

## Basic Thermodynamics

Prof. S. K. Som

Department of Mechanical Engineering

Indian Institute of Technology, Kharagpur

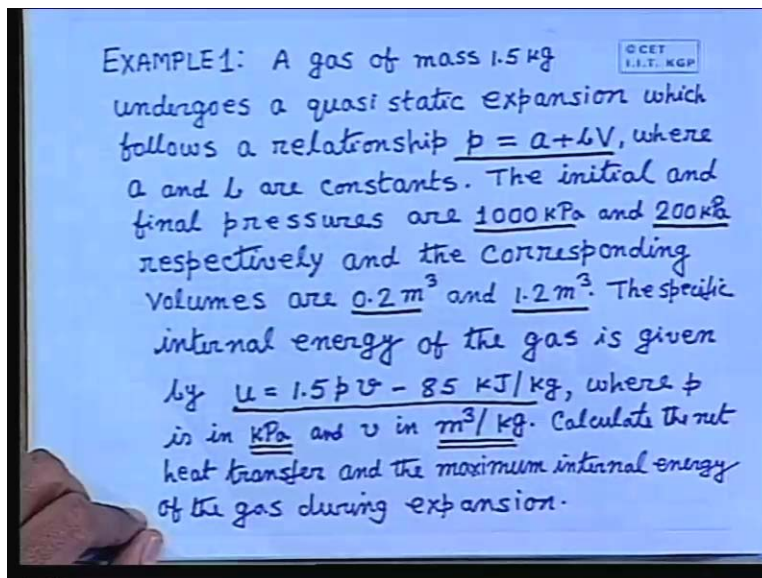
Lecture - 05

First Law - III

Good morning, I welcome you all to this session. In the last two classes, we have discussed the analysis of first law of thermodynamics to closed and open systems. In this class, we will solve some problems to clear our concept about this analysis of first law to closed and open systems. Through some practical problems, we will see how these analyses are being utilized.

Well, so let us start with the problems.

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First problem, example one: This is a problem relating to the application of first law in a closed system and we start with a very simple problem - straightforward application. A gas of mass 1.5 kg undergoes a quasi static expansion, you may or may not write the entire problem, you can write only the pertinent points.

For example, a gas the mass of which is 1.5 kg, undergoes a quasi static expansion, already we know that is  $pdV$  work, which follows a relationship  $p$  is equal to  $a + bv$ , that is the

relationship  $p$  and  $V$ ,  $p$  is equal to  $a + bV$ , where  $a$  and  $b$  are constants. This is the law of the process displacement work, where the pressure and volume changes. The initial and final pressures are 1000 kiloPascals and 200 kiloPascals respectively. The initial pressure is 1000 kiloPascals and the final pressure is 200 kiloPascals. That means it is an expansion process where the pressure decreases. The corresponding volumes are 0.2 meter cube - that is the initial volume and 1.2 meter cube - that is the final volume. The specific internal energy of the gas is given by...I told you earlier that regarding this internal energy, how does it relate with the pressure volume, this we will see afterwards, but at the present moment we will assume some relationship which will be given as  $u$  is equal to  $1.5 pv$  where  $V$  is the specific volume and  $p$  is the pressure minus 85 kilo Joule per kg. This  $u$  is expressed in kilo Joule per kg provided we substitute  $p$  in this equation in kiloPascals; these things are very important utilizing this equation. If you do a mistake, so you will lose marks in examination.

Concept remains the same, but to get the correct answer we have to be very careful.  $v$  in meter cube per kg; that means, if you express  $p$  and  $v$  in these units, then  $u$  will be given by kilo Joule per kg according to this relationship. These constants - the numerical values - are adjusted like that.

Calculate the net heat transfer and the maximum internal energy of the gas during the expansion. The problem is clear to you? So, now, how to solve the problem? First of all, we will have to find out the net heat transfer. So, this is a problem of a closed system.

(Refer Slide Time: 04:47)

OCET  
I.I.T. KGP

$$Q_{1-2} = u_2 - u_1 + \int_1^2 p dV$$

$$W_{1-2} = \int_1^2 p dV$$

$$p = a + bV$$

$$\left. \begin{aligned} 1000 &= a + b(0.2) \\ 200 &= a + 1.2b \end{aligned} \right\} \rightarrow \begin{aligned} a &= 1160 \text{ kPa} \\ b &= -800 \text{ kPa/m}^3 \end{aligned}$$

$$\left. \begin{aligned} p_1 &= 1000 \text{ kPa} \\ V_1 &= 0.2 \text{ m}^3 \\ p_2 &= 200 \text{ kPa} \\ V_2 &= 1.2 \text{ m}^3 \end{aligned} \right\}$$

$$W_{1-2} = a(V_2 - V_1) + \frac{b}{2}(V_2^2 - V_1^2)$$

$$= 600 \text{ kJ}$$

For a closed system, we will always write the first law in this fashion, as we know already what to write;  $Q_{1-2}$ , let 1 and 2 be the initial and final state points is equal to  $u_2$  minus  $u_1$  plus integral of  $p dV$ , that is the work 1 to 2, this is the work transfer  $W$ . That means  $W_{1-2}$  is integral of  $p dV$ . It is the very simple problem straightforward applications. (Refer Slide Time: 05:37)

Now we know this  $p$  is a linear function of  $v$ , a plus  $bv$ ; so we can straightforward integral  $d$ . But to get a numerical value, we have to know the numerical values of these constants  $a$  and  $b$  and it is very simple; it is found from these two conditions; that means, it is written; when  $p_1$  is equal to 1000 kiloPascals, what is  $V_1$ ?  $V_1$  is equal to 0.2 meter cube; this is one set. Another is  $p_2$ ;  $p_2$  is how much?  $p_2$  is equal to 200 kiloPascals. What is  $V_2$ ?  $V_2$  is equal to 1.2 meter cube. Now if we substitute this  $p$ , not meter cube per kg only meter cube, very good,  $P$  is equal to  $a$  plus  $bv$ ; this is the relation. That means, we will write this 1000 in kiloPascals, I am writing, accordingly the unit will come. 1000 is equal to  $a$  plus  $b$ , 0.2 because, I am not converting into Pascals by multiplying with 10 cube unnecessarily, the number will be very high, so  $b$  in meter cube. Then we write 200 is equal to  $a$  plus  $1.2b$ . If you solve these two equations, you will get  $a$  is equal to 1160 kiloPascals. You have done this problem? Just now you are doing? Very good. The unit of  $a$  has to be kiloPascals because it is pressure.

What is the value of  $b$ ?  $b$  is equal to minus 800 kiloPascals per meter cube. Very simple problem that is why you are so prompt. Therefore, I get  $av$ . Now, what is  $W_{1-2}$ ? Tell me.  $W_{1-2}$  is equal to  $a$  into  $V_2$  minus  $V_1$  plus  $b$  by 2 into  $V_2$  square minus  $V_1$  square. All this students may not catch so fast as for wide spectrum of the students, so we will go slow.

Now we have got the values  $V_2$  is equal to 1.2 meter cube,  $V_1$  is equal to 0.2 meter cube and ' $a$ ' is in kiloPascals, ' $b$ ' is in kiloPascals per meter cube. If you substitute this value, you get the value of  $W$  as 600 kiloJoule. If you just substitute the value  $a$  in kiloPascals and  $V_2$  minus  $V_1$  in meter cube, so kiloPascals into meter cube will be kiloJoule. Here also (Refer Slide Time: 08:46 min), if you substitute kilopascals per meter cube and this is  $V_2$  square; therefore, you get the value 600 kiloJoule.

(Refer Slide Time: 09:04)

$$W_{1-2} = \int_1^2 p dV$$

$$p = a + bV$$

$$\left. \begin{aligned} 1000 &= a + b(0.2) \\ 200 &= a + 1.2b \end{aligned} \right\} \rightarrow \begin{aligned} a &= 1160 \text{ kPa} \\ b &= -800 \text{ kPa/m}^3 \end{aligned}$$

$$W_{1-2} = a(V_2 - V_1) + \frac{1}{2}(V_2^2 - V_1^2)$$

$$= 600 \text{ kJ}$$

$$Q_{1-2} = u_2 - u_1 + 600 \text{ kJ}$$

$p_1 = 1000 \text{ kPa}$   
 $V_1 = 0.2 \text{ m}^3$   
 $p_2 = 200 \text{ kPa}$   
 $V_2 = 1.2 \text{ m}^3$

Now what is  $Q_{1-2}$ ?  $Q_{1-2}$  is equal to  $u_2$  minus  $u_1$  plus 600 kiloJoule. Now, here  $W$  is coming to be plus; so this sign automatically comes when you integrate this. We put the limit final minus initial. So, final is the upper limit; initial is the lower limit. Depending upon the final and initial values of  $V$  the sign of this quantity is determined. So it is determined as a positive quantity which physically signifies that work is coming out of the system. Now how to find out  $u_2$  minus  $u_1$ ? From the property relation, **School level problems in fact**. What is this property relation? This is kiloJoule per kg.

