**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

**NPTEL**

**NPTEL ONLINE CERTIFICATION COURSE**

# Convective Heat Transfer

**Lec-20**
**Tutorial: Convection inside duct and mass transfer**

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Hello welcome in the last lecture of my course convection heat transfer. In this lecture we will be doing some sums okay, and we will be targeting some sums in the domain of convection inside a pipe line, inside a duct. As well as we will try to see one sum related to mass transfer okay. So first let me show you what are the problems we are having. So first problem is like this.

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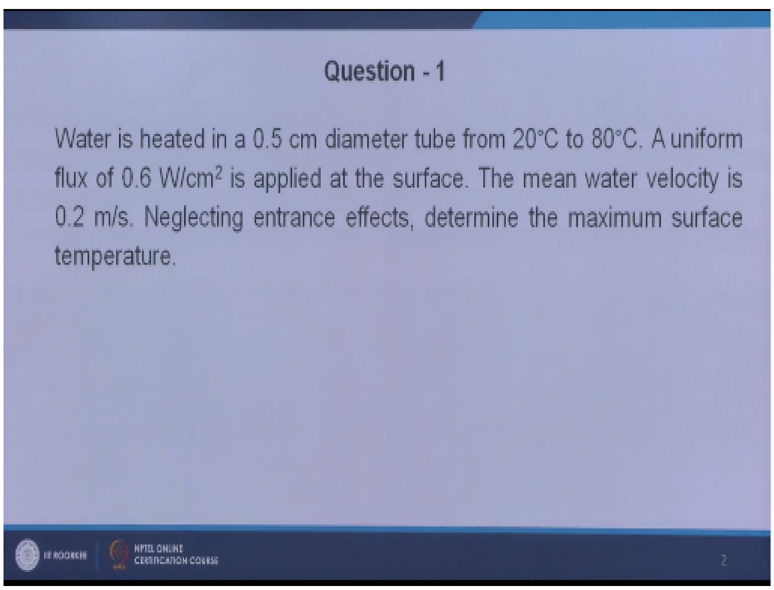


Let us say we are having water which is being heated in a water is being heated in a 0.5cm diameter tube, so tube is having 0.5cm diameter from 20° to 80°. A uniform flux of 0.6 W/cm$^2$ is applied to the surface of the tube okay. So that means you have a uniform heat flux case over here okay. The mean water velocity is 0.2 m/s and you have to neglect the entrance effect, so thermal entrance region need not to be considered, you have to determine the maximum surface temperature of the tube okay.

So this is the problem we are having, so this you can see this is nothing but actually pipe flow having constant applied surface heat flux okay. So let us see how this problem can be solved over here, so to solve this to get the problem what we are having we will be taking a schematic of the problem. Let us say this is the pipe line whatever we are having.

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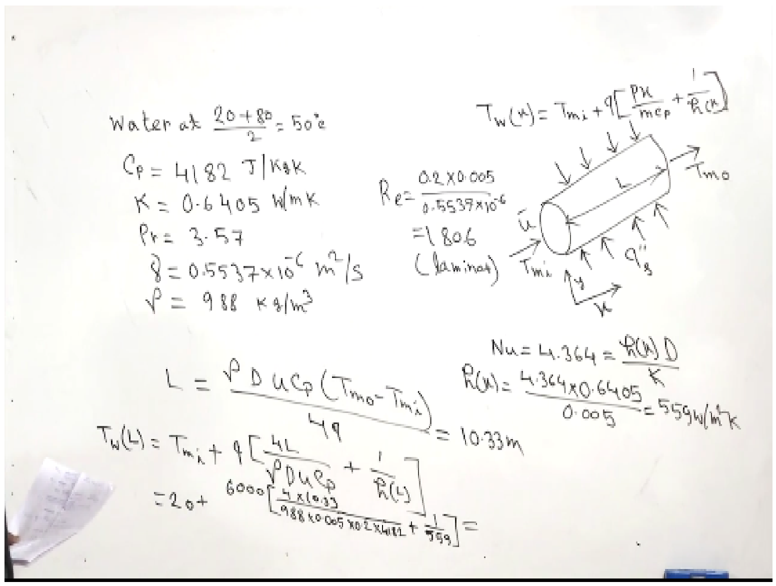


So let us say this is the pipe line whatever we are having and we are having certain inflow having velocity let us say ubar okay and the temperature of the inflow let us say Tmi and on the other hand side we are having the outflow this is Tmo okay. So inflow temperature and outflow temperature we have shown. Let us say throughout the pipe we are having constant heat flux, so we are having constant heat flux like this okay.

