

So, what is happening there? There also the liquids are liquid through the liquid this bubbles are getting escaped. While getting escaped the hot gas which is hot vapour which is coming out it is giving away the heat, 'right' and there is a current convection current that is being prevailing on the surface of the hot container there from the whole liquid, 'right'. So, this is what a pictorial depiction of this 'right'.

What happens to the particles in a liquid or a gas when you heat them the particles spread out and become less dense, 'right' like this.

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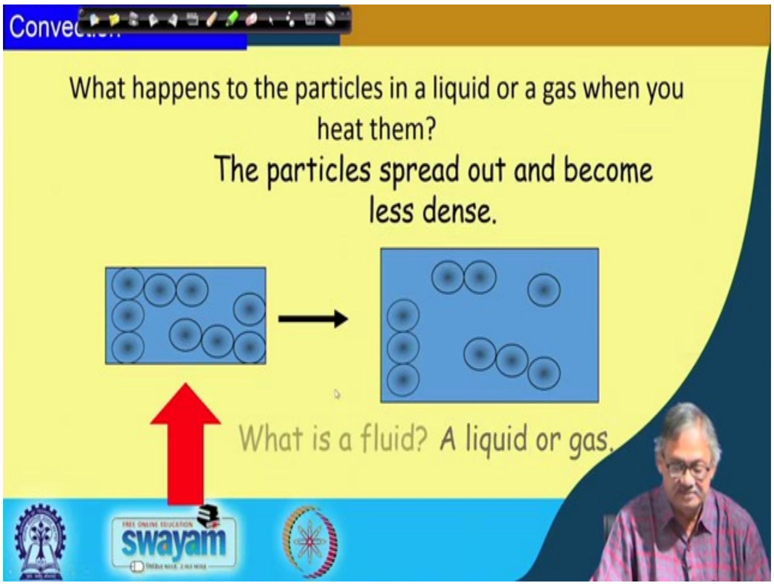

So, you are heating; so, these if these are the particles of the liquid. So, they spread out like this and thereby they are becoming less dense, 'right' this is what is happening. Now, of course, the question comes to what is the fluid 'right'? So, we can say a fluid is a liquid or a gas, 'right', both liquid and gas they are together or individually they are considered as fluid, 'right'. So, this way the particles are generating or propagating heat, 'right'.

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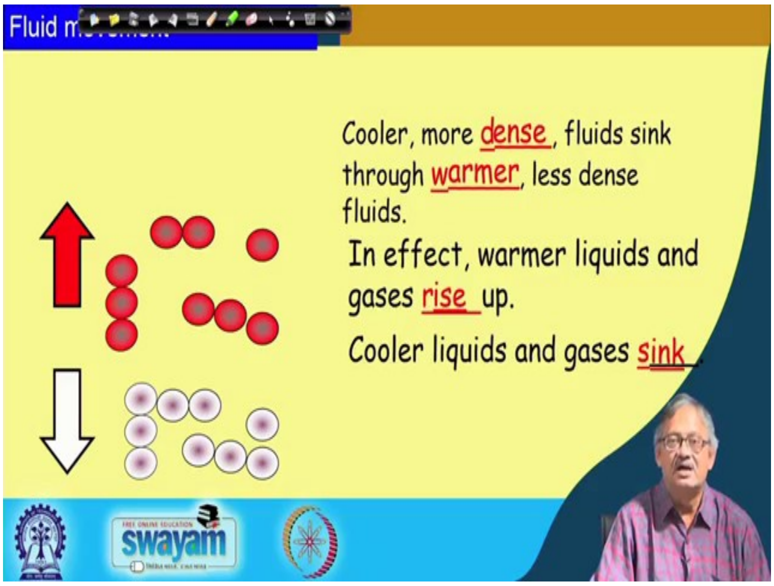

So, this is another pictorial view that the cooler, more dense, fluid sink through warmer, less dense fluids, ‘right’. In effect, warmer liquids and gases rise up and cooler liquids and gases sink, ‘right’. This is what is happening this is the warmer liquid particles, they are moving up and these are the colder liquid, which are denser and they are sinking. This way there is a convection current that is created and that is conveying the heat in the liquid.