(Refer Slide Time: 09:56)

internal energy of the gas is given by  $u = 1.5 p v - 85 \text{ kJ/kg}$ , where  $p$  is in  $\text{kPa}$  and  $v$  in  $\text{m}^3/\text{kg}$ . Calculate the net heat transfer and the maximum internal energy

$$u = 1.5 p v - 85 \times \pi$$

$$= 1.5 p v - 85 \times 1.5$$

$$u_2 - u_1 = 1.5 (p_2 v_2 - p_1 v_1) = 60 \text{ kJ}$$

$$Q_{1-2} = \underbrace{600}_{W_{1-2}} + \underbrace{60}_{u_2 - u_1} = 660 \text{ kJ}$$

CET  
I.I.T. KGP

If I want to find out capital U, we will have to multiply with the mass; that means, V will be the volume; this V is also in meter cube per kg. That means, I will write the equation rather in this fashion.

U is equal to 1.5 pV minus 85 into mass of the gas. This is the relationship between the pressure volume and the total internal energy of this system. Then the equation becomes U is equal to 1.5 pV minus 85 into 1.5, but this part is constant, it is not required in finding out the change. So, change will be given by  $U_2$  minus  $U_1$  is equal to 1.5 into  $p_2V_2$  minus  $p_1V_1$ , which is equal to 60 kiloJoule. Therefore,  $Q_{1-2}$  is equal to 600 plus 60, that means 600 is  $W_{1-2}$  and 60 is  $u_2$  minus  $u_1$ , is equal to 660 kiloJoule.

What is the next part? The maximum internal energy. How do you do this part? Calculate the maximum internal energy of the gas during the expansion. How do you do it? Tell me.

[Conversation between Student and Professor – Not audible ((00:11:32 min))]

(Refer Slide Time: 11:34)

The image shows a handwritten derivation on a blue background. The equations are as follows:

$$U = 1.5 pV - 85 \times 1.5$$

$$U = 1.5(a + bV)V - 85 \times 1.5$$

$$\frac{dU}{dV} = 1.5(a + 2bV) = 0 \quad (\text{for maximum or minimum})$$

$$\frac{d^2U}{dV^2} = 1.5 \times 2b = \quad V = -\frac{a}{2b}$$

$$U_{\max} = 1.5 \left\{ a + b \left( -\frac{a}{2b} \right) \right\} \left( -\frac{a}{2b} \right) - 85 \times 1.5$$

$$= 1.5 \left( \frac{a}{2} \right) \left( -\frac{a}{2b} \right) - 85 \times 1.5$$

$$= 503.2 \text{ kJ}$$

Let us first write u. What is u? u is equal to 1.5 pV minus 85 into 1.5. So, you express this in one variable. That is p is a plus bV, then we get u is equal to 1.5 into a plus bV into V minus 85 into 1.5. It does not matter whatever it is until and unless we are interested in finding out them. It will be required when we find out the maximum internal energy. Let us make du by dv. What is du by dv? du by dv is equal to 1.5 into a plus 2bV and said this is equal to 0 for maximum, but this curve has only a maximum with the values of a and b, how?

$d^2 u$  by  $dv^2$  is negative. What is  $d^2 u$  by  $dv^2$ ? That is equal to  $1.5$  into  $2b$  and  $b$  is negative in this problem; minus  $800$  kiloPascals per meter cube. Therefore, this shows with these values of  $ab$ , this curve, that means the relationship between  $u$  and  $V$ , shows only a maximum (Refer Slide Time: 13:03 min). So, this is the condition for maximum not a minimum. So that maximum condition is given. So that  $V$  is equal to minus  $a$  by  $2b$ .

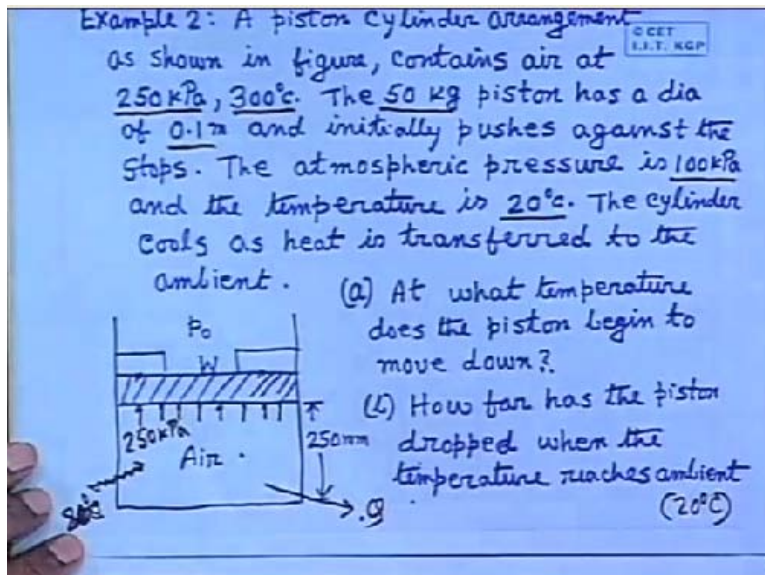
Therefore maximum internal energy will be found out  $u_{\max}$  is equal to  $1.5$  into  $a$  plus  $b$  into minus  $a$  by  $2b$  into minus  $a$  by  $2b$  minus  $85$  into  $1.5$ . By substituting the values this we can simplify into  $1.5$  into  $a$  by  $2$  into minus  $a$  by  $2b$  minus  $85$  into  $1.5$ . So, the minus in the  $a$  will get cancelled with the minus in the  $b$ . Ultimately, I do not know the sign of this, but it will be composite. What is the value? The value will come is  $503.2$  kiloJoule; this is the change in the maximum internal energy.

[Conversation between Student and Professor – Not audible ((00:14:23 min))]

Maximum internal energy.

It is the maximum internal energy during the expansion. Any query? It is a very straightforward problem applied to a closed system. Straightforward application of the law that  $Q$  is equal to  $u_2$  minus  $u_1$  or  $\Delta u$  plus  $w$  which is  $pdV$  work incase  $pdV$  work it is the integration of  $pdV$ .

(Refer Slide Time: 15:04)



Now, let us go to the second problem number 2; example 2: A piston cylinder arrangement as shown in figure contains air at 250 kiloPascals - that means, the initial pressure of the air - and

300 degree Celsius. This is the piston cylinder (Refer Slide Time: 15:36 min). The 50 kg piston, that means, the piston has a weight of 50 kg and it has a diameter of 0.1 meter and initially pushes against the stops - that means, physically. What is this? There is a pressure of 250 kiloPascals. This pressure exerts a force which balances the **wet** plus the atmospheric pressure and the reaction against these stops (Refer Slide Time: 16:23 min), so that piston is kept fixed with this stop. The atmospheric pressure is 100 kiloPascals and the temperature is 20 degreeCelsius, which is the initial temperature.

[Conversation between Student and Professor – Not audible ((00:16:39 min))]

It is atmospheric temperature. . The atmospheric temperature is 20 degree Celsius. Now, the cylinder cools as heat is being transferred from the cylinder Q to the ambient. At what temperature does the piston begin to move down? That is part one. How far has the piston dropped when the temperature reaches ambient? That means 20 degree Celsius.

Now, you see what is the problem? Try to understand the problem physically. Now the piston is fixed to this (Refer Slide Time: 17:25 min). When we cool it, this will be cooling at a constant volume, so pressure will be reduced. When you take the heat from this at a constant volume the pressure will be reduced. When the pressure will be reduced, both pressure and temperature will be reduced, but the volume will remain same, because piston is fixed to this. When pressure will reach a value, the piston will try to descend downward direction. So, from the mechanics point of view, what will happen at the point when piston is just trying to descend down?

