Concepts of Thermodynamics
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Lecture – 14
First Law of Thermodynamics for a Control Mass System

Today, we will start with the First Law of Thermodynamics. First Law of Thermodynamics is a very intuitive physical law which is nothing, but the law of conservation of energy.

We will try to get into the details of the first law of thermodynamics to the extent that we desire. But we will start with something which is very intuitive and that intuitive is like; how to write the energy balance for a control mass system.

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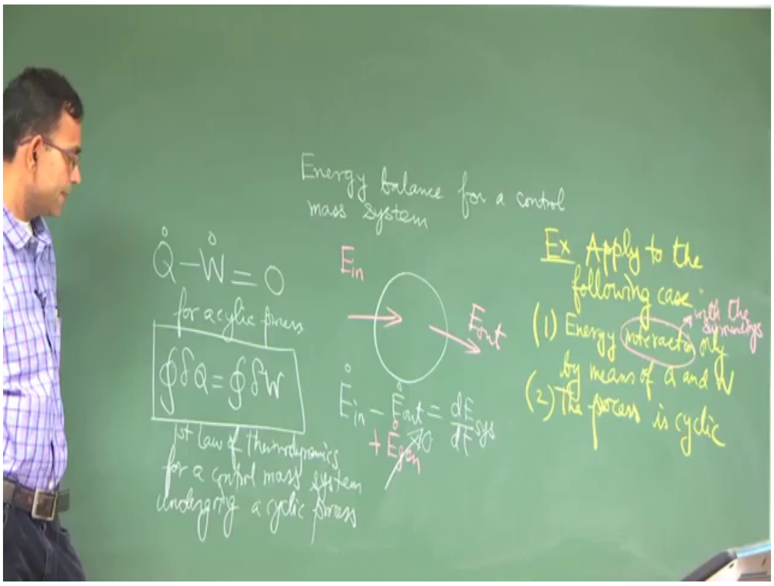

So, let us say; that there is a control mass system. Some energy is transferred to it, some energy leaves from it and then the remaining energy. So, some energy is coming into it, some energy is going out of it. So, whatever energy is getting in and whatever energy is going out we can say that energy in minus energy out is equal to the rate of energy in minus the rate of energy out is nothing but the rate of change of energy of the system itself right.

So, here we are making one assumption that within the system everywhere the energy is the same right. That locally the energy is, specific energy here is something here it is something here it is something. It is just like considered as a lumped mass where we are writing the total energy E. So, this total energy is distributed I mean it may be unevenly distributed also that does not matter. What matters is that this is like a lumped body which has a total energy E because it is a lumped body how it is distributed inside it, does not matter.

So, it is a unique value E for the system ok. And then therefore, this E is a function of time only and not a function of position. That means, in terms of these properties per unit mass that property is uniformly distributed within the system. So, this is a very intuitive physical law and I will try to give an analogy or draw an analogy of this, with say instead of energy balance let us talk about money balance.

So, let us say that this is a bank account. So, somebody has deposited some money in the bank and then the same person has after sometime withdrawn some money. So, when the energy, when the money comes in and when the money comes out whatever is the rate at which the bank balance changes in the difference between these two. You might argue that the bank can give some interest right and that interest sometimes is written in terms of energy generated right. So, energy generated is like the money generated out of the interest.

So, some money has been deposited in the bank account, some money has been withdrawn, but you see that in your bank account the net change is little bit more than the difference between these two and that is because the bank is giving you some interest. Now let us try to apply this for a system where the interaction is only heat transfer and work done. So, example apply to the following case; number 1, energy interaction only by means of Q and W heat transfer and work done.

And the process is a cyclic process. So, if the energy interaction is by means of only heat and work. So, energy interaction only by means of heat and work, interaction means interaction with what. So, interaction the system interacts with only the surroundings right. Energy interaction with the surroundings that we must specify, only by means of heat and work and that means, there is no energy generation only the system is interacting with the surroundings through heat transfer and work done. So, this is 0 heat transfer.

So, net in minus out energy transferred by heat, we say Q dot the rate of energy transferred by heat. If it is transferred to the system it is positive right as per our sign convention develop, so we write this as positive. And work done if work flows out of the system it is positive. Therefore, it comes with the out the net positive heat transfer comes with in net positive work transfer comes without as per our sign convention. And this must be 0 for a cyclic process this is very important right.

Why? For a cyclic process the system comes back to it is original state because that is the definition of a cyclic process. What is the definition of a cyclic process? You start with the state point you go through a sequence of points and then sequence of state points and then you come back to the same state. So, once you come back to the same state point there is no net change of the energy of the system right. So, this is equal to 0. So, this is in terms of the rate process.

