Course on Momentum Transfer in Process Engineering

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Lecture 29

Module 6

Flow through nozzle-problems and solutions

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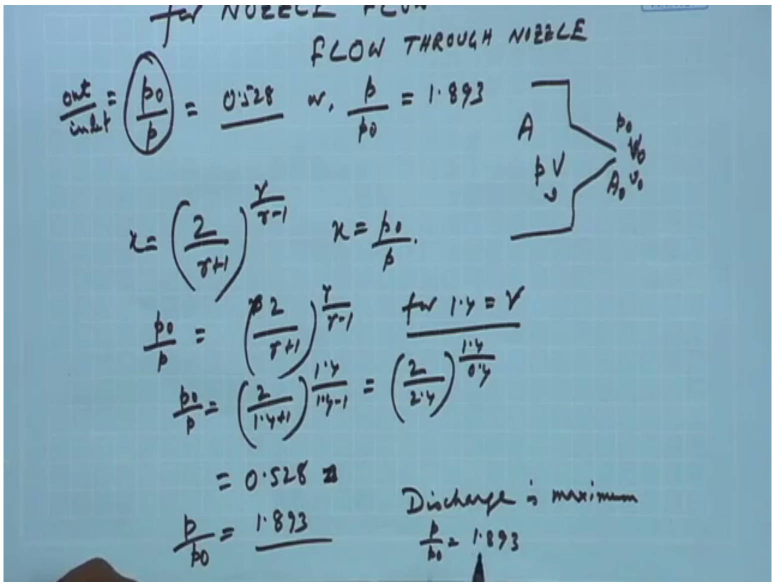

Yeah, so we finished up the last class if you remember that for nozzle flow again or flow through nozzle we have seen that p0 over p is equals to 0.528 or p by p0 is equals to 1.893, what it implies? It implies that we said this was the nozzle, right? And here the pressure was p specific was volume was V (small) velocity was small v and there at the tip the pressure was p0 volume was V0 specific volume was V0 and velocity was v0, right? And area is here if it A here A0, right? So this was the case in that case the pressure ratio this is tip to the inside or we can say outlet to inlet, right?

This is pressure ratio outlet to inlet or tip to (())(2:01) that is coming to be equals to 0.528. Now the question was we left here I mean it was hardly finished if we recapitulate a little that we had we had this relation that x is equals to 2 by gamma plus 1 into 2 by gamma plus 1 to the power gamma by gamma minus 1, right? So we said this that x was equals to p0 by p, right? So p0 by p was equals to 2 by 2 by gamma plus 1 to the power gamma by gamma minus 1, right?

Now, this was so now we said for a diatomic gas the value of gamma is equals to 1.4 if it is assumed, then if we write p0 by p is equals to 2 by 1.4 plus 1 to the power 1.4 by 1.4 minus 1 this becomes equals to 2 by 2.4 to the power 1.4 divided by 0.4 if we look at this calculator, right? If we look at the calculator if we look at the calculator is not we are not getting calculator here, right? We are not getting calculator here so, okay if do not get calculator then it can be that if you can check also that the calculator is like that okay in the accessories calculator is there and we can fix up yeah we got the calculator and if we take scientific calculator, then no need scientific but still we have some more.

So then we have 2 by 2 by 2.4, right? So it is and there 1.4 by 0.4, so we write 2 by 2.4, right? This is equals to 0.833 to the power so x to the power y to the power we write 1.4 by 4 1.4 divided by 0.4 so this comes to this and if we do that it becomes 0.528, right? This is what is coming 0.528. So that is what we had written that 2 by this is equals to 0.528 and if you do the inverse of this inverse of this it is 1.89 say 3 equal to not this, then p by p0 that becomes 1.893, right? So this is a typically value this value we have to remember let us take out this calculator once again.