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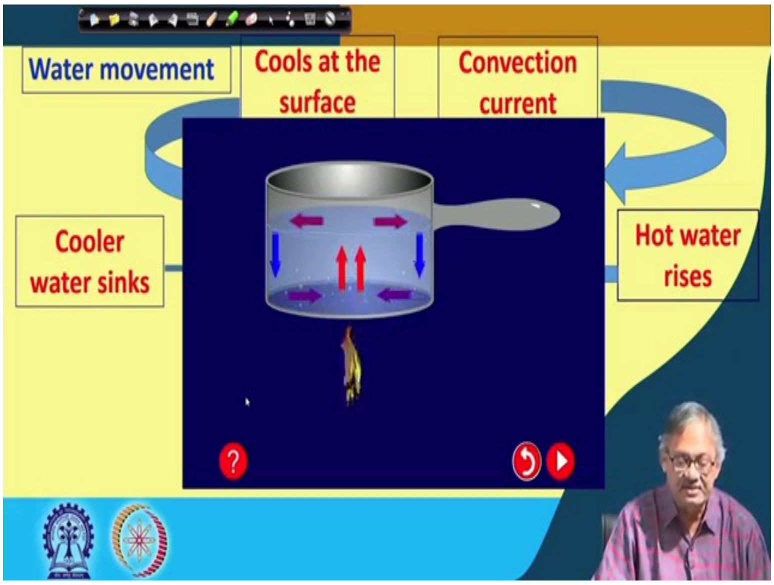

This is what I was just saying that mummy when she is preparing that tea, so, this is how the convection current is happening, ‘right’. So, cooler water that sinks that blue colour they are cool and this hot is going up that is hot water rises, ‘right’. This is called that water movement cools at the surface and there is convection current this service is getting cooled and hot water rises. This way this is happening, ‘right’.

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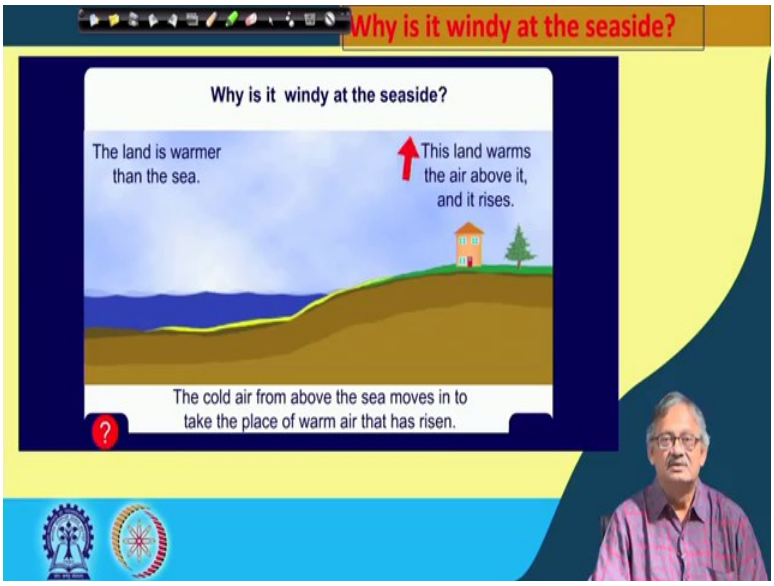

So, we can then say another thing another example is that why is it windy at the seaside, ‘right’? You will see that wherever you are going near the sea you are always getting a breeze always getting a wind blow in the seaside, ‘right’. This is because land is warmer than the sea, ‘right’ this is this from the seashore this is coming and land warms the air above it and it rises like this.