So, if you are considering the total heat transfer and total work done you can write cyclic integral of heat is equal to cyclic integral of work, if you. Now, find out the total heat transfer and total work done that is integrate this over the cycle and over time. So, physically what does it mean? Physical it means that if you transfer some heat to the system the system holds the capacity to do an equivalent amount of work. Historically when Joule did his experiment which all of you have perhaps learnt in your school high school.

Then the units of heat and work used to be different and then heat was used heat unit was used as calorie and work unit was used as Joule. So, to account for the mismatch of the heat unit and the work unit a mechanical equivalent of heat was a conversion factor that was used to relate these two. However, in SI unit the heat and work both are in the unit of joule. So, therefore, no conversion factor is required. So, this you can say is a statement of first law of thermodynamics which is nothing, but an accounting of energy balance which I have already told that first law of thermodynamics for a cyclic process under gone by a system.

For a control mass system undergoing a cyclic process. But you know this may be a very initial point to start our discussion. But in reality the processes that are taking place are not cyclic process always. So, to understand that how we can write the first law of thermodynamics for any general process for a control mass system we will try to advance a little bit from the cyclic process, for any process under taken by a control mass system.

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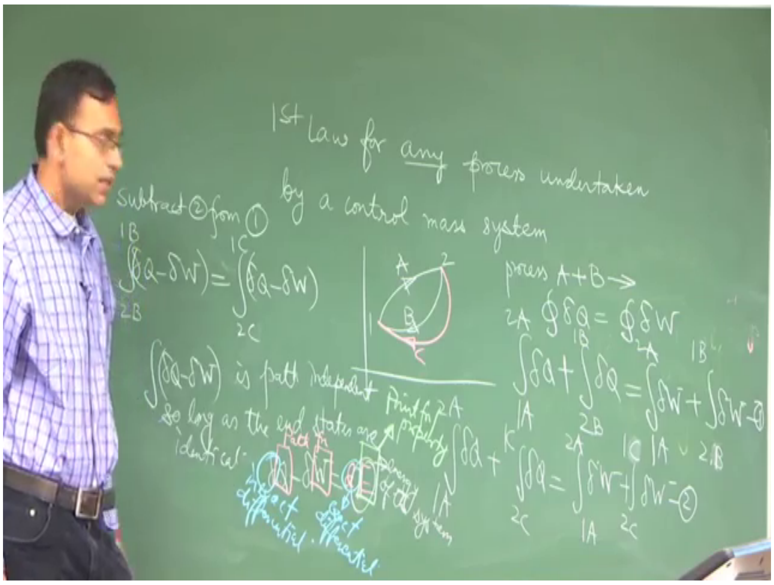

Now we assume that there is some plain, let us say p v diagram as an example it could be any two independent properties. We consider a process cyclic process having two constituent processes. So, we start with one and go to two via path A and come from 2 to 1 via path B. We consider another cyclic process between the same state points where we go from 1 to 2 via path A. But come back from 2 to 1 via path C.

So, now we can write for the process A plus B cyclic integral of dell Q is equal to cyclic integral of dell W. I have already told you in one of the previous lectures that why these are not d Q and d W because these are path dependent functions and these are called as cyclic integrals. That means, integral over the entire cyclic process or in mathematical terms these are called as canton integral; integral over a closed canton.

So, 1 to 2 by path A plus 2 to 1 by path B is same as 1 to 2 dell W by path A plus 2 to 1 dell W by path B. Similarly 1 to 2 dell Q plus 2 to 1 now by path C; this is the other cycle is equal to 1 to 2 by path A plus 2 to 1 by path C. So, now let us say this is equation number 1, this is equation number 2 you subtract 1 from the other subtract 2 from 1.

If you subtract equation 2 from equation 1 so, you can write very interestingly although dell Q and dell W individually are path dependent we see that the difference of dell Q and dell W that is dell Q minus dell W this it is integral from 1 to 2 does not depend on whether the path is B or C. And this paths B and C are absolutely arbitrary. That means, integral of dell Q minus delta W is path independent. So, long as the end states are identical.

So, if that be the case then you can write dell Q minus dell W as the exact differential of a property, this property is called as energy of the system. So, whatever terminology as energy we intuitively started with to discuss about the first law for the cyclic process that energy is now defined in terms of the difference of work and heat transfer. So, this E, this is defined as energy of the system.

So, why this is dE and not delta E? The reason is that when you integrate this, if you write integral of dE that is E1 minus E2 right. And that is the correct thing because the difference of or the integral dE from 1 to 2 that is E1 minus E2 is something that does not depend on whether from 1 to 2 you went by path B or by path C ok.

