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NPTEL ONLINE CERTIFICATION COURSE

Course
on
Laws of Thermodynamics

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Lecture 11: Tutorial 3: First Law of Thermodynamics for Open systems

Good morning and welcome you all to this lecture session of the course laws on thermodynamics laws of thermodynamics earlier class we discussed the application of first law to an open system or a control volume and we derived the equation in general form when the control volume is around steady state and from there the special case for a steady state control volume and the equation is referred to a steady flow energy equation in this class we will solve some problems which are the applications of the energy equation that means energy equation applied to a control volume an open system.

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Problem 1: Two air flows are combined to a single flow. One flow is 1 m^3/s at 20 C and the other is 2 m^3/s at 200 C, both at 100 kPa. They mix without any heat transfer to produce an exit flow at 100 kPa. Neglect kinetic energies and find the exit temperature and volume flow rate.

So let us first start with the first problem, problem one which state that two airflows are combined to a single flow one flow is $1m^3/s$ that is the volume flow rate at 20^0 C and the other is $2m^3/s$ at 200^0 C the degree is not is emitted inadvertent mistake by both at 100 kPa they mix without any heat transfer to produce and exit flow at 100kPa neglect kinetic energies and find the exit temperature and volume flow rate.

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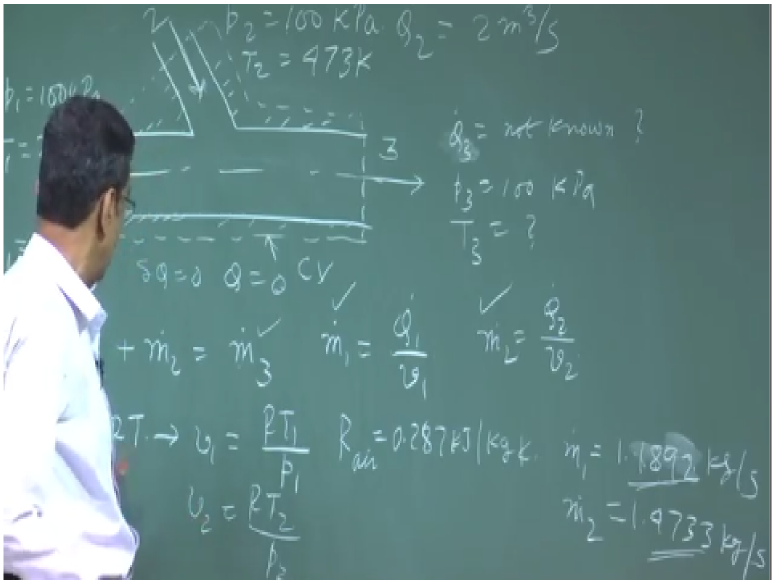

So problem is like this two flows are combined to a single this is a pipeline this is one flow this is another flow coming and this is going out one flow is coming here this is one flow this is another flow coming through this and this is going out let us this is the inlet section of one flow this is the inlet section of one flow let us define a control volume like this is the control volume and there is no heat transfer with the surrounding of this pipeline that means the entire pipeline is insulated.

That means no heat transfer no heat transfer that means ∆Q is 0 or Q is 0 now let this section is designated by one let this section where this constriction of the surface of the control volume at this stream cutis section 2 and this is section 3 combined stream now the quantity given is that P_1 is 100kPa now let me see the problem P_1 is 100 kPa and T_1 is 293 T_1 is to 20^0C it is given P_1 is 293 K and the volume flow rate $Q_{1.}$ is 1m ^{3}/s for the section 2 P_2 is also 100 kPa T_2 is 200^0C that means 473K and Q_2. = that is the volume flow rate 2 m ^{3}/s now at 3 the condition let us consider the m3 now sorry m3 note Q3. is unknown is not known not known we have to find out this we have to find out the volume flow rate and the temperature the exit temperature but exist pressure is same because both the pressures at the inlet is same.