Whereas, the cold air from the sea above the sea moves into to take the place of warm air that has risen. So, warm air because it is the surface of the land is hot so, this is producing hot air. So, that is heating up whereas, cold air from your sea it is coming up and gradually it is replacing the hot air on the seashore. That is why it is windy on the seaside, ‘right’.

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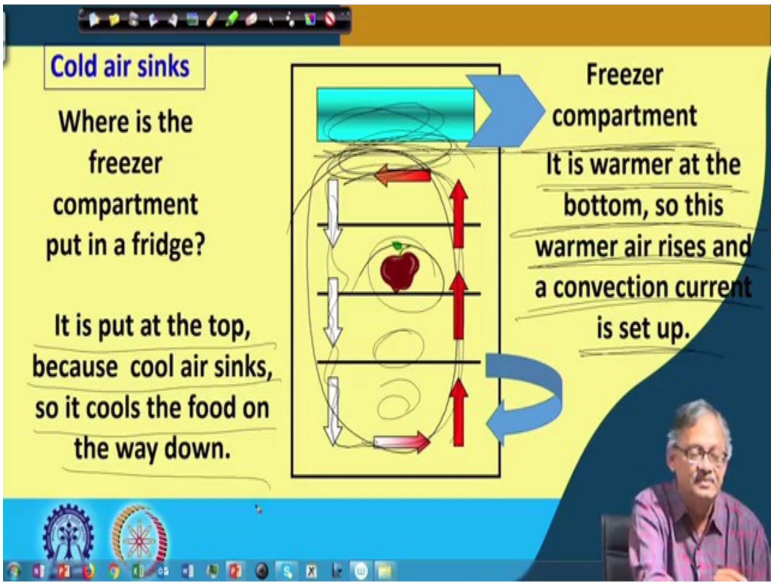

So, if we look at another pictorial view that the cold air sinks where is the freezer compartment put in fridge which we have already said, 'right' and this is the freezer compartment. This is the freezer compartment and this is producing that a cold, 'right'; it is warmer at the bottom. So, this warmer air rises and a convection current is set up.

So, hot air that is getting risen and the moment it is coming in contact with that cold freezer compartment this is getting colder and the cold air because of the higher density that is going gradually down, 'right'. This way the convection current is there and your food material are kept in the different shelves they are getting gradually cold, 'right'.

So, it is put at the top because this freezer compartment freezes put at the top because cool air sinks. So, it cools the food on the way down, 'right'. So, this is how the household refrigerators they work and how without fan the food materials they are getting cold or they are getting chilled, 'right'.

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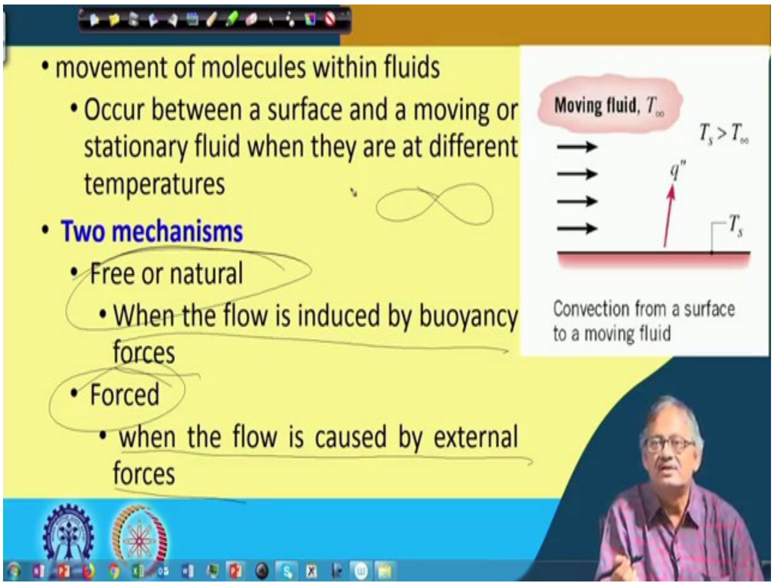

So, next we see that movement of the molecules within the fluids occur between a surface and a moving or stationary fluid when they are at different temperatures. For example, here we are showing that moving fluid is like this it is happening, 'right' and the $T_{surface}$, 'right' is higher than $T_{environment}$. That is why that the surface is getting heated up, the air is getting heated up, that is going up and the cold air that is coming and replacing this hot air, 'right'.