So, that is why it is d and not delta. So, when you write dE of something this is called as exact differential. So, let me write down these terminologies; this is in exact differential, this is exact differential. So, the function which comes with an inexact differential is called as path function where as the function that comes with exact differential is called as point function or property.

So, this and this, these are path functions. And this is called as point function or property. Why it is a property because the change in property does not depend on the path, it only depends on the end state points. So, with this understanding let us go a little bit deep into the statement of the first law of thermodynamics for a control mass system for any process. So, we will rewrite the equation.

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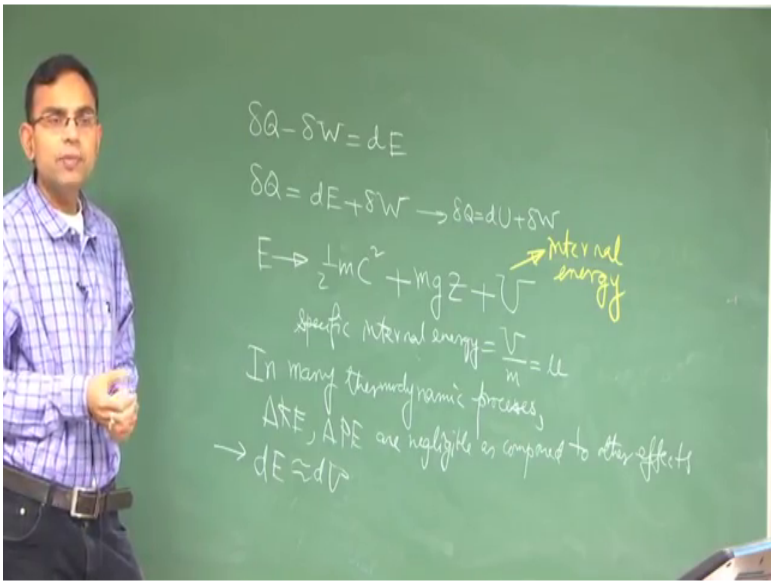

So, we can write, so physically what does it mean if you transfer some heat to the system it may use some of the heat to do work. And the remaining heat will actually be used to increase the energy of the system ok. So, this E now what is this? This E is considered to be kinetic energy that is half m may be let us write half m C square. I am not writing half mv square because v in thermodynamics we already used for volume.

So, this is actually that half mv square this is potential energy and any form of energy which is other than the kinetic and potential energy this is called as internal energy. So, we come up with a new property called as internal energy. So, the potential energy depends on the reference state. Similarly the internal energy also depends on the reference state potential energy why does it depend on the reference. So, potential energy is mg into the height with respect to the data.

So, that date with respect to the data whatever is the height based on that the potential energy is calculated, internal energy is also calculated based on a reference. So, sometimes in the thermodynamic property table in addition to kinetic, sorry in addition to pressure volume temperature data you will see additional properties. So, this is the first additional property that we learn from the thermodynamics, first law of thermodynamics that is specific internal energy, this is small u.

So, all the energies or all the parameters the total is capital letter or uppercase, the total per unit mass is small letter or uppercase that is called as specific ok. So, this specific internal energy is tabulated along with pressure volume and temperature data in the table and you will see that this may be necessary for working out problems related to the first law of thermodynamics. So, physically why I mean, what is the origin of this is essentially intermolecular form of energy.

So, kinetic and potential energies are macroscopic manifestations of the mechanical energy. But other than that there are several intermolecular forms of energy due to molecular configuration and all these things essentially sum up with it in the form of internal energy. So, from classical thermodynamics or macroscopic thermodynamics point of view which we are studying in this particular course; in the classical thermodynamics prospective the internal energy is any form of energy which is other than kinetic and potential energy, that is how it is define. Instead of getting into in it is detailed intermolecular picture which occurs on physics will provide.

Here we are considering that this is a form of energy which can be attributed due to the intermolecular form of energy. So, now interestingly in many thermodynamic processes the changes in kinetic energy and potential energy are negligible as compared to other effects. So, in that case d E will be approximately equal to d U. So, then this will lead to, this is the form of the first law that most of you are familiar from your school level.

Now when you are asked to describe the assumptions behind this equation sometimes students make mistake by saying neglecting kinetic energy and potential energy. The fact is that it is not kinetic energy and potential energy those are negligible as such, is the change in kinetic energy and potential energy that is eligible as compared to other forms of energy. So, today we have learnt the following, we have started with a basic physical law concerning energy balance and from the basic physical law concerning energy balance.

We came up with a description that connects the heat transfer and work done in a cyclic process. And that we described as the first law of thermodynamics for a cyclic process. Therefore, the first law is nothing, but an expression for energy balance expressed in terms of heat transfer and work done. So, then we extended that to the first law of thermodynamics for a control mass system for any process. And that boil down to this form and then for special cases when kinetic energy and potential energy is; changes in kinetic energy and potential energy are negligible.