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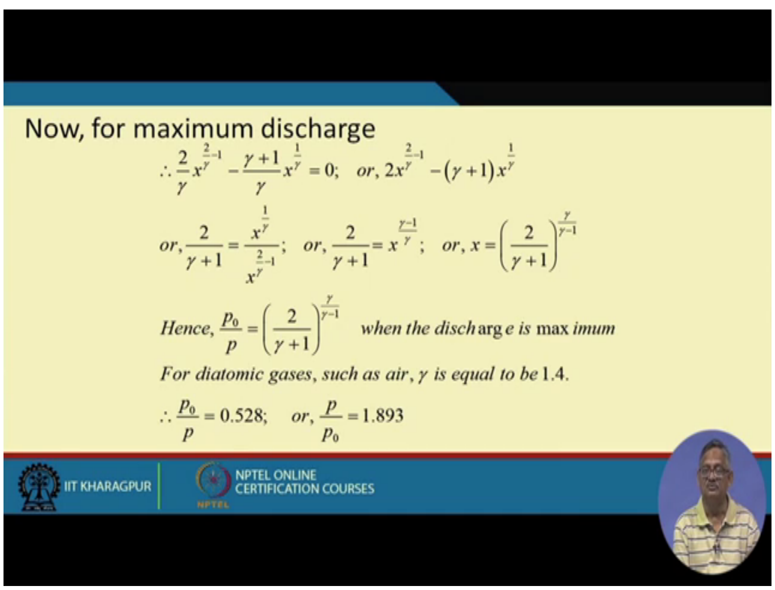

So we enlarge it, so this has a typical value why this p0 by p that is pressure the tip to the pressure at the inlet this ratio is 0.528 and if you remember that we said that when the discharge is maximum for that the condition was dw dp0 0, right? So if dw dp0 is 0 corresponds to a maximum velocity, then the pressure ratio comes to for a diatomic gas rather whose value is 1.4 gamma (())(6:56) that heat capacity ratio, right? If that is 1.4, then the pressure ratio from the tip to the to the inlet is pressure ratio for tip to inlet is 0.528.

That means if the pressure ratio between tip and the interior is or outlet to inlet is 0.528 we can say the discharge is maximum we can say that the discharge is maximum when the pressure ratio is p by p0 by p 0.528 that is outlet to inlet or the reverse if it is inlet to outlet then also it can said inlet to outlet is p by p0 that is equals to 1.893. So when the inlet to outlet pressure ratio is (point) 1.893 then also we can say the discharge is maximum, right? So if pressure ratio is anyone 1.893 inlet to outlet or 0.528 outlet to inlet, then we can tell the discharge is maximum or for maximum discharge the pressure ratio inlet to outlet has to be 1.893 or outlet to inlet has to be 0.528 then only we can say the discharge is maximum, right?

This we have to keep in mind this is very helpful for finding out both discharge and the velocity at the tip to find out that, right?

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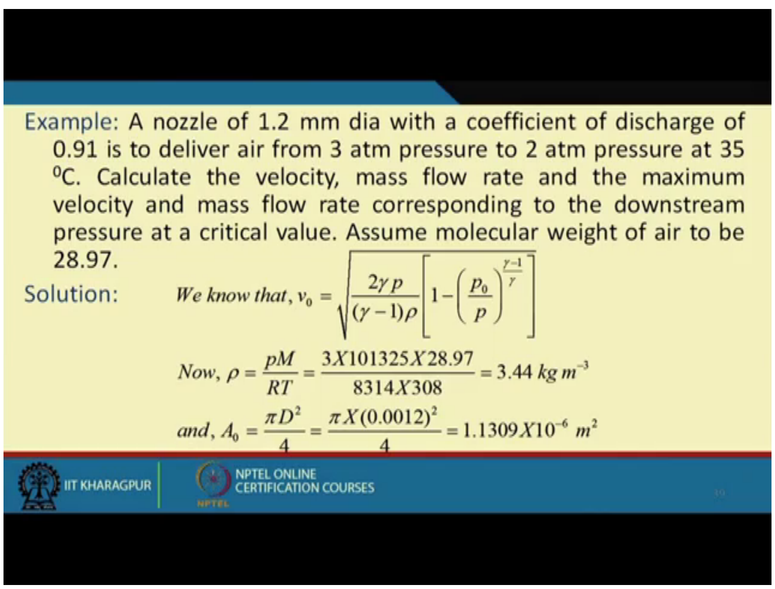