So this heat flux let us say we consider that is qs’’ okay. So this is the situation we need to find out what is the temperature of the pipe wall okay. So this is the problem we are having in our hand. So to do that first let me try to derive what is the wall temperature with respect to my type axial direction X okay and let us say this is my radial direction Y. So in this case we can write down that q amount of heat, let us say q amount of heat is being supplied to the pipe wall.

So q into perimeter of the pipe and length X so this is the total area through which the heat is being supplied. So qxpxx=whatever amount this amount of heat will be taken by the water inside. So mxCp[Tm(x)] so this is actually the mean temperature of the fluid or we can say the temperature of the fluid. So [Tm(x)-Tmi] okay so in this inflow temperature, so temperature of the fluid will be increasing by virtue of this heat addition.

So if you continue from here we can write down Tm(x) is actually equals to Tmi+qPx/mCp okay, so this we have seen okay. Now if you try from the other hand let us say we try to find out from heat transfer so q will be actually heat transfer coefficient h, let us say this h is obviously a function of x, so let me write down hx multiplied by your wall temperature. So let us say Tw, Tw x which will be also a function of x, Twx-(Tm(x) okay, because heat is being transferred from the wall to the fluid okay.

So this is from my heat transfer, so if we add this two, so from here also we can see what is wall temperature so Twx is actually coming equals to Tm(x) and then +q/h(x) q is a constant so I am not taking that one as function of x, so this we have seen. Now here we have already found out what is Tmx if you out the Tmx from here to here then I can get Twx is actually is equal to we can say Tmx will be replaced by Tmi+qPx/mCp okay.

So this is actually Tmx+q/h(x) okay, so this we can write down so ultimately this Twx let me write it over here Twx can be written as Tmi+ let me take q common so it will be qxPx so Px/mCp+1/h(x) okay. So this becomes my equation of the wall okay. So we have to start with this one in this problem you see we have to first see what is the perimeter and what is the m for this tube, so let me do that one over here.

So if we do that part over here, then we can simplify this equation further, let me show you how we can do that. So we have seen this PLq is actually equivalent to mCp and then Tmo-Tmi why I have written this, because this is considering the whole pipe line let us see the pipe is having length L okay, so for the whole pipe line inlet temperature and exit temperature is coming over here and L is coming over here PxL is the total area through which the heat flux is being applied.

So if you try to find out L from here, so L will become mCp and then Tmo-Tmi okay divided by Pq. So if you try to put now the value of m and P in terms of the tube, so m will be Л/4 $D^2$ρ and then for the axial direction we have to take u okay, and then this cP(Tmo-Tmi) will remain okay.

And in the lower side P can be written as ЛD which is nothing but perimeter for the tube okay and q okay, after simplification this can be written as ρDuCp(Tmo-Tmi)/4q, D will be cancelling out the δ*Q. So we are find out this scale over here okay.

So now you see let us also try to find out ,the final expression for the T W ,by putting P M n the terms of the tube ,if you doo so the T W ,of the X .actually , it becomes T W of X ,actually becomes T M I +Q ,we have taken in the common ,by writing this equating now ,Q I have taken common and then case of P/A and the C P and I have aim over here we have already did, what is P/D. And there the D will nothing but the square of the *u, if u put over there, it will become 4L/δ D U C P okay, the δ D P C P/1 v/H and in the L H /L so this is actually expression for in the T W in the end of the pipe L, because I have put X L over here okay,

So this will the equation were found out this equation it will have that will found so next let us try to see in these flow. So whatever we are flowing over here, so the Reynolds number. So get the Reynolds number we have to get the property. So let me show you the property. So let me keep these two final form of the equation over he and this was s other property, if you try to see now we have to try the properties you see it was actually 20%and 80%. So the properties we need to find at the 60% okay.

So in the water at 60% and in the mean temperature and the water at 50%. So the water at 20 +80/2 so that means =to 50% okay. So from this we can get the properties as first let me see as the C P that will be important. So the Cp will be 4182, so this we can find out from in the steam table and 4182 that is per Kelvin, so then we are k, and the thermal conductivity k that is that is actually, it will be also coming in the steam table, 0.6405okay .watt per meter kg.