[Conversation between Student and Professor – Not audible ((00:18:01 min))]

No.

[Conversation between Student and Professor – Not audible ((00:18:03 min))]

No.

[Conversation between Student and Professor – Not audible ((00:18:07 min))]

Pressure plus atmospheric pressure plus.

[Conversation between Student and Professor – Not audible ((00:18:14 min))]

Will be equal to the atmospheric it is the pressure inside the gas very good, but now what it is?

It is not like that now at this condition one.

[Conversation between Student and Professor – Not audible ((00:18:21 min))]

Why?

[Conversation between Student and Professor – Not audible ((00:18:23 min))]

Normal forces are added, the reaction will be 0, the forces on both the sides except this reaction forces, **that means** pressure and the weight and the pressure forces will be equal to each other. These normal forces here will be 0 (Refer Slide Time: 18:44 min). Then, if you reduce the pressure any more it will automatically descend down. Therefore, we have to find that pressure and if we know the pressure, we can find out the temperature. This is the problem. This part is more of mechanics than of thermodynamics. What is this pressure? Calculate. What is this atmospheric pressure? Let me write in terms of atmospheric with pressure  $p$  and all these things.

(Refer Slide Time: 19:22)

$p_0 A + N = p A$   
 $p = p_0 + \frac{W}{A} = 100 \text{ kPa} + \frac{50 \times 9.81 \times 4}{\pi \times (0.1)^2 \times 10^3}$   
 $= 162.45 \text{ kPa.}$   
 $\frac{T}{162.45} = \frac{300 + 273}{250}$   
 $T = 372.33 \text{ K, } t = 99.33^\circ \text{C}$   
 $p, V, m, T$   
For air  
 $pV = mRT$   
 $R = 287 \text{ J/kg K.}$

Let the weight of the piston be  $W$ . I can write this as  $p_0 A$  plus  $W$  is equal to  $p$  into  $A$ , where  $A$  is the area of this piston and  $p$  is the pressure when the piston will be in a position to descend down. So therefore,  $p$  is equal to  $p_0$  plus  $W$  by  $A$ ; the atmospheric pressure due to the **weight** of the piston. The pressure of the air at which the piston will just try to descend down will be  $p_0$  plus  $W$  by  $A$ . Now substitute the values. What is  $p_0$ ? What is the value? 100 kiloPascals. This part also has to be expressed in kiloPascals. We get  $p_0$  is equal to 100 kiloPascals plus 50 kg into mass 9.81 Newton into 4 divided by area, **what is the diameter of area?**  $\pi$  into 0.1 square into 1000. **Wm** into  $G$ , that is the weight expressed in Newton,  $\pi d$  square by 4 is the area kilopascals; that means, kilo Newton per meter square. So, this becomes equal to what? 162.45 kiloPascals. This is the pressure when the pressure will be reduced from 250 kiloPascals to



162.45 kiloPascals, the piston will try to descend, but the question is, at what temperature does the piston begin to move down? Now question is that I know the pressure, but how can I know the temperature?

[Conversation between Student and Professor – Not audible ((00:21:39 min))]

Constant volume  $p_1$   $p_2$ . Therefore, let  $T$  be the temperature, then  $p$  by  $t$ , that is 162.45; rather I write this way -  $T$  by  $p$  is 162.45; this is equal to what? The initial temperature is 300 degree Celcius.

[Conversation between Student and Professor – Not audible ((00:22:08 min))]

Actually, it is 273.15, but for our practical purpose we will take it as 273 divided by  $p$ . What is  $p$ ?  $p$  is 250 kiloPascals,  $p$  is to be in kilo Pascals. This gives  $T$  is equal to what? 99.. Therefore, we get  $T$  is equal to 372.33 k which gives  $t$  is equal to 99.33 degree Celsius. Now where from you got  $p_1$  by  $T_1$  is  $p_2$  by  $T_2$ ?

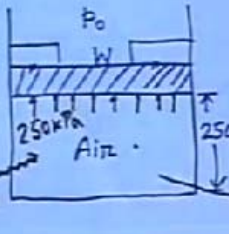
[Conversation between Student and Professor – Not audible ((00:22:49 min))]

Volume, but you are not supposed to know the first law, so that I tell that sometimes it will be given; if it is not given, then for air I recapitulate the earlier things: you always know that if  $p$  is the pressure,  $V$  is the volume,  $m$  is the mass and  $T$  is the temperature of a certain mass of gas  $M$ . Then for any ideal gas this is the relationship:  $pV$  is equal to  $mRT$ . For any ideal gas, pressure, volume, temperature and mass is related by this equation where  $R$  is a constant for that particular gas and is known as characteristic gas constant. We will see afterwards if this mass is changed to another unit – moles - which is nothing but the mass scaled with the molecular rate, then this constant is same for all ideal gases. But if you do not scale the mass by the molecular way rather mass simply has the amount in terms of kg, then it is the constant which is varying from gas to gas and is known as characteristic gas constant. For many other problems, you have to use this equation. So you have to remember one thing - the value of  $R$ ; this may not be given. Even for the examinations also because you are supposed to know certain values; so,  $R$  is one of such. For air, this value is 287 Joule per kg, in SI unit it is 287 Joule per kgk. This we will always remember that  $pV$  is equal to  $287 mRT$  where  $p$  is in basic unit Newton per meter square,  $V$  is in meter cube,  $m$  in kg and  $T$  in Kelvin.

Now let us come to the next part. How far has the piston dropped when the temperature reaches ambient how do you find out?

(Refer Slide Time: 25:14)

Example 2: A piston cylinder arrangement  
as shown in figure, contains air at  $250\text{ kPa}$ ,  $300^\circ\text{C}$ . The  $50\text{ kg}$  piston has a dia of  $0.1\text{ m}$  and initially pushes against the stops. The atmospheric pressure is  $100\text{ kPa}$  and the temperature is  $20^\circ\text{C}$ . The cylinder cools as heat is transferred to the ambient.



(a) At what temperature does the piston begin to move down?  
(b) How far has the piston dropped when the temperature reaches ambient ( $20^\circ\text{C}$ )

[Conversation between Student and Professor – Not audible ((00:25:13 min))]

[Conversation between Student and Professor – Not audible ((00:25:16 min))]

So **how** to  $p_2V_2$  correct, but temperature is changing why temperature will be constant, which is 20 degree Celsius.

[Conversation between Student and Professor – Not audible ((00:25:26 min))]

$V$  by  $T$  is constant.

[Conversation between Student and Professor – Not audible ((00:25:32 min))]

One solution is that  $V$  by  $T$  is constant, so you can find out the  $V$ , pressure remains constant that is one. Another person is telling that  $T$  will remain constant.  $T$  is not constant because it is given there.

[Conversation between Student and Professor – Not audible ((00:25:48 min))]

Pressure is remaining constant is the answer for it; that means, we will have to find the  $V$  by making the pressure constant, so that you can use the same equation  $pV$ .

(Refer Slide Time: 26:09)

OCET  
I.I.T. KGP

$$p_0 A + W = p A$$
$$p = p_0 + \frac{W}{A} = 100 \text{ kPa} + \frac{50 \times 9.81 \times 4}{\pi \times (0.1)^2 \times 10^3}$$
$$= 162.45 \text{ kPa.}$$
$$\frac{T}{162.45} = \frac{300 + 273}{250}$$
$$T = 372.33 \text{ K}, \quad t = 99.33^\circ \text{C}$$

$p, V, m, T$   
For air

$$pV = mRT$$
$$R = 287 \text{ J/kg K.}$$

If pressure remains constant  $V$  by  $T$  is constant, you can find out the volume.

(Refer Slide Time: 26:15)

OCET  
I.I.T. KGP

Example 2: A piston cylinder arrangement  
as shown in figure, contains air at 250 kPa, 300°C. The 50 kg piston has a dia of 0.1 m and initially pushes against the stops. The atmospheric pressure is 100 kPa and the temperature is 20°C. The cylinder cools as heat is transferred to the ambient.

(a) At what temperature does the piston begin to move down?  
(b) How far has the piston dropped when the temperature reaches ambient ( $20^\circ\text{C}$ )

OCET  
I.I.T. KGP

Why the pressure will remain constant? Can you tell me those who have told that pressure will remain constant that will come from the physical concept?