For example, if we look at this problem that a nozzle of 1.2 millimeter diameter with a coefficient of discharge of 0.91 this coefficient of discharge 0.91 is given by the manufacturer is to deliver here from 3 atmosphere pressure to 2 atmosphere pressure at 35 degree centigrade. Calculate the velocity mass flow rate and maximum velocity and through mass flow rate corresponding to the downstream pressure at a critical value whatever it is. Assume molecular weight of air to be 28.97.

So I repeat, it is a nozzle of 1.2 millimeter diameter with a coefficient of discharge of 0.91 is to deliver air from 3 atmosphere pressure to 2 atmosphere pressure at 35 degree centigrade. Calculate the velocity mass flow rate and the maximum velocity and mass flow rate corresponding to the downstream pressure at a critical value. Assume molecular weight of air to be 28.97, what we understand by downstream pressure?

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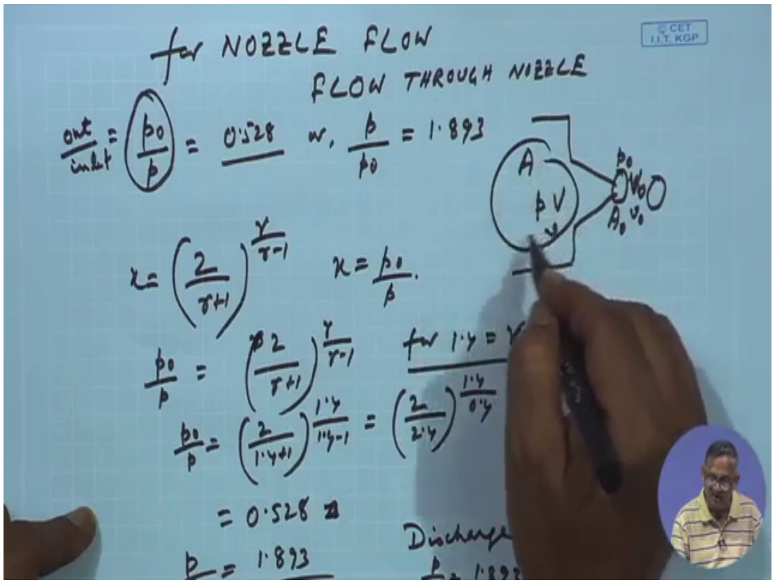

So if this is the upstream, then this is the downstream, right? So at the tip is the downstream and this corresponds to this p0 v0 capital V0 or specific volume at the tip 0 and or v0 or interior is A, P, V, v like that, right?

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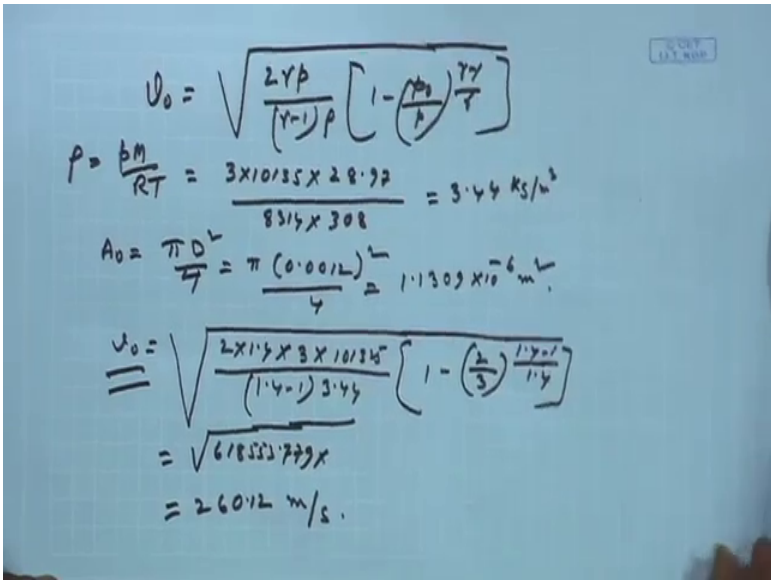