And then we have the prandtl number, the prandtl number 2.57 @ 50%for the water, then we are having Q okay, ∞ will also require $0.5537*10^{-6}$ okay ,meter per sec and the new are having the ∞ ant then it will be require and then it will be 9.88 water per 50% k G per meter cube. Okay with all these properties we will try to first find out what is the Reynolds number so let us find the laminar or turbulent, so if you try to see the Reynolds number, the Reynolds number will become $2.20005/0.5537*10^{-6}$ so the Reynolds number will come out in the sa in the 1806, so that means it is less than 2400 laminar.

So the laminar, so if it is laminar we are having the constant heat flux case and the pipe flow we can use the nozzle term coordination so let me see these order already I have told in the lecture so for the constant heat flux the assent number will become 4.assent number will 4.364 ,so this assent number can be written as H X and the diameter in the tube K ,so the H X will become 4.364*0.6405/0,005this will be come out to be 55.9 watt per meter square per Kelvin.

Now as we are obtain in the let us try to get the result of the l the ∞ is known to the V 9.88 D is known to be 0.005 and the ∞ is to given the actually 0.2 miter per second ,okay the CP we are obtain for the stability temperature for thee 41 .82 out let and them inlet temperature are known as in the 20% respectively and the Q is common so you can get the constant value of the L so all the parameters are known will be getting the l coming out to be in the 10.33 meter okay.

On the other hand the surface of the temperature the T M I is kn ∞ own it is nothing, but your it is .0 watt per the meter square and the value of the L is known and it is nothing but just now we calculated the 3 3 meter ∞ the D U C P are all known to be in you just now we are found over here and the H l will 559 .so if put all these the 20 + 6000 and the density and the 0. ..5 and the diameter ,then it is multiplied by 0.2 is the velocity and the C P is 4.182 on the +1/ H I have found 559 and then I put all these the values the T W at the end if the pipe line and it will becomes something around 90.7% centigrade.

So in this problem we have found out to answer, so let me so in the correct answer here ,so the correct answer will be 90. 7 and this is the first problem we have okay, the next let me tell you ni the next problem we will be trying over so the next problem.

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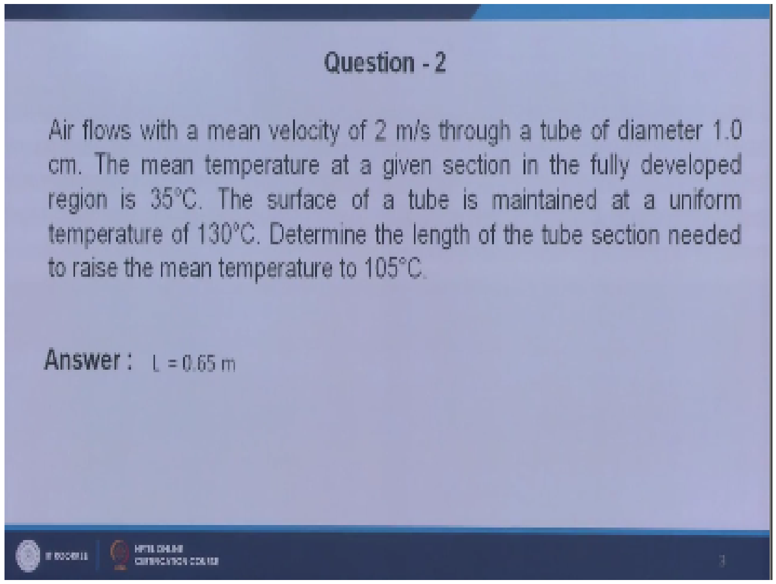


Ant in the mean velocity of the 2 meter per second through the tube diameter of 1 centimeter and the mean temperature at a given section and the fully developed region and the 35 % so here you see we are having the constant wall temperature and the surface of the tube is maintained at uniform temperature and 130% you have to determine once in the next and the previous and the previous and the length of the tube section and the raise the temperature and 2 to 105 %.

So the out let temperature is 105 % so it just simulate to the previous one only the difference we are having uniform temperature okay let me show you the problem over here once again. Now this time we have to see here table because my working flow it is becoming here so let me show you with here this problem how it will be working.