[Conversation between Student and Professor – Not audible ((00:26:22 min))]

Atmospheric, but inside pressure of the gas, why it will be constant?

[Conversation between Student and Professor – Not audible ((00:26:28 min))]

Because always we will consider that the piston descends in an equilibrium condition, where we will neglect the inertia of the piston in a sense that is the acceleration will be neglected. It is slowly moving. If it moves with a uniform velocity there also there is an equilibrium of forces, but in this case of thermodynamics all such problems of this sort will always be considered when the piston descends down or goes up it is always in equilibrium; the total force acting on both the sides of the pistons are equal. We neglect the acceleration of the piston. If we make so then atmospheric pressure is constant, then the weight of the piston is constant; that means, gas pressure has to be same. It is a displacement work at constant pressure, but we do not have to use the  $p dV$  formula; only thing is that we have to use that now  $V$  by  $t$ . So, we have to find out the volume.

(Refer Slide Time: 27:25)

$$\frac{V_f}{V_i} = \frac{T_f}{T_i}$$

$$V_f = 1.544 \text{ m}^3 \rightarrow h = 0.1966 \text{ m}$$

$$\text{drop in height} = (0.25 - 0.1966) = 5.34 \text{ cm}$$

Let this volume is  $V_f$  by  $V_i$  is equal to  $T_f$  by  $T_i$ . So you find out  $V$  and what we will get, but we have to find out what?

[Conversation between Student and Professor – Not audible ((00:27:54 min))]

What is the value of  $V$ ? Just a moment.

[Conversation between Student and Professor – Not audible ((00:28:03 min))]

You know  $V_i$ ;  $V_i$  is not known.

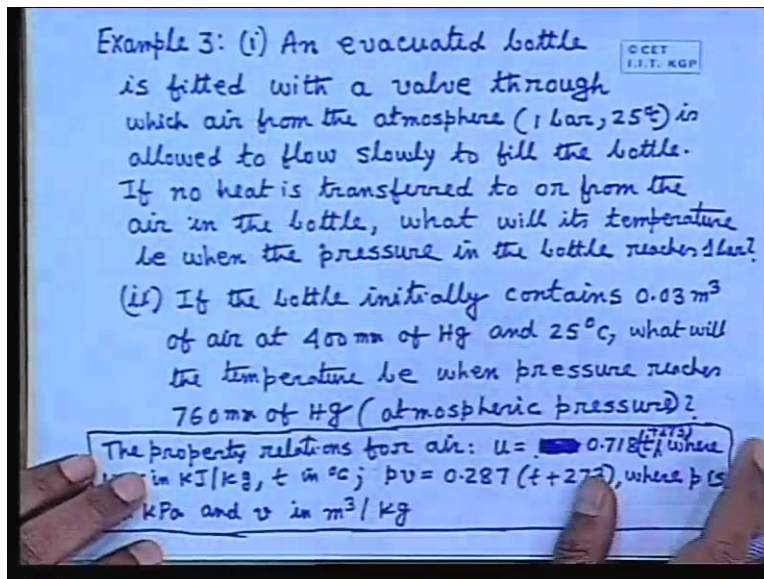
[Conversation between Student and Professor – Not audible ((00:28:16 min))]

Initial  $V_i$  is not known. Just a minute.

[Conversation between Student and Professor – Not audible ((00:28:29 min))]

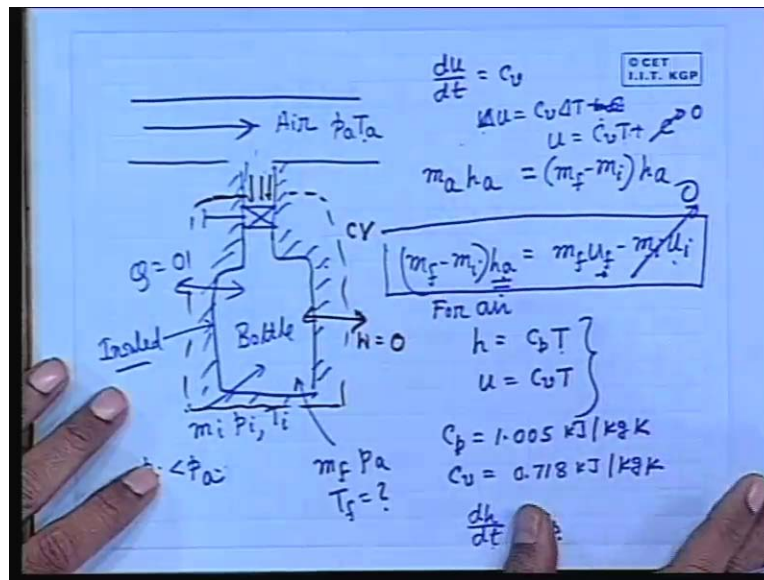
So initial  $V_i$  is known; therefore, we can find out the  $V_f$ . The value of  $V_f$  is 1.544 meter cube, which gives  $h$  as 0.01966. How do you get it? So, the drop in height will be 0.25 minus 0.1966 that is 5.34 centimeter. So, this temperature is which temperature (Refer Slide Time; 29:28 min)?  $T_i$  is the temperature at which it starts falling. So we know this temperature, we know the final temperature, it is told in the problem that it will reach ambient temperature, we can very well use this, pressure remaining constant. This is another type of problem. There are few more complicated problems, which I will be solving in tutorial classes. I do not know how much I can do for these sessions, these audiovisual classes.

(Refer Slide Time: 30:09)



Now, I come to another interesting problem. This is a very standard problem for an open system on control volume. First law for an open system on control volume is known as problem of charging of a bottle. How it is done? First of all, you see that problem. Before going through this problem, I should better discuss.

(Refer Slide Time: 30:32)



Let us consider a bottle here. This is a typical problem of charging a bottle which is being charged. Let us consider there is a valve, which is being connected to a pipeline which contains air. This is the practical problem; there is a main pipeline through which air flows at a constant  $p_a$  and  $T_a$ , and these are pressure and the temperature of the air which is flowing. There is a valve and there is a bottle which contains initially a mass  $m_i$  and its pressure is  $p_i$ , its temperature is  $T_i$ . If  $p_i$  is less than  $p_a$  then what will happen? If I open this valve, then air will gradually flow in this bottle. Let us consider the entire thing is adiabatic; that means, insulated or no heat transfer. In thermodynamic sense, the heat transfer is 0 in either direction. Now what will happen practically? The air will continue to flow or to charge the bottle.

When the mass of air will increase in this bottle of fixed volume, what will happen? The pressure and temperature both will increase. This process will automatically stop, naturally stop. This is not a continuous process; so, it will be automatically stopped when the pressure inside the bottle will reach the value of  $p_a$ ; no flow will take place in that pressure equalization case; the process will naturally stop. Parameter of interest to be known is the temperature. At that condition, what will be the temperature in the bottle, if we do not allow any heat to come out or go in. Because pressure will be equal to  $p_a$ , that means what will be the final temperature of the bottle when the process naturally stops. How to solve this problem?

This is a problem of application of first law to a control volume and unsteady state. How you would do the problem? You take this (Refer Slide Time: 33:05 min) bottle as a control volume.

There is an inflow to the control volume but outflow is 0 and you write for a finite time, not in the rate form, the equation which I develop in the rate form, if we integrate that we will get in the finite form. The work transfer is also 0; here there is no work interaction.

Let us consider at the end of this process the mass in the bottle is  $m_f$ , pressure is automatically  $p_a$ , and  $T_f$  is to be found out. Now what is the energy influx to this control volume during the entire process is the mass of the air which has come. Let this is  $m_a$  times the specific enthalpy of the air associated with this pressure and temperature and this  $m_a h_a$  is equal to  $m_f$  minus  $m_i$  into  $h_a$ . I am not writing everything like that. This is the influx of energy to the control volume. It is a very simple problem  $m_f$  minus  $m_i$  into  $h_a$  will be equal to the change in the internal energy of the control volume that is  $m_f u_f$  minus  $m_i u_i$ . Now you can ask me: sir, you are telling the most practical problem is that engineers are interested to know what is the temperature? But this equation, where it is temperature from the property relations, we will know how  $h$  relates with the temperature for air and how  $u$  relates with the temperature for air. From this equation we can find out what is  $u_f$  knowing  $m_i$ ,  $u_i$  and  $h_a$ . So, we can find out  $u_f$  and from  $u_f$  we can find out the temperature. In this connection, I like to tell you that for air if it is not otherwise given.