So if we solve this problem, then it comes that we know that v0 or velocity was under root 2 gamma p by gamma minus 1 into rho into 1 minus p0 over p to the power gamma minus 1 by gamma, right? So now given rho we know is nothing but pm by RT, right? From the problem given it is 35 degree centigrade, right? So p was given at 3 atmosphere to 2 atmosphere, right? So if we take 3 atmosphere 3 into 101325 Pascal into its molecular weight is given 28.97 divided by the gamma R is 8314 and temperature given is 35 so 273 plus 35 is nothing but 308.

So if we calculate this, then how much it comes let us see, we have done we have kept the calculator yeah we have kept the calculator here, so if we multiply that 3 into 1 3 into 101325 into 28.97 .97, right? Is equal to this divided by 8314 sorry 8314 divided by 308, right? Is equal to 26.99 let us I hope we do the thing because we had cancel this somehow. So 3 into 101325 into 28.97 divided by 8314 into 308 so this becomes this equal to 3.43 so 3.4389 that means we can write take 3.44, right? Kg per meter cube, right?

So we take this, then we can say that rho is so much, right? rho is so much, so 3.44 kg per meter cube and A0 that is the tip area is nothing but pi D square by 4, D is given pi into 0.0012 that is 1.2 millimeter whole square divided by 4 this becomes equals to pi into 0.0012 square is equal to so much divided by 4 that is equal to 1.1309 1.1309 into 10 to the power minus 6 so much meter square, right? If this is so much so we know that what is the rho and m. Therefore, v0 we can write is equals to under root 2 into 1.4 into pressure if we take it to be 3 into 101325 3 kilo

Pascal so 3101325 gamma is 1.4 minus 1 rho we have found out 3.44 into 1 minus A0 is 2 p is 3 to the power 1.4 minus 1 divided by 1.4, right?

So this if we see again through calculation how much it is, then we see it is 2 into 1.4 1.4 into 3 into 3 into 101325 101325 divided by or is equals to divided by 1.4 minus 1 1.4 minus 1 into 3.44, right? So this is equals to this, right? And equal to under root of 618553.779 into we still have into 1, 2, 3, right? 1 minus we have taken unnecessarily so many, right? 1 minus 2 by 3, right? To the power 1.4 minus 1 that is 0.4 by 1.4 0.4 divided by 1.4, right? 0.4 divided by 1.4 is this much, right? So if we close all is equal to this much it is under square root, so square root 260.

So it was 260.12, right? Is equal to 260.12 meter per second. So velocity has come to v so much. Now we need to find out the discharge, right?

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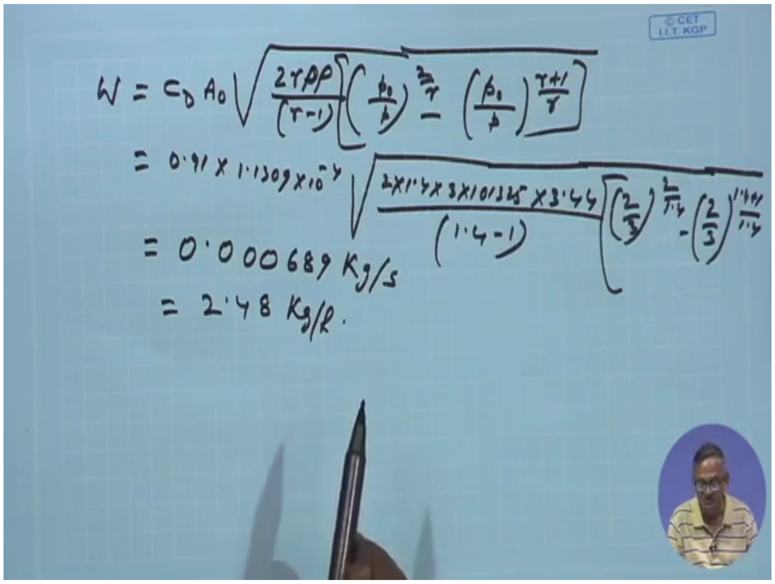