So there is an isobaric mixing at the same pressure but exit temperature is not known it is to be found out so what we will do we will just apply the first law of thermodynamics to this now if we consider this m1. as the mass flow rate at Inlet and m2. as the another inflow mass stream then this is =m3. now m1. can again be written as Q1. by specific volume at Inlet similarly m2. can be written as specific the flow rate divided by specific volume at the inlet 2

Now the specific volume can be found out from the condition of p1 t1 how can I write you know that the relation PV is equal to RT for any ideal gas for any ideal gas, okay where P is the pressure V is the specific volume R is the characteristic gas constant and T is the temperature okay. So therefore we can find out from here v1 is r T1 / P1we know T1 293 K we know P 100kiloPascals and we have to substitute the value of R in the corresponding unit.

If you put it in kilo Pascal's so R will be in kilo Joule per kg K and for R the value of R is 0.28 7 kilo Joule easily you have to remember this part kg k this is the value of kilo joule per kg K, so if you put R this key 1 you know and P1 you know you find out V1 and in a similar way you find out V / R T2 P2 and where P2 is for 73 and P2 is same 100 kilo Pascal’s and you can find out V2 so therefore if you find out V1 and V 2 you can find out m1 and m1. and m2. so therefore you can find out m1. and m2.

And you can find out the mass flow rate at the section 3 this is found out I am not solving the problem in details but you have to solve it I will give you the answer of the rod but I am giving the answer now m1. will come out to be 1.m1 . will come out to be 1. m1 . is coming out to be 1.4733 1.4 7 3 3 kg/ s m2. will come out to be m1. if sorry 1.189 1.1892 and m1 m2. is 1.4733, 1. 4733 kg/ps 1.47 there may be little variations because they have taken the volumes where the specific volume from the air table no they are found out by R T1 pure.

So you will get this exact value m1dot and m2 dot you get the value of m3 dot, now to find out the temperature, because you cannot find out the Q2. until like Q3 until and unless you know the temperature, so m3. is known now, now m1. m2. m3. m1.m 2m3.unknown now you have to find out the temperature t3 now you write the energy equation steady flow energy equation this is a steady flow and therefore there is nothing is changing within the control volume.
So therefore we can write m1 doth1 neglect kinetic energies it has been told in the problem and potential energy also always neglected this is not to be told you always neglect so that becomes the energy in flow and that equal to the energy outflow and here energy receiving and going assuming by the control volume and leaving the control volume is only in terms of the mass flow rate because there is no work and heat interactions working Direction is 0, in this case there is no our interaction and it has been told that entire thing is insulated.

There is no heat transfer to the surrounding so therefore even if the temperature is greater than the surrounding it may be or may not be I do not know but we do not put our brain into that because it is told there is no heat interaction, so therefore this will be the specific form of the energy equation you may not have to remember that you can just simply by your fundamental principle you can write this is the energy coming in with a 1.neglecting the kinetic and potential energy this is with the incident and this is going out and steady flow case this has to be same so therefore now we can write for an ideal gas.

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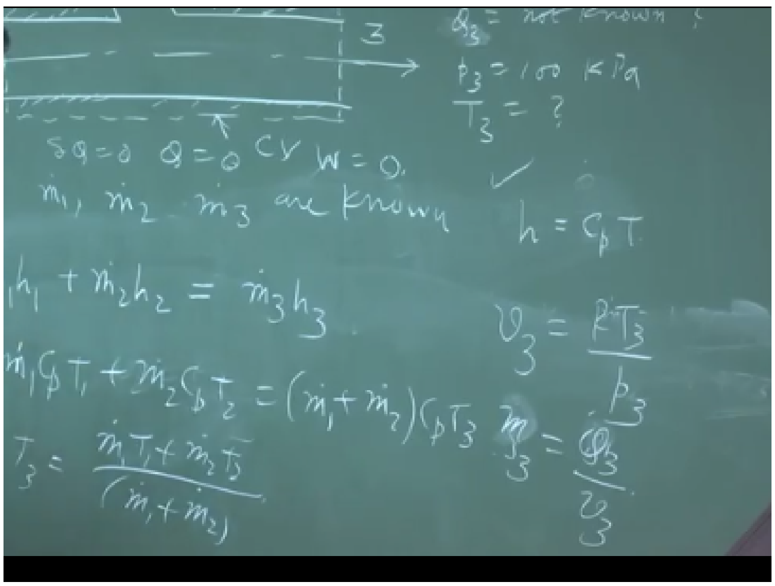