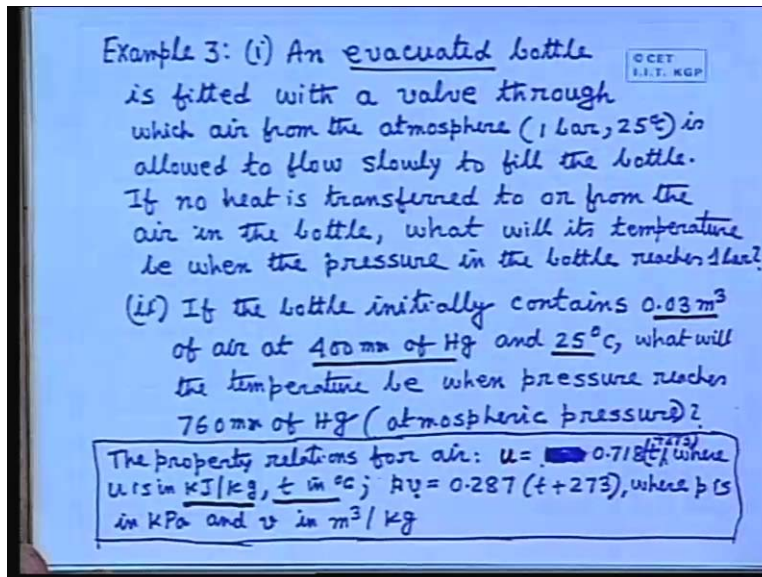
You will always assume  $h$  is equal to  $c_p$  into  $T$  and  $u$  is equal to  $c_v$  into  $T$  for air, where the values of  $c_p$  is 1.005 kiloJoule per kgK if it is not otherwise given. If the properties relationships are given, you do not use that, we use the property relationship.  $C_v$  is equal to 0.718 these are the values of  $c_p$   $c_v$ . This comes from the fact that for any ideal gas, internal energy is a function of temperature; enthalpy is a function of temperature; that means, they are function of temperatures only not of any other property. That means, one can write if you follow the definition that  $du$  by  $dt$ , because  $u$  is a function of temperature there is no question of writing  $\Delta u$  divided by  $\Delta t$  is equal to  $c_v$ . So you integrate it, you get  $\Delta u$  is  $c_v \Delta T$  plus constant. If you make it  $\Delta u$  is  $\Delta T$ , but if you just integrate to give  $u$  is  $c_v T$  plus  $C$  constant. So if you make the assumption that at  $T$  is equal to 0 internal energy is 0 that is  $C$  is 0. In the similar way, we can write using this equation,  $dh$  by  $dt$  for ideal gas is  $c_p$ . I am not writing  $\Delta h$  divided by  $\Delta t$  at constant pressure, because  $h$  is not a function of pressure it is only the temperature.

Therefore, I can write  $dh$  by  $dt$  and it becomes  $c_p$  this will be taught afterwards for an ideal gas. If we integrate it, we get  $\Delta h$  is  $c_p \Delta t$  or  $h$  is simply  $c_p$  into  $t$  at  $T$  is equal to 0, we consider the  $h$  is also equal to 0, so that  $h$  is  $c_p T$  and  $u$  is  $c_v T$ . If these property relationships are known, I

can utilize this formula to find out the temperature. In case of an evacuated bottle if the bottle contains 0 mass at 0 pressure; so, this will be 0.

So the application of this equation is there in this problem three.

(Refer Slide Time: 38:01)



Now you read this problem (Refer Slide Time: 38:02 min) which appears to be very simple. An evacuated bottle is fitted with a valve through which air from the atmosphere, that means the condition of the flowing air at 1 bar. What is bar? Bar is 100000 Newton per meter square at 25 degree Celsius and this is precised at the the atmospheric pressure and temperture. Atmospheric pressure is little more 1.01 bar, however is allowed to flow slowly to fill the bottle.



(Refer Slide Time: 38:35)

OCET  
I.I.T. KGP

Air  $p_a T_a$

$Q=0$

Insulated Bottle

$H=0$

$m_i p_i, T_i$

$m_f p_a$   
 $T_f = ?$

CV

$\frac{du}{dt} = c_v$

$u = c_v T$

$m_a h_a = (m_f - m_i) h_a$

$(m_f - m_i) h_a = m_f u_f - m_i u_i$

For air

$h = c_p T$

$u = c_v T$

$c_p = 1.005 \text{ kJ/kgK}$

$c_v = 0.718 \text{ kJ/kgK}$

$\frac{dh}{dt} = ?$

Now here question comes: sir, why you have neglected kinetic energy associated with this? (Refer Slide Time: 38:39 min) We go slowly, here also I have use that slowly filling up. That means the velocity is neglected, velocity is so small that the kinetic energy part is much small compare to this enthalpy part. So that I am only using the enthalpy part as the total energy; kinetic energy is neglected.

(Refer Slide Time: 39:01)

OCET  
I.I.T. KGP

Example 3: (i) An evacuated bottle is fitted with a valve through which air from the atmosphere (1 bar, 25°C) is allowed to flow slowly to fill the bottle. If no heat is transferred to or from the air in the bottle, what will its temperature be when the pressure in the bottle reaches 1 bar?

(ii) If the bottle initially contains  $0.03 \text{ m}^3$  of air at 400 mm of Hg and 25°C, what will the temperature be when pressure reaches 760 mm of Hg (atmospheric pressure)?

The property relations for air:  $u = 0.718 t$  (where  $u$  is in kJ/kg,  $t$  in °C);  $p v = 0.287 (t + 273)$ , where  $p$  is in kPa and  $v$  in  $\text{m}^3/\text{kg}$

Air from the atmosphere is allowed to flow slowly to fill the bottle. If no heat is transferred to or from the air in the bottle that means bottle is totally insulated. What will its temperature be when

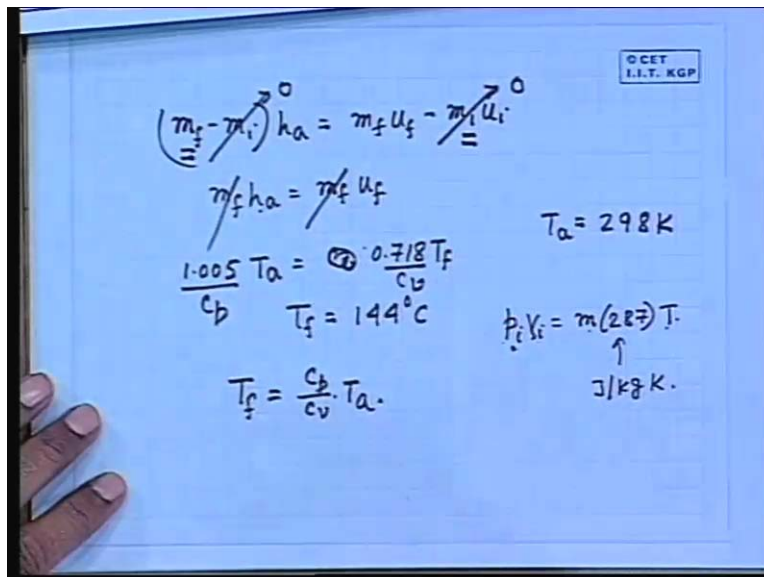
the pressure in the bottle reaches 1 bar? The pressure will be same as that one that is the process will be automatically stop. If the bottle initially contains 0.03 meter cube of air at 400 millimeter f Hg and 25 degree Celsius where first bottle is evacuated. Here you see the property relationship is like this; this is the value of  $c_v$  what we have told  $T$  plus 273. So when this relationship is given one student may not know what is ideal gas? What is  $c_p$ ? What is  $c_v$ ?