This is the form of the first law for a control mass system undergoing any process that we came up with. In this process we have come across a new property called as internal energy, please try to look into the thermodynamic tables that you might have in your textbook. And let me see whether in this computer file I have some yes, so yes.

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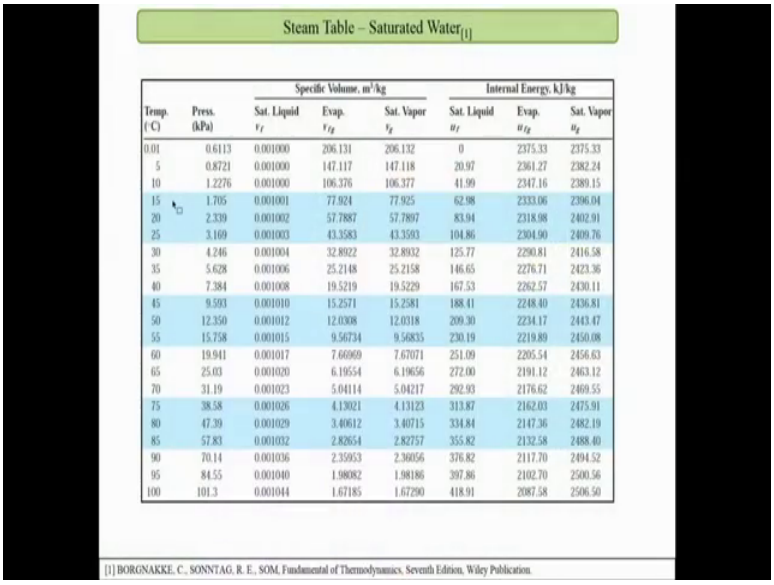

Steam Table – Saturated Water[1]

		Specific Volume, m³/kg			Internal Energy, kJ/kg		
Temp. (°C)	Press. (kPa)	Sat. Liquid v_f	Evap. v_{fg}	Sat. Vapor v_g	Sat. Liquid u_f	Evap. u_{fg}	Sat. Vapor u_g
0.01	0.6113	0.001000	206.131	206.132	0	2375.33	2375.33
5	0.8721	0.001000	147.117	147.118	20.97	2361.27	2382.24
10	1.2276	0.001000	106.376	106.377	41.99	2347.16	2389.15
15	1.705	0.001001	77.924	77.925	62.98	2333.06	2396.04
20	2.339	0.001002	57.7887	57.7897	83.94	2318.98	2402.91
25	3.169	0.001003	43.3583	43.3593	104.86	2304.90	2409.76
30	4.246	0.001004	32.8922	32.8932	125.77	2290.81	2416.58
35	5.628	0.001006	25.2148	25.2158	146.65	2276.71	2423.36
40	7.384	0.001008	19.5219	19.5229	167.53	2262.57	2430.11
45	9.593	0.001010	15.2571	15.2581	188.41	2248.40	2436.81
50	12.350	0.001012	12.0308	12.0318	209.30	2234.17	2443.47
55	15.758	0.001015	9.56734	9.56835	230.19	2219.89	2450.08
60	19.941	0.001017	7.66969	7.67071	251.09	2205.54	2456.63
65	25.03	0.001020	6.19554	6.19656	272.00	2191.12	2463.12
70	31.19	0.001023	5.04114	5.04217	292.93	2176.62	2469.55
75	38.58	0.001026	4.13021	4.13123	313.87	2162.03	2475.91
80	47.39	0.001029	3.40612	3.40715	334.84	2147.36	2482.19
85	57.83	0.001032	2.82654	2.82757	355.82	2132.58	2488.40
90	70.14	0.001036	2.35953	2.36056	376.82	2117.70	2494.52
95	84.55	0.001040	1.98082	1.98186	397.86	2102.70	2500.56
100	101.3	0.001044	1.67185	1.67290	418.91	2087.58	2506.50

[1] BORGNAKKE, C., SONNTAG, R. E., SOM, Fundamental of Thermodynamics, Seventh Edition, Wiley Publication.

So, I will show you in the screen that you can see that just like specific volume temperature pressure you have a last column which is the internal energy in this table. So, just like you have Vf Vg Vfg. Similarly you have Uf Ug Ufg. So, just like pressure volume temperature you can consider internal energy also as a property.

And you can take that property from the property table just like as you take the property of pressure volume of temperature from the property table tabulated in the books. So, with this little bit of introduction on first law for a control system and introduction to internal energy as a property; we stop here today, and we will continue in the next lecture.