This you have to use it is given by C_P into T that is C_P is the specific heat at constant pressure and T is the absolute temperature so if you write this then you can write m1. C_PT_1 + m2. C_PT_2 = m3 is (m1. + m2.) Cp and for an ideal gas CP is constant and it is not also vary with temperature so therefore CP-CP will cancel out so it does not matter whether CP values we do not we know or not so simply T3 is found out to be m1. T_1 + m2 T_2 /m1 + m2.

And you know m1. You know m 2. and you know T1,T2 you can find out the value of T3, when you find out the value of T3 you can find out the value of T3 as RT3/P3, P3 is 100 kilopascals R is the same point 287 kilo Joule per kg then when you know T3 from this energy equation then you can find out the value of P3 and you can find out Q3. is a sorry M3 . M 3.is Q3/V3, okay. So this is the first problem okay. Now we come to the second problem, now we come to this second problem.

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Problem 2: A 25-L tank, that is initially evacuated is connected by a valve to an air supply line flowing air at 20 C, 800 kPa. The valve is opened, and air flows into the tank until the pressure reaches 600 kPa. Determine the final temperature and mass inside the tank, assuming the process is adiabatic. Develop an expression for the relation between the line temperature and the final temperature using constant specific heats.

Now a 25 liter tank that is initially evacuated is connected by a valve to an air supply line following flowing air at 20 degree Celsius 800 kilo Pascal, the valve is open until air flows into the tank and the air flows into the tank until the pressure reaches 600 kilo Pascal's, determine the final temperature and mass inside the tank assuming the process is adiabatic, develop an expression for the relation between the line temperature and the final temperature using constant specific heats, try to understand the problem there is an initially evacuated tank connected by a bulb to an air supply line.

And air is supplied at 20 degree Celsius and 800 kilo Pascal's the valve is opened air flows until the pressure reaches 600 kilo Pascal's when the valve is closed, determine the final temperature and mass inside the tank assuming the process is adiabatic. Now develop an expression for the relation between the line temperature and the final temperature using constant specification. Now this problem is also very interesting problem, now let us see the problem what the problem tells.

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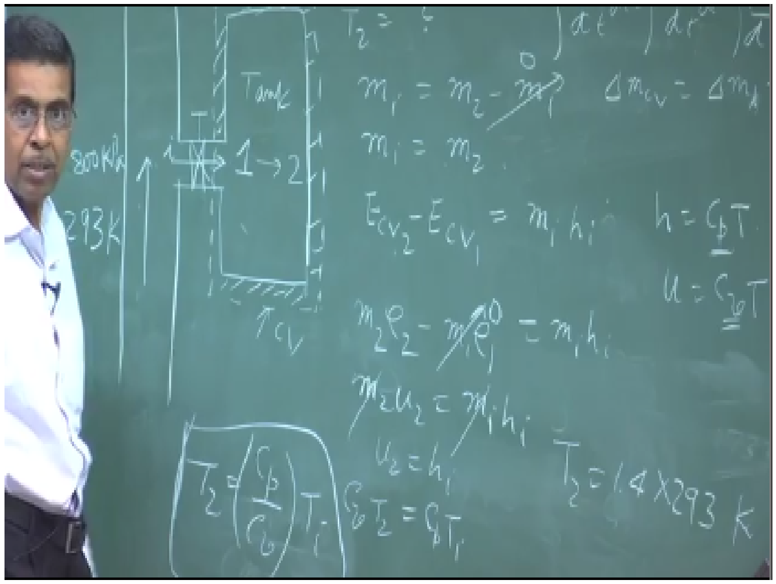

This problem tells that there is a line which connects to a tank which connects to a closed tank this is tank and the tank is insulated it is adiabatic condition there is no heat transfer from the tank, this air is flowing for example in this there is a bulb, now first the valve is open so that the air goes into the tank we take a control volume like this, surrounding the tank and cuts the control surface here where the mass coming in.