In ideal gas what is the value of  $c_p$ ? How it does it relate? He will use this simply as a mathematical formula. That  $u$  is equal to  $0.718$  into  $t$  plus  $273$  and he will leave simply this as a mathematical formula as far as the property relationship is concerned. That  $pv$  is equal to  $0.287$ ,  $t$  is equal to  $273$ , where  $u$  is in kiloJoule per kg it is given. These types of equation where these numerical constants are there are always specified like that. If you substitute this variable, that is independent variable, in this unit we get the dependent variable in this unit. So this type of equation are always specified; otherwise there is no meaning to these equations. So  $pv$  is this, where  $p$  is in kilo Pascals and  $v$  is in meter cube per kg and  $t$  is in degree Celsius. If you add these two we get the  $h$ ,  $h$  is  $u$  plus  $pv$  that is  $h$  is equal to  $1.005$  into  $t$  plus  $273$ .

[Conversation between Student and Professor – Not audible ((00:41:02 min))]

Please write it. So, how to solve this problem? Just we apply this equation. What is the equation? That  $t$  is equal to  $144$ . Do you have written it? This equation (Refer Slide Time: 41:24 min). Now we will be solving; that means, I write this equation.

(Refer Slide Time: 41:26)

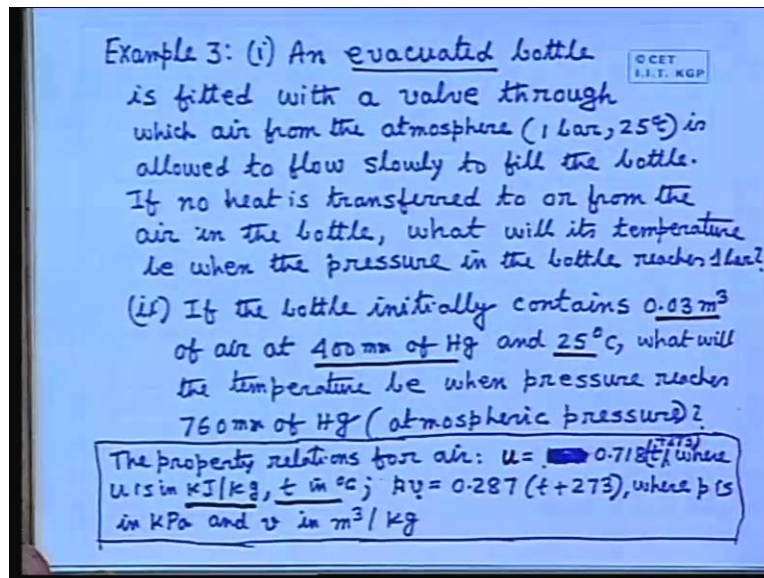


$m_f$  minus  $m_i$  into  $h_a$  is equal to  $m_f u_f$  minus  $m_i u_i$ ; very interesting result will come out; that is, now  $h_a$  is equal to  $u_f$ . Therefore,  $h_a$  is 1.005 as far as the property relationship are given. Therefore we get  $1.005T_a$  is equal to  $0.718T_f$ .  $T_a$  is equal to what?

[Conversation between Student and Professor – Not audible ((00:42:29 min))]

The air temperature is 25 degree Celsius - 298k. With this I get  $T_f$  is 144 degree Celsius. It is very interesting thing that we know this for air, for any ideal gas,  $h$  is  $c_p$  that means 1.005 is  $c_p$  and 0.718 is  $c_v$ . That means the final temperature, if the bottle is evacuated will be the ratio of specific heat times the temperature of the air which is greater than 1; the air temperature will be multiplied by the ratio of the specific heat, for air we know this is 1.41. So, if the ambient temperature is 25 degree Celsius, the inside temperature will be 1.41 into 298. So, it is the ratio or specific heat which will be multiplied with the air temperature to get the final temperature of the evacuated is the thermal rule, but it is true. When we deal with an ideal gas and the bottle is evacuated, but if the bottle is not evacuated, then we will have to take care of  $m_i$  and we will have to find out the  $m_f$  also. Then you can find out the value of  $u$ .

(Refer Slide Time: 43:39)



In the second case, the bottle initially contains 0.3 meter cube. This will give the value of  $m_i$  because initial pressure is given, initial temperature is given. How can you find out  $m_i$ ?

(Refer Slide Time: 43:54)

$$(m_f - m_i) h_a = m_f u_f - m_i u_i$$
$$m_f h_a = m_f u_f$$
$$\frac{1.005}{c_b} T_a = \frac{0.718}{c_v} T_f$$
$$T_f = 144^\circ\text{C}$$
$$T_f = \frac{c_b}{c_v} T_a$$
$$p_i v_i = m(287) T_i$$

↑  
J/kg K.

$T_a = 298\text{ K}$

OJET  
I.I.T. KGP

Because we know  $p_v$  is equal to  $mRT$  I have already told, so  $p_i v_i$  is equal to  $m$  into  $287$  into  $T$ . This is Joule per kg. So that these things are to be in consistent unit Newton per meter square meter cube per kg and Kelvin and  $m$  is in kg. This is meter cube not meter cube per kg; this is meter cube this is kg. Now from this, we can find out the value of  $m_i$  and we can apply these equations to find out the  $T_f$ . This I am giving you as an exercise with the answer for  $T_f$ . What is the answer for  $T_f$ ? In that case, what is the problem? I will give you the answer for this, just wait for sometime. Let me see the answer for it, whether I do have or not, just wait.

This is exercise for you; so, I must give you the answer for it. Well, just wait. Okay, you do it. I will tell you the answer in the next class. This is your home exercise. I have misplaced the answer somewhere; so, I will tell you the answer in the next class.

[Conversation between Student and Professor – Not audible ((00:45:42 min))]

Which one? Yes, the volume will remain constant.

Volume will remain constant. The simple algebraic manipulations then I will come to problem number four. Time is up? What is the time?

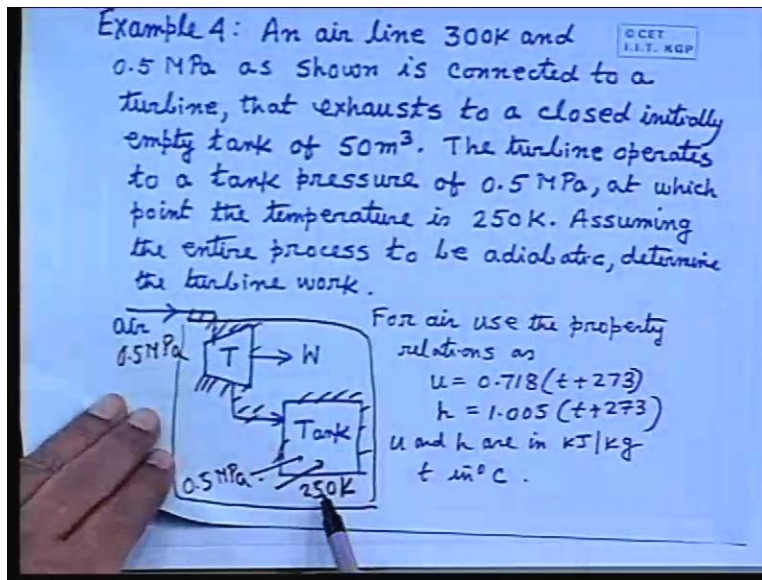
[Conversation between Student and Professor – Not audible ((00:46:04 min))] okay

Do you have a class now?

[Conversation between Student and Professor – Not audible ((00:46:08 min))]

Lunch. Just wait because they have some time for them. So, wait.

(Refer Slide Time: 46:18)



Problem four: an air line at 300 k and 0.5 MegaPascals as shown is connected to a turbine. This is the airline, this is connected to a turbine (Refer Slide Time: 46:32 min), that exhausts to a closed initially empty tank of 50 meter cube. Almost the similar problem, but we ask a different quantity. The turbine operates to a tank pressure of 0.5 MegaPascals. Now what happens this air line is at 0.5 MegaPascals, that means here the pressure is 0.5 MegaPascals and the turbine operates to a tank; the turbine operates till the tank pressure is 0.5 MegaPascals, at which point the temperature is 250 k; the temperature of the tank becomes 250 k that means, this is the point when the process terminates automatically the same thing. Assuming the entire process to be adiabatic, both the turbines and the tank along with the pipelines are adiabatic, determine the turbine work. We have to find out what is the turbine work? Tell me which one you will consider as a control volume place, any one of you?