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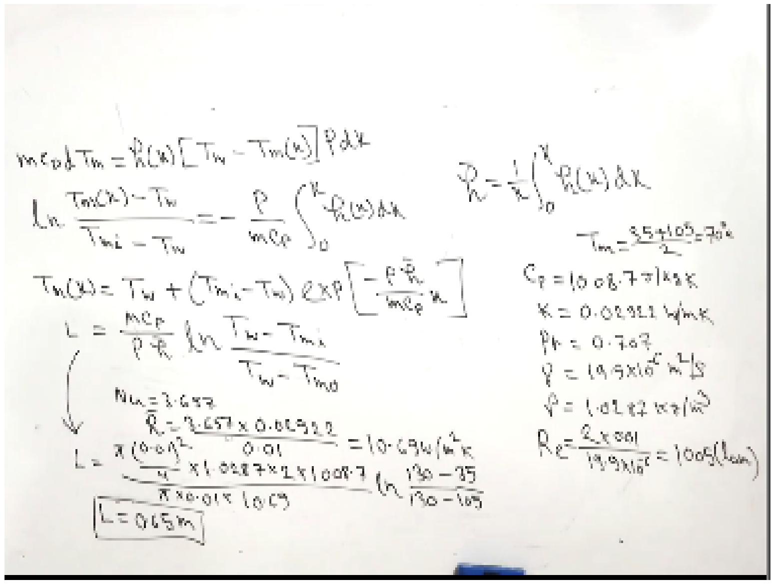


So first just like the previous one let me first derive what will be the wall temperature so $mc_p$ dTm so change of the bulk temperature of the fluid is actually equivalent to hx heat transfer coefficient then the temperature gradient obviously Tw – Tmx at bulk temperature at location x multiplied the area through which it is coming so p is the perimeter d is the infinitesimal length okay.

Now if you do the integration both sides then you will be getting ln of mean temperature at x – Tw surface temperature or wall temperature you can say Tmi okay inlet temperature minus Tw is equal to –p mcp 0 to x hx dx okay. So after this if we proceed further and we consider that h is nothing but heat transfer coefficient is nothing but 1/x 0 to x hx dx so average heat transfer coefficient if you write down like this then this from here tm can be written as mean temperature of $h_e$ fluid Tmx can be written as Tw wall temperature is known to us for this case.

So Tw + and that is constant Tw Tmi – Tw x e $e^{xp}$ $e^{-p}$ average heat transfer coefficient because this integration is becoming h bar okay. Ph bar / mcp x x okay, so this is the equation we have got. Now if you want to put x = l then finally you get l = mcp p h bar okay then ln, now Tx will become actually Tw – Tmi okay now Tx will become Tno so the at the outlet the value becomes Tno, so this Tx actually became Tno okay.

So this equation we get for the l, so now we need to just first initial that whether the flow is laminar or not and get the fluid property and then find out the value of l, so first let me tell you the fluid property so you see we are having temperature $35^0$ and $105^{0,}$ so mean temperature is 35 so Tm is actually 35 + 105 / 2 = $70^0$C, so at $70^0$C for here we find out the properties you can get it from a table so cp is 1008.7 j/kg Kelvin okay, your thermal conductivity k is 0.02922 w/m Kelvin okay, Pr number is actually 0.707 okay then μ is actually 19.9 x $10^{-6}$ okay $m^2$/second and ρ will be also required 1.0287kg/$m^3$ okay.

So with this properties if you try to first find out what is Reynolds number which is nothing but 2x 0.01 / 19.9 x $10^{-6}$ this comes out to be 1005 which is nothing but laminar okay so this is laminar. So once you get this is laminar immediately you can understand what is the heat transfer coefficient becomes so heat transfer coefficient will be Nusselt number will be as it is constant temperature Nusselt number will be 3.657, so this already we have discussed.

So Nusselt number becomes 3.657 okay so if you write down Nusselt number in the form of h then you will be getting h is nothing but 3.657 x 0.02922 this is nothing but the k okay so Nusselt number x k /d which is nothing but 0.01cm okay. So her from we get the heat transfer coefficient is 10.69w/$m^2$ Kelvin. So now we have everything in this equation h bar was required so this is h bar, now we can put everything over here so l is becoming now so let me write down l once again from here so l is nothing but π x $d^2$, d is nothing but $(0.01)^2$ /4 x your ρ is density for here is 1.0287 okay velocity.