There are two mechanisms for this one is free natural free or natural convection when the flow is induced by conveyance forces then it is called natural convection, 'right' and when it is by some forced convection, when the flow is caused by external forces this external force is generally we referred to as a fan, 'right' generally we refer to as a fan. So, fan is causing that force of the air replacing the cold air by hot air and all rather hot air by cold air and vice versa. This way the convection current is generated.

This is also one reason why there are huge breezes or storms when it is happening 'right'. So, the place where storm is occurring from the colder side the cold air is coming and the hotter side this hot air is being displaced by that cold air. That is why there is a huge blow up that is why there is a huge blow and of air current and there is a convection 'right' force convection it can be said is. So, so though it is not by fan that is called by definitely because of the delta T, 'right'.

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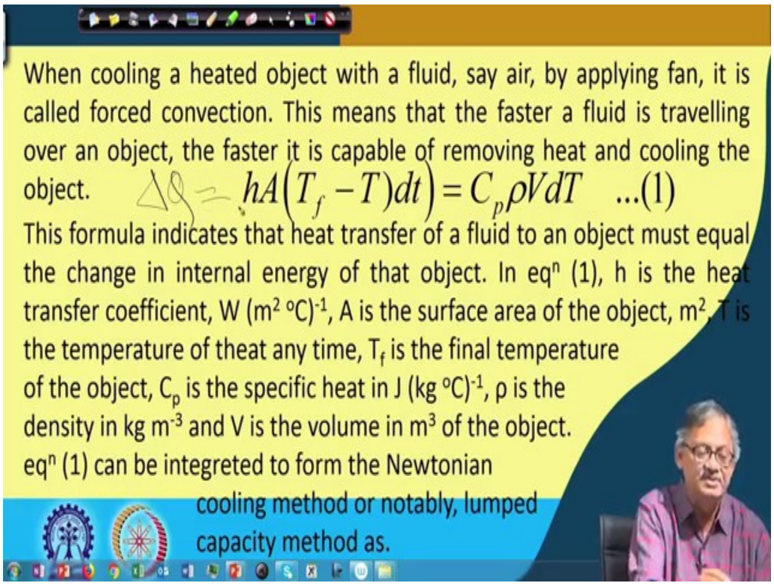

Now, if we look at that the two ways when cooling a heated object with a fluid say air by applying fan it is called forced convection, 'right' it is called forced convection and this means that the faster a fluid is travelling over an object, the faster it is capable of removing heat and cooling the object, 'right'.

And, this is governed by the formula called a Newton's law of cooling that is

$$hA\left(T_f - T)dt\right) = C_p \rho V dT$$

. So, this is the also known as Newton's law of cooling, 'right' where this ΔT or ΔQ is equal to or Q is equal to simply we can write Q is equal to hAΔT, 'right' or in this case since it is there is also dt that is in the time dt how much heat has been transferred.

The formula indicates that heat transfer of a fluid to an object must equal to equal the change in internal energy of the object, 'right'. So, that is the convective heat transfer or convective heat must be equal to the internal generation internal energy generation, 'right' $mC_p dt$.

And, this equation in this equation of course, h is the heat transfer coefficient h is the heat transfer coefficient in watt per meter square degree centigrade, A is the surface area of the object in meter square and T is the temperature of the temperature of T is the temperature of the at any time of the object it should be of the object at any time, T_f is the final temperature of the object and C_p is the specific heat in joules per kg degree centigrade, 'right' and rho is the density in kg per meter cube and V is the volume in meter cube of the object, 'right'.