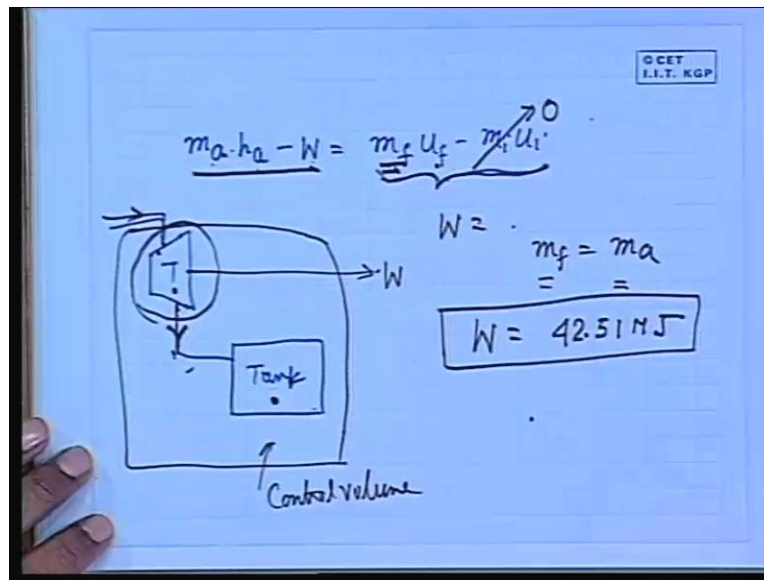
[Conversation between Student and Professor – Not audible ((00:47:56 min))]

Only turbine.

[Conversation between Student and Professor – Not audible ((00:47:58 min))]

Turbine and tank together. We take turbine and tank together; what will be the equations? Then in that case also there is an inflow only. It is a definite process over a finite time.

(Refer Slide Time: 48:29)



The mass of air which has come into the enthalpy of air, that is the mass coming in, energy coming in minus the work done  $W$  control volume will be equal to  $m_f u_f$  minus  $m_i u_i$  because this is nothing but the change in internal energy of the control volume. If we look back to our steady flow energy equations integrate it with respect to  $dt$ . Then we get these values that finite quantity of mass times the specific stored energy. Finite quantity of work, finite quantity of heat and the change in the internal energy. That means, it is written over a finite time period for definite quantity of matter for a given process. Not in the rate basis.

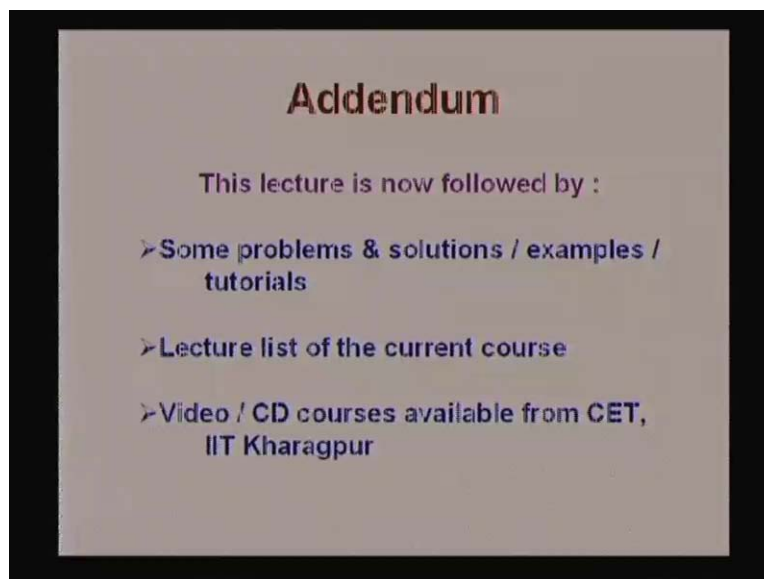
Therefore here also (Refer Slide Time: 49:23 min) you can write this that means, if I again draw the picture this is the turbine, this is the tank. I am considering this as the control volume. Now here one point is very important, now this is the energy entering to control volume there is no exit to the control volume (Refer Slide Time: 49:50 min). This is the work done by the control volume that means, this is this minus this must be equal to the increase in internal energy of the control volume, but turbine part of the control volume does not undergo any change in the internal energy because it is a steady state device. So, within the turbine things are steady the mass which is coming in is going out that means energy which is coming in equal to going out in the form of work and in the form of energy going to with this mass which is coming to this tank.

Therefore, as far as turbine part is considered, there is no change in the internal energy. Internal energy is changing only in the tank part which is in unsteady mode. Therefore, if we consider this as a control volume, the change in the internal energy is contributed only by the tank. This is

the only key point of this problem; so that you can write this **any** query; you can ask me which will give the  $W$ . Now what is the value in this case? This is an evacuated bottle or the tank is empty. Therefore this is 0 (Refer Slide Time: 51:05 min), you can find out  $m_f$  and this  $m_f$  is equal to  $m_a$ , because there was no mass. So final mass is the mass which has come during that interval of time through the control volume; that means, the entire control volume system. So,  $m_f$  is equal to  $m_a$ . You can find out  $m_a$ ; here  $m_a$  does not cancel out because work is there. Otherwise, we have to find out the work per unit mass that is all right, but here  $m_a$  we can find out because the final temperature and pressure of the tank is given and volume of the tank is also given or not 50 meter cube. We can find out the mass by the same formula; for the air  $p v$  is equal to  $m$  into  $RT$ . You know the mass; you know the internal energy at the final point, because final temperature is given. When the mass pressure reaches 0.5 megaPascal, temperature is 250 k. We utilize this equation; so if we know  $u_f$  and  $h_a$  we can find out by using this equation where  $t$  plus 273 this is given 300 k that means  $t$  plus 273 is already given in that form 300 k. We can find out the value of this. Finally work comes out to be 42.51 MegaJoule. You do it and you will see this is the final work done by the turbine that is 42.51 MegaJoule.

These are the four problems, where you can have an idea how this concepts of first law applied to closed system and open systems are utilized. Well, any query? **This is the lunch time so, I think there will be no query. Problems are simple. Okay then, thank you.**

(Refer Slide Time: 53:11)



(Refer Slide Time: 53:23)

## Tutorials

- Questions related to the topics of a lecture are included after each lecture
- Solutions are provided at the end of the next lecture
- It may not be possible to provide solutions to all problems

(Refer Slide Time: 53:36)

## Review Questions

(from Lecture No.1 to Lecture No. 5)

1. What is the difference between a control mass system and a control volume system at steady state when the amount of mass within the system in both the cases remains invariant with time ?
2. What are the conditions to be fulfilled for a system to be specified by its properties as thermodynamic coordinates in a thermodynamic plane ?



(Refer Slide Time: 54:08)

3. What is meant by thermodynamic properties ?
4. Define intensive and extensive properties ?
5. How many independent intensive properties are required to fix the state of a system of following types :
  - (i) single component single phase system.
  - (ii) single component two phase system.
  - (iii) single component three phase system.

(Refer Slide Time: 54:38)

6. What is Zeroeth law of thermodynamics ?
7. What is meant by thermodynamic equilibrium ?
8. What is dead state of a system ?
9. What is meant by a quasi-equilibrium process?
10. What are the fundamental requirements for a quasi-equilibrium process to take place ?

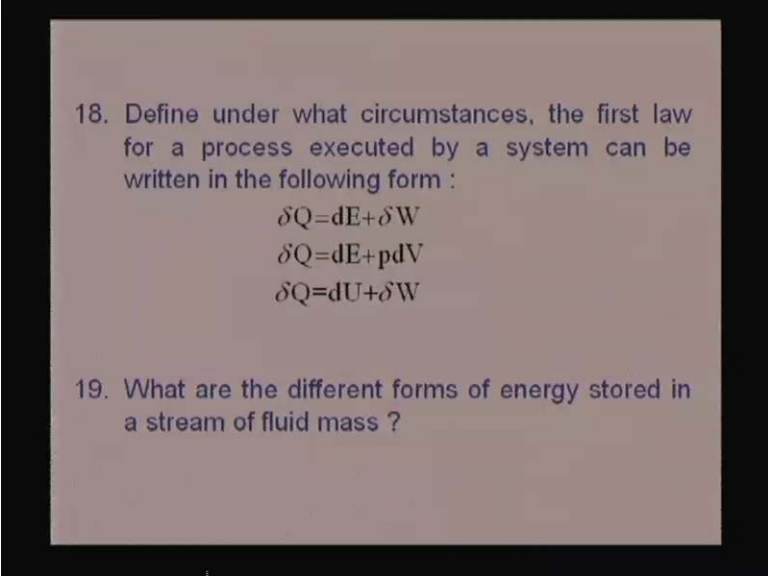
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11. What is the thermodynamic difference between work and internal energy ?
12. What are the different forms of work transfer between a system and its surroundings ?
13. Under what conditions, the work transfer between a closed system and its surroundings becomes equal to ?