Velocity is nothing but your 2 m/second so it is 2 so this becomes your m and then cp just now we have find out for mean temperature 1008.7 / first it will be coming perimeter which is nothing but π x d 0.01 x you are having h bar just now we are found out h bar has 10.69 and then we are having logarithmic over here so logarithmic of Tw which is nothing but $130^0$ wall temperature minus of inlet temperature $35^0$ / $130^0$ – $105^0$ is the outlet temperature.

So this is 105 so if you calculate this l this becomes 0.65m so this is my final answer okay so let me show you the final answer over here. Let me go to the next problem so next problem is related to mass transfer here I have shown the problem.

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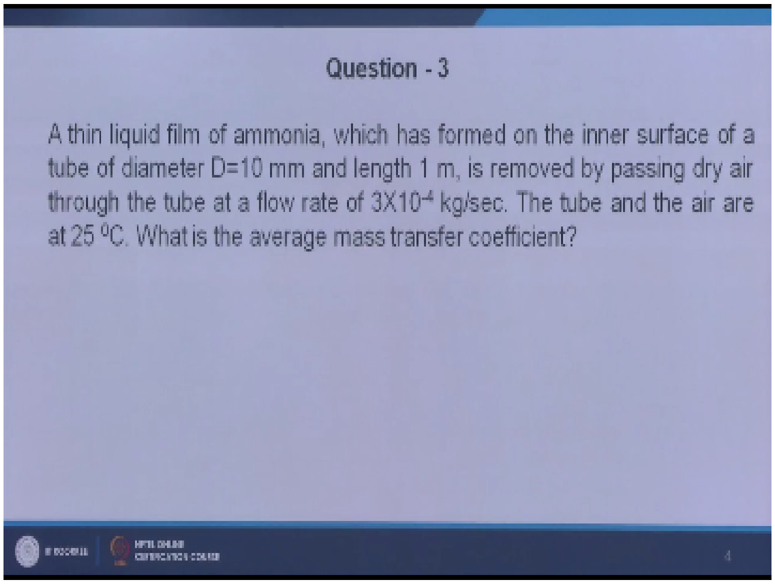


A thin liquid film of ammonia, which has formed on the inner surface of a tube f a diameter D = 10 mm and length = 1m, is removed by passing dry air through the tube at flow rate of 3x $10^{-4}$ kg/s. the tube and the air are at $25^0$ c what is the average mass transfer coefficient, so in this case we have to find out the mass transfer coefficient. So this is the problem involving mass transfer, so let me first show you the schematic of the problem and then I will be going to the derivation of the solution okay.

So let me show you the schematic okay, so it is a problem related to mass transfer whom we have learnt in the $19^{th}$ lecture, so let me show you the schematic first. So here we have the schematic we are having a tube okay.

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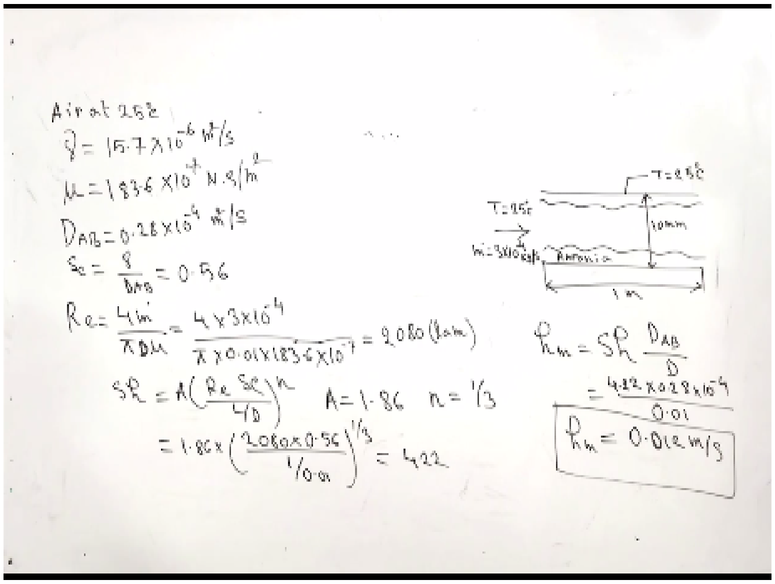


We are having a tube, where we are having ammonia film, so this is the ammonia film okay, the tube is having the diameter 10mm okay, the tube is having the temperature of $25^0$ c okay and the length of the tube, that is also given it is given as 1m okay. So we are having ammonia film over here okay, and here is some air flow okay, so air flow is having the flow rate of m= 3 x $10^{-4}$ kg/sec okay and we have to actually find out and the temperature is inflow temperature is T =$25^0$ c okay.