So, this equation can be integrated to form that Newtonian cooling method or notably lumped capacity method, 'right'.

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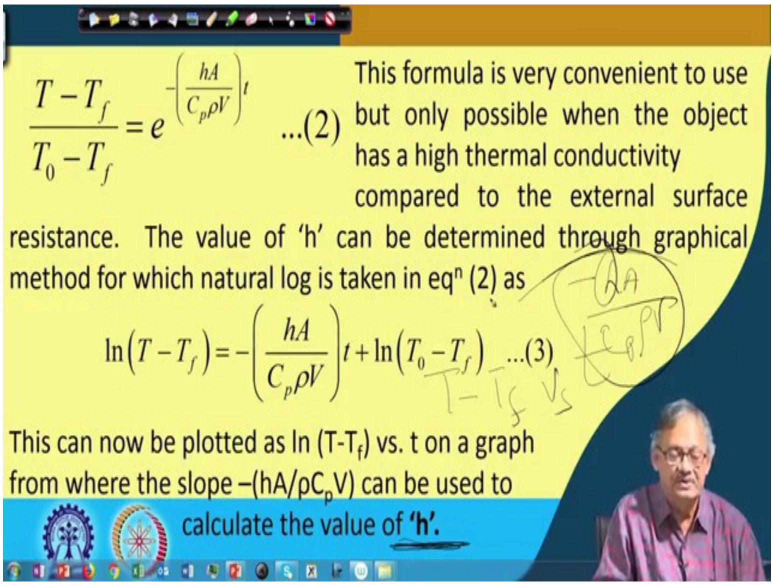

So, this can be done like this that $(T-T_f)/(T_0-T_f)$ this is equal to $e^{-(hA/\rho CpV)t}$. So, this one integration the previous equation on integration we can write that equation means this equation this equation on integration, we can write like this, 'right' and this one integration gives us the Newtonian law of cooling or Newton's law of cooling as $(T-T_f) / (T_0-T_f) = e^{-(hA/\rho CpV)t}$, 'right'.

So, this formula is very convenient to use, but only possible when the object has a high thermal conductivity because unless the object has a high thermal conductivity that the lumped system formula cannot be used, 'right'. So, this high thermal conductivity compared to the external surface resistance that is h; compared to the value of h the value of k that should be very high which we have in detail discussed earlier, 'right'. So, that convective heat transfer coefficient that resist convective resistance must be low compared to the conductive resistance, ‘right’ that we have said earlier in many cases.

So, equation 2, this we can rewrite and if we take the log we can say that $\ln\left(T - T_f\right) = -\left(\frac{hA}{C_p \rho V}\right)t + \ln\left(T_0 - T_f\right)$, ‘right’ this can now be plotted in $T-T_f$ versus time, ‘right’. So, this is $T-T_f$ versus time on a graph from where the slope is $-\left(\frac{hA}{C_p \rho V}\right)$ can be used to calculate the value of h ‘right’. So, the value of h can be calculated from a graph of $T-T_f$ versus time T where the slope of the graph will give h, ‘right’. So, the slope of the graph will be $-\left(\frac{hA}{C_p \rho V}\right)$, ‘right’. So, this from there we can find out the value of h.

So, coming to the end of the this beginning class of the convection that we can say that this is primarily governed by and known as the Newton’s law of cooling, ‘right’. So, Newton’s law of cooling says that $hA\Delta T$ is the Q and from as we said the h, the value of h is very fundamental and this has to be measured or calculated as the case may be, ‘right’. So, we will do in subsequent classes the h are the importance of h that is heat transfer coefficient and how it can be measured or how it can be calculated or some problems associated with them we will do that, ‘right’.

Thank you.