Material and Energy Balance Computations
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Lecture-45
Tutorial-I

Welcome back, so I hope all the concepts that we have discussed regarding the different components of the thermodynamic entities are clear to you. And as I promised in the previous class today, we start taking up some problems. And I also introduce you to one major resource that will be very useful for many of the calculations, which is called the steam table. You might have used steam table in several contexts but let us take a thorough look at what the steam table looks like?

And then I have prepared a small tutorial sheet which is embedded in the ppt, so when you get the class scribbles you will also get a copy of that. And let us try to, so in front of your eyes I will solve the problem step by step. So, that all of you can understand how exactly to proceed with steam table. So, one way of looking at it is you have the steam table out here and you solve the problem.

But there are certain minor concepts, and which is the right way of handling the stream table? And since this is a second-year course where you are essentially building your concepts, your capabilities your skill sets. So, it is a good idea to sort of spend some time on trying to understand what exactly is a steam table? The genesis of steam table is based on the fact that, I mean there is a basis of course which I will refer to when I talk about the steam table or show the steam table.

It is based on the fact that steam is not an ideal gas and for since I am moving on to steam table, let us also sort of formally talks about it. That you can have two types of steams, that is you can have either saturated steam or superheated steam. So, saturated steam of course you understand that at a given temperature and pressure, whatever is the boiling temperature the water has fully vapourized into steam and it is saturated.

So, if there is some cooling, immediately condensation will start happening. But please do understand that this cooling is associated with release of latent heat. And latent heat we have already discussed is high, not only it is higher than sensible heat but latent heat for boiling or evaporation or vapourization is very high. So, you can on one hand have saturated steam on the other hand you can have super heated steam.

So, which is like steam and then it is heated beyond the boiling temperature at that particular pressure. So, if you have steam at 1 atmospheric pressure and let us say you have steam at 100°C, in very simple terms that is going to be saturated steam. On the other hand, if you have steam again let us say at 1 atmospheric pressure and then the steam temperature is 200°C, it is going to be super heated steam, this is clear, this is number 1.

Now, so we all know that the boiling point or the boiling temperature of water is 100°C but please do not forget this is limited to the fact that it is only at 1 atmospheric pressure. So, if I just ask you a simple question what is the boiling point of water at 2 atmospheric pressure? Answer is none of you can tell it, so these are the type of information that you will get from the steam table, this is important.

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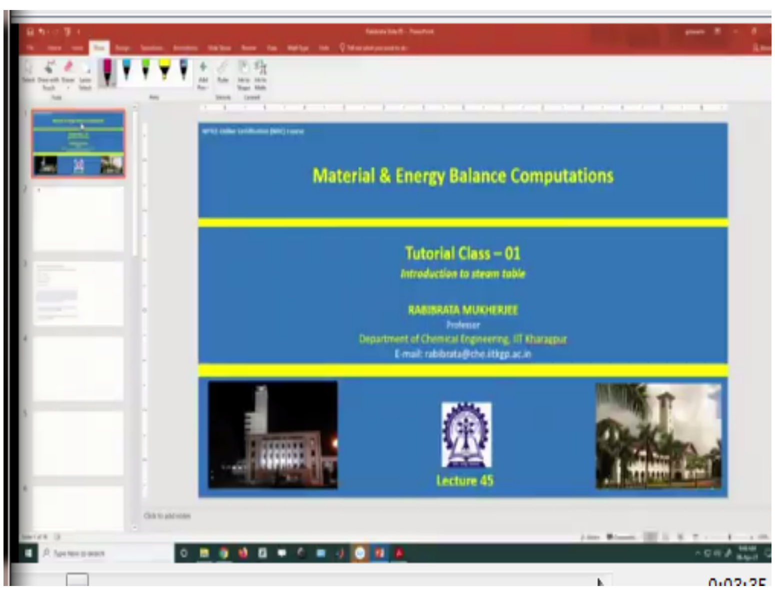

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