Now try to understand problem physically dull there is a line where the air flows and the line pressure is what the line pressure is line pressure is or evacuated tank line the following line flowing air at 20 degree Celsius 800 kilo Pascal's that means if this is the condition I in the line Pi = 800 kilo Pascal 800 kilo Pascal's kilo Pascal's and Ti = 20 degree valve a near supply line following a at 20 degree means 293K this is the condition okay.

So now this air goes into this the tank is initially evacuated there is nothing any no air at all so here comes into the tank is initially evacuated there is nothing any no air at all so air comes into the tank and it is pressure and temperature increases, there is no heat flow because of the mask introduction both pressure and temperature increases this is the physical problem. Let us consider that tank state initial state is 1 it goes to the final state 2, now initial state 1final state 2 so final state is giving P2 initially it is evacuated so everything is 0.

So final state is P2 600kPa and we have to find out what is T2 they will have an expression for the relation between the line temperature and the final temperature using constant specific, this is a very interesting problem this is known as charging a tank at an adiabatic condition. Now here if you draw a control volume like this, now this is an unsteady problem because there is an inflow there is no outflow and the mass in that tank is changing, okay.

So why write this a mass and energy everything is changing temperature is changing if I write the continuity equation you do not have to recall any equation unsteady term equal the flow unsteady flow energy question and all this thing you just simply see that if you write the energy equation now and if we consider that in a finite time the mass which is coming which has come in to this is mi this must be equal to m2-m1 that means if I integrate simply that earlier equation dmcv/dt is dmo/dt is simply the integration –dmi/dt.

If you integrate it with dt over a time dt then simply it is ∂m say that is the change in the mass of this is ∂mo that means the mass which is sorry, it is i not in it is i it is all the mass which are coming minus mass which has gone out, simply this is integrated and it comes like this, so therefore you do not have to remember any equation and integrate it is simply by your principle of conservation of mass continuity that if over that time when this valve is stopped when P2 600kPa has reached.

Then I consider mi amount of mass as cross or has come from the line to the tank and that must be equal to m2 that is the final mass-m1 and m1is 0 evacuated time, so therefore mi is equal to final mass. Now if we recall or you do not have to recall if you recall you will get the same thing that the change in the internal energy within the control volume that means Ecv2-Ecv1 that means we integrate the ∂Ecv/∂t terms that means Ecv2-ecv1 is exactly equal to what there is no heat working direction that will be equal to the inflow energy with this mask, that means it is by that finite time mi.hi simply mi.hi that means this is the change of energy in the control volume it is equal to the mass which has entered into the control volume across this section and this energy is hi because we neglect kinetic energy and potential energy.

So only energy is Q+Pv that is enthalpy ,enthalpy at the conditioned line condition hi, this Ecv2 is what m2.e2 and this is Ecv is 0 specific energy this is 0, m 1 is 0 there is no mass, so there is no energy so this is equal to mihi. Now this e2 that is the energy contained in the tank is only in the form of intermolecular energy, because there is no motion it is a closed tank or even if there is some motion we just neglect motion of the gas.

So therefore the energy contained in the control volume is only in the form of intermolecular energy that means we can write as m2u2 is mihi since m2 and mi is same u 2 is hi that means u2 is hi, now for any perfect gas I told earlier that h is Cp.T similarly U is Cv.T where Cp is the specific heat at constant pressure and U is the specific heat at constant volume. So therefore for any ideal gas H can be expressed as C_P x T and u can be expressed as C_V x T this comes from the genesis which may be beyond the scope of your course here that enthalpy and internal energy of an ideal gas is a function of temperature okay is a function of temperature only and specific heats are constant over the range of temperature.