So w we have found seen is Cd A0 2 gamma p gamma p rho divided by gamma minus 1 into p0 minus by p to the power to the power 2 by gamma minus p0 by p to the power gamma minus 1 by gamma, right? Gamma plus 1 by gamma, right? So if we add the value is now Cd is given already is 0.91, A0 we have found out 1.1309 10 to the power minus 4 under root 2 into 1.4 into 3 into 101325 into 3.44 divided by rho is 3.44 1.4 minus 1, right? This times, right? This times 2 by 3 to the power 2 by 1.4 minus 2 by 3 to the power 1.4 plus 1 by 1.4, right? All under root.

So if we now again see how much is the discharge, then we start from there 2 into 1.4 into 3 into 101325 into 3.44, right? This is so much divided by 1.4 minus 1 that is 0.4, right? So that is 0.4 and this is equals to this, right? Times, right? So 1, 2 let us take, then 2 by 3 that is 0.66 2 by 3, 3, 3 to the power 2 by 1.4 this is equals to this much, right? 1.4 okay, so this actually if we close it here then you cannot write here also point, so this minus we have done that mistake minus 2 divided by 3 to the power 114 plus 1 2.4 by 114 2.4 by 1.4 that is 14, right? This, right? This is equals to so much, now this is under root, right? Under root into 10 x to the power minus 4 this, right? into 1.1309 is equals to this into 0.91 is equals to no no something wrong somewhere we have done.

Actually should have come this is equals to 0.000689 so much kg per second, right? And that should be equals to 2.48 kg per hour, right? So this is the discharge, right? So we have found out what is the discharge what is the velocity, right? Next comes what is the what is the velocity when is the discharge is maximum, right?

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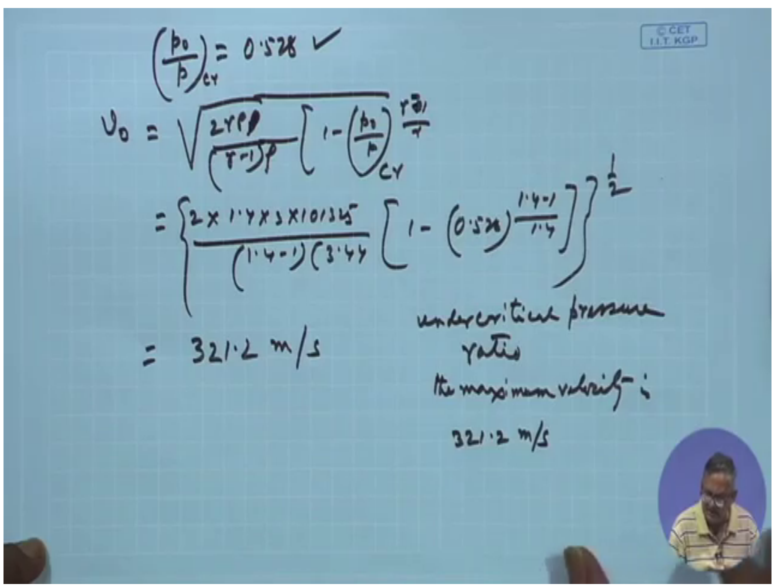

Now discharge becomes maximum only when let us bring it out discharge becomes maximum only when p by p0 by p that is equals to 0.528. So corresponding to p0 by p equals to 0.528 what is the velocity if that should be the maximum velocity, right? So we have for seen that v0 was under root 2 gamma p rho by gamma minus 1, right? 2 gamma p 2 gamma p rho or v 2 gamma p gamma minus 1 this was v gamma pV or gamma p by rho, okay.