So we have to find out what is mass transfer coefficient in chain okay. So for this situation if we try as air is $25^0$ c, so let us find out what are the properties required, so here Air $25^0$ c so first we require γ what is mean 15.7 parameter discosticity 15.7 x $10^{-6}$ $m^{2/s}$ then we require what is the discosticity μ which is nothing but 183.6 x $10^{-7}$ N.S/ $m^{2.}$ We require the diffusiblity WE can find from property of air at $25^0$ c.

So this becomes 0.28 x $10^{-4}$ $m^{2/s}$ , we have seen earlier speed number, so ultimately the speed number will become μ/DAB so once we get this we can get the ratio of that so it becomes 0.56 okay. So these two ratio will become 0.56 and if you calculate this and you can calculate Renaults number so 4m/πDμ, so m dot is given, so if you put the value over here 4 x 3 x $10^{-4}$/ π x 0.01 x 183.6 x $^{10\ -7}$okay.

So if you put this the Renaults number will become 2080 which is nothing but laminar zone, so we can use all the laminar equations. So we know that we have already seen this number is important for mass transfer, so schedule number is also shown A x Re Se/ L/D $^n$ okay, here we need to find out the value of A and the value of n okay. Now let me tell you for this type of pipe flow cases. This I have not told you in the lectures.

So A will be coming out has 1.86 and n will be nothing but 1/3 okay. So if you apply this then we can find out for the schedule number this becomes 1.86 okay 2080 smith number we have found as 0.56 over here, 0.56 n/D, n is actually 1m okay, so 1/ D d is 10mm, which is nothing but 1m to the $^{1/3}$ okay. So if you calculate this so schedule number will become 4.22.

Now this schedule number will be helping me to find out the mass transfer coefficient, hm which we have discussed in lecture which is = schedule number D x AB/ D diameter okay, so it is evolves into the Nusselt number, is hd/ k okay, so from here I have obtained the value of DAB from the property table which is nothing but we can get 4. 22 okay x 0.28 x $10^{-4}$ / D, diameter of the 0.01, so my mass transfer coefficient comes out to be 0.012 m/s okay.

So this is the final answer we are having for this problem, let me show you the answer over here 0.012 as we have obtained.

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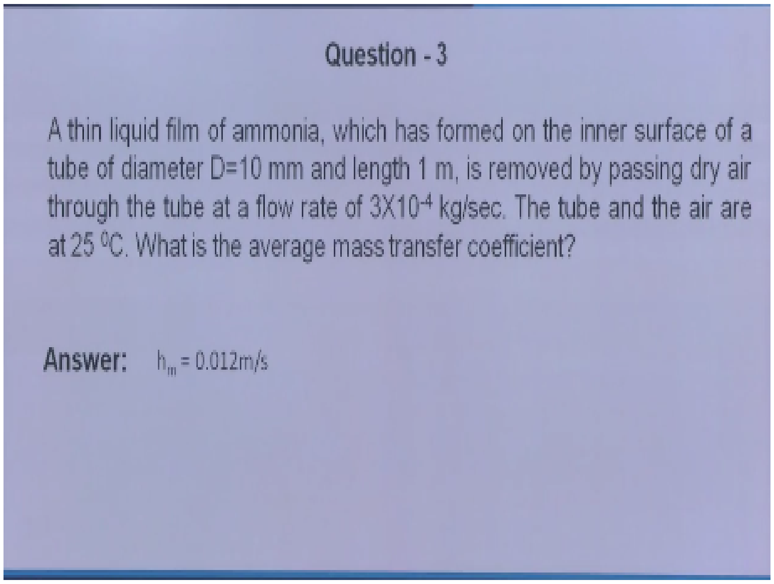


So this is very nice example of mass transfer question, please keep on practice sums like this and all the best for the exam thank you.

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