And therefore we can write H is CP T and U is CV T this you just take it at the present moment for any ideal gas we can express enthalpy and internal energy is like that. Now this u2 is H I care for we can write CV t2 is CPTI, so therefore t2 becomes is equal to CP/ CV x T I. So this is the general expression, so this is the general expression that the final temperature will be always the ratio of specific heat times the line temperature.

So therefore with the numerical data you can solve the problem that is why a part of the problem is develop so t2 is CP so simply you multiply 8 and 293 with the ratio CP / CV for air it is 1.4 so t2 will be 1.4 times this 293 this is the answer, so this is the expression t2 is CP / CV x TI okay. Now we will come to the next problem. Now we will write the next problem go to the next problem see the next problem.

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Problem 3: A nitrogen line at 300 K, 0.5 MPa is connected to a turbine that exhausts to a closed, initially empty tank of 50 m^3. The turbine operates to a tank pressure of 0.5 MPa, at which point the temperature is 250 K. Assuming the entire process is adiabatic, determine the turbine work.

In nitrogen line at 300k and 0.5 mega Pascal is connected to a turbine that exhaust to a closed initially empty tank of 50 meter cube okay the turbine operates to a tank pressure of 0.5 mega Pascal's at which point the temperature is 250 K okay, assuming the entire process is adiabatic determine the turbine work. So nitrogen is connected to a turbine line turbine exhaust to a tank and ultimately it stops so in the tank reaches the point 5 mega Pascal's and the temperature is 250 K assuming the entire process is adiabatic determines the turbine work. Let us come to this problem this problem is like this come to the board for this problem.

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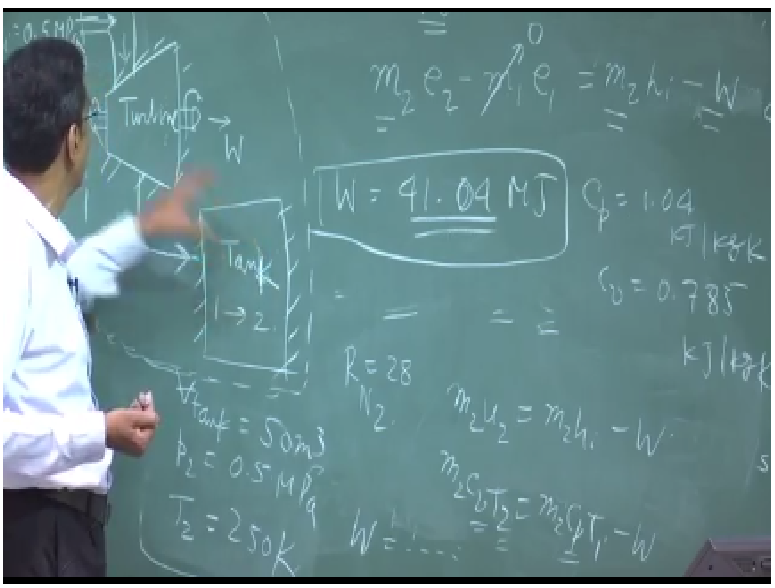

The problem is like this a very simple problem only a turbine is there it is same as the earlier one this is the line, and now this exhaust to a tank the only difference is that here the turbine develops and work W the sub is rotating this is the turbine this is the line which we denote that I the tank which is initially evacuated however we take the initial state at two and final state at initial state at one final state at two.

Here according to the problem let me see what are the values pi ti given so PI is now 0.5 mega Pascal's VI is 0.5mega Pascal's Vi is 0.5mega Pascal what is Ti given the line temperature 300k, 300k is connected now the tank is closely initially empty, empty tank of 50 meter cube that means tank volume is 50 meter cube that is the volume of the tank always I write volume as v-cut to differentiate it from the velocity V now the final pressure of the tank is 0.5 mega Pascal's and final temperature of the tank is T_2 is what final temperature of the tank to 50k.