This was that into 1 minus p0 by p this to the power gamma plus 1 by gamma under critical, now this p0 by p is when 0.528 that is called typical pressure ratio this is called critical pressure ratio. So if the pressure ratio is 0.528, then that is outlet to inlet or exit to inlet, right? Then it is called critical pressure ratio. So that is denoted as cr, so p0 by p to the power gamma plus 1 by gamma or this was no not plus this was minus gamma minus 1 by gamma critical. So we write 2 into 1.4 into 3 into 101325 divided by 1.4 minus 1 into 3.44, right? Into 1 minus p0 by p is 0.528 to the power 1.4 minus 1 by 1.4, right?

This whole to the power half, right? So this if we calculate then it comes to be 321.2 meter per second, right? 321.2 meter per second that means under critical pressure ratio under critical pressure ratio the maximum velocity maximum velocity is 321.2 meter per second, right?

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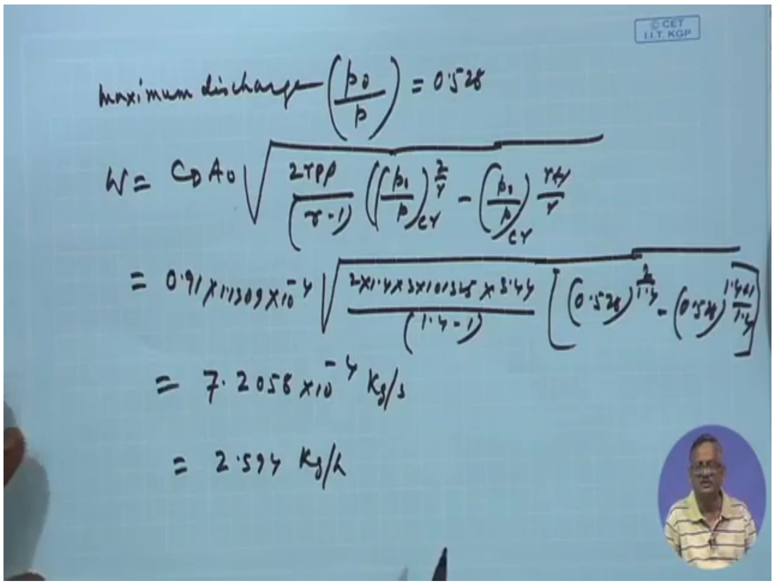

So we can also write then the maximum discharge corresponding to the critical pressure ratio so the maximum discharge corresponding to the critical pressure ratio of p by po over p equals to 0.528 if that be true, then we can write w is equals to Cd A0 under root 2 gamma p rho by gamma minus 1 into p0 by p to the power 2 by gamma under critical minus p0 by p to the power gamma plus 1 by gamma under critical, right? So this becomes 0.91 into 1.1309 into 10 to the power minus 4 under root 2 into 1.4 into 3 into 101325 into rho is 3.44 by 1.4 minus 1 into 0.528 to the power 2 by 1.4 minus 0.528 to the power 1.4 plus 1 by 1.4, right?

So this becomes equals to if we calculate then that comes to equals to 7.2058 into 10 to the power minus 4 kg per second so it is very small number in terms of hour it will be 2.594 kg per hour. So we see that the discharge maximum is 2.594 the velocity maximum is 321.2 normal discharge is 2.48 and here it was 2.594, right? 2.48 kg per hour, whereas it is 2.594 kg per and hour the this velocity was also found out to be 260.12, whereas maximum velocity 321. something 321.2.

So this way if you calculate if you find out the velocity at the discharge velocity at the tip corresponding discharge and maximum velocity corresponding to maximum discharge that comes under critical pressure ratio that is p0 by p is equals to 0.528, right? Thank you.