(Refer Slide Time: 55:25)

14. Is paddle wheel work is a reversible work or irreversible work ?
15. How do you define a thermodynamic cycle ?
16. The first law of thermodynamics is the statement of conservation of certain quantity. What is this quantity ?
17. What thermodynamic property of a system is defined by the first law ?

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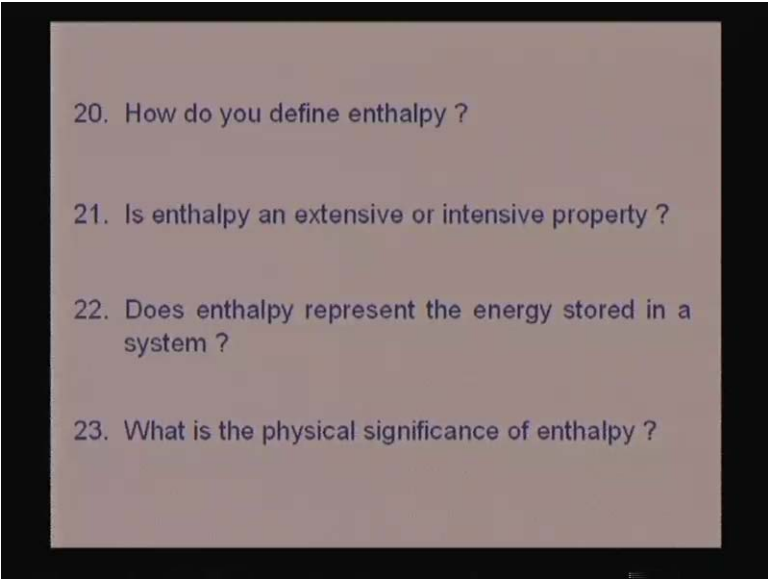


18. Define under what circumstances, the first law for a process executed by a system can be written in the following form :

$$\delta Q = dE + \delta W$$
$$\delta Q = dE + p dV$$
$$\delta Q = dU + \delta W$$

19. What are the different forms of energy stored in a stream of fluid mass ?

(Refer Slide Time: 56:26)



20. How do you define enthalpy ?

21. Is enthalpy an extensive or intensive property ?

22. Does enthalpy represent the energy stored in a system ?

23. What is the physical significance of enthalpy ?

(Refer Slide Time: 56:57)

24. What do you mean by steady flow energy equation ?

25. How does the specific heat at constant volume relate to internal energy of a system ?



26. How does the specific heat at constant pressure relate to enthalpy of a system ?

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Answer to the above questions are given at the end of Lec No. 6

(Refer Slide Time: 57:34)

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9. Digital Computer Organization	Prof. P.K. Biswas	28x1hr
		Contd...

(Refer Slide Time: 58:00)

10. Wavelets & Multirate DSP	Prof. M. Chakraborty	48x1hr
11. Neural Networks & Applications	Prof. S. Sengupta	37x1hr
12. Digital Signal Processing	Prof. T.K. Basu	36x1hr
13. Networks, Signals and Systems	Prof. T.K. Basu	31x1hr
14. Theory of Electrical Machines	Prof. S.N. Bhadra	42x1hr
15. Electrical Machines – I	Prof. T.K. Bhattacharya	38x1hr
16. Special Electrical Motors	Prof. K.V. Ratnam	44x1hr
17. Electromagnetic Field Theory	Prof. K.V. Ratnam	50x1hr
		Contd...

(Refer Slide Time: 58:12)

18. Generalized Electrical Machine Analysis	Prof. K.V. Ratnam	48x1hr
19. Industrial Automation & Control	Prof. S. Mukhopadhyay	30x1hr
20. Estimation of Signals & Systems	Prof. S. Mukhopadhyay	27x1hr
21. Dynamics of Physical Systems	Prof. S. Banerjee	30x1hr
22. Illumination Engineering	Dr. N.K. Kishore	20x1hr
23. Modeling & Simulation of Dynamic Systems	Prof. A. Mukherjee	38x1hr
Contd...		

(Refer Slide Time: 58:25)

24. Theory & Practice in Machining	Prof. A.B. Chattopadhyay	54x1hr
25. Robotics & Robot Applications	Prof. A.B. Chattopadhyay	40x1hr
26. Fluid Machines	Prof. S.K. Som	32x1hr
27. Fluid Mechanics	Prof. S.K. Som	49x1hr
28. Basic Thermodynamics	Prof. S.K. Som	34x1hr
29. Intelligent Machines & Systems	Prof. C.S. Kumar	
30. Applied Thermodynamics for Marine System	Prof. P.K. Das	25x1hr
Contd...		

(Refer Slide Time: 58:38)

31. Design and Analysis of Algorithms	Dr. T.K. Dey	33x1hr
32. Programming & Data structure	Prof. P.P. Chakraborty	32x1hr
33. Introduction to Database Mgmt. Systems	Prof. P.P. Chakraborty	36x1hr
34. Introduction to Software Engineering.	Dr. R. Mall	31x1hr
35. Switching and Finite Automata Theory	Prof. S.C. De Sarkar	33x1hr
36. Information Systems	Prof. S. Ghosh	30x1hr
Contd...		

(Refer Slide Time: 58:51)

37. Electronic Design Automation	Prof. I. Sen Gupta	35x1hr
38. Internet Technologies	Prof. I. Sen Gupta	30x1hr
39. Computer Architecture & Operating Systems	Prof. S.C. De. Sarkar	32x1hr
40. Object Oriented System Design	Prof. A.K. Majumder Dr. S. Sarkar	38x1hr
41. Computer Networks & Communication	Prof. Ajit Pal	40x1hr
42. Microprocessors & Microcontrollers	Prof. A. Pal	30x1hr
Contd...		

(Refer Slide Time: 59:04)

43. VLSI System Design	Prof. D. Roy Chowdhury	30x1hr
44. Artificial Intelligence	Prof. P. Dugupta	28x1hr
45. Numerical Analysis & Algorithms	Prof. P. Neogi	40x1hr
46. Optoelectronic Materials & Devices	Prof. D.N. Bose	42x1hr
47. Materials For Electronics	Prof. C. Jacob	34x1hr
48. Quantum Mechanics	Dr. S. Bharadwaj	40x1hr
49. Enterprise Resource Planning	Prof. D. Acharya	35x1hr
Contd...		

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50. Human Behavior In Organizations	Prof. K. Chakravarti	46x1hr
51. Industrial Management	Prof. S Sahu, Prof. S. Srinivasan, Prof. K. Chakravarti	41x1hr
52. Leadership	Prof. K. Chakravarti	13x1hr
53. Strategic Management	Prof. K. Chakravarti	11x1hr
54. Transfer Process in Food Engineering	Prof. T.K. Goswami	
55. Introduction to Cryogenic Engineering	Prof. K. Chowdhury	63x1hr
Contd...		



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56. Advanced Materials & Processes	Prof. B.S. Murty	27x1hr
57. Digital Communications	Prof. S. Chakrabarti	39x1hr
58. Design of Reinforced Concrete Structure	Prof. N. Dhang	
59. System Analysis and Design	Prof. B. Mahanty	40x1hr
60. Strength & Vibration of Marine Structures	Prof. A.H. Sheikh Prof. S.K. Satsangi	33x1hr
61. Mechanics of Floating Bodies	Prof. A. Bhar, Prof. D. Sen, Prof. S.C. Misra	42x1hr
		Contd...

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62. Maritime Regulation	Prof. A. Chatterjee Prof. P. Mishra Prof. N.D. Sarkar	32x1hr
63. Maritime Transportation & Engineering Economics	Prof. O.P. Sha Prof. S.C. Mishra	34x1hr
64. Marine Materials	Prof. N.R. Mandal	40x1hr
65. Performance of Marine Vehicles at Sea	Prof. D. Sen Prof. S.C. Mishra	40x1hr
66. Dynamics of Mechanical Systems	Prof. A. Chakrabarti Prof. D. Kastha	37x1hr