So you have to find out the turbine work and we enter system is adiabatic entire system is added now we take a control volume like this surrounding this in circumscribing or enveloping this entire system control volume like this where a part of the control surface cuts this inflow line with where it enters to the turbine that is the line of nitrogen and it comes to this it is also an unsteady problem because there is only one inflow to the tank but there is no outflow and at the same time.

The temperature and temperature pressure mass everything changes in the tank so here also it is a steady flow energy equation and the same mass flows to the turbine and the tank and we consider that the mass which has been introduced during the operation of the turbine when the tank reaches this condition is in then we write the energy equation energy equation is what this m_2 e_2 that means the energy in the tank.

That is the control volume at to – energy in that tank at the initial state that is the change in the energy in the control volume but here you can ask me a question very interesting and this is the concept of the problem everything is routine this is the concept that the control volume consists of both turbine and the tank but I am considering the mass and the internal energy of the tank this is because the turbine is operating at a steady state that is the clue of the problem that means it is so that during the operations the turbine operates and ultimately at some point it stopped during its operation the internal energy within the turbine does not change.

So therefore if you take also as a part of the control volume both tank and the turbine so changing the internal energy of the turbine is zero so therefore in with regard to the change in internal energy of the control volume it is the internal energy changing the tank only and that is because - what it has come that is the mass so this mass is nothing but the m - m_1 is zero the same mass M_2 has come from the line and it is h_i that means you see here only difference that this is the mass change in the internal energy control volume is equal to the energy which is received.

And another thing will come what is that what is the difference between the earlier one here work is done so work is done out by this control volume that means - W that means the control volume is received this energy that is the energy inflow with the mass M_2 and the enthalpy of the line h_i minus the work done equals to the change in the internal energy of the control volume okay, this m_2 and this m_2 is same because m_1 is 0 final m_2 is m_2 that means the change in the mass is m_2 change in the mass of the control volume is m_2 and this m_2, has come from that under steady state through the turbine.

So therefore this m_2 s carat and influence energy m_2 x hi, we neglect the kinetic and potential energy – the work done work developed by the turbine, so that is the only difference that what? So therefore here you know the m_2 how to know the m_2? you know P_2 you will know T_2 okay, so you can find out the specific volume or you can find out this way that P_V = R this you tell that mRT now P_2 V_{tan} that is the $v_2 = m_2$ r.

So you know t2 you know R here nitrogen is there, so R for nitrogen is 28. So you know V tank 50 meter cube, you know p_2 T2 you find out in, so when you find out game then e2 is what again I write this equation m_2 sorry m_2 $u_2 = m_2$ h i- W, so u_2 it $m_2 C_v t_2 = m_2 C_{pt}$ you and I told $C_{PT\,i}$ h is C_{PT} + t- w here you know everything if you know the value of C_P and C_V you note P_2 and P_I also, so therefore you can find out what?

You can find out the earth okay you can find out the work output, so you know m_2 you know t_2 and t_1 you can find out the work output. Now C_P values are like this C_P = 4 nitrogen 1.04KJ/kgk you take this value and Cv is equal to some point 785 per kg k and you get the work out. The answer is like this they have taken the values of this UNH from the table so there will be little bit of difference the value will be the final answer, we final answer will be W is equal to the final answer will be 41.00 for MJ

You will get something close to that 40.01 for MJ, that is the answer so therefore you understand how you can apply these you do not have to recall any unsteady flow energy question just simply you apply your brain, the conservation of energy how you can write the difference with the earlier problem is that that work is developed by this so therefore the amount received with the inflow energy minus V was developed accounts for the energy change in the control volume and initially it is evacuated.

So this part is 0, so into and by continue to your conservation of mass the amount of mass which has come to the control volume during the operation is equal to the mass which is flowing to the line so line mass flow is same this is the amount of mass enters the control volume. So finally we get with this application of this equation and the concept that h is C_{PT} and we get the value of W everything is given only the workout has to be found out okay today up to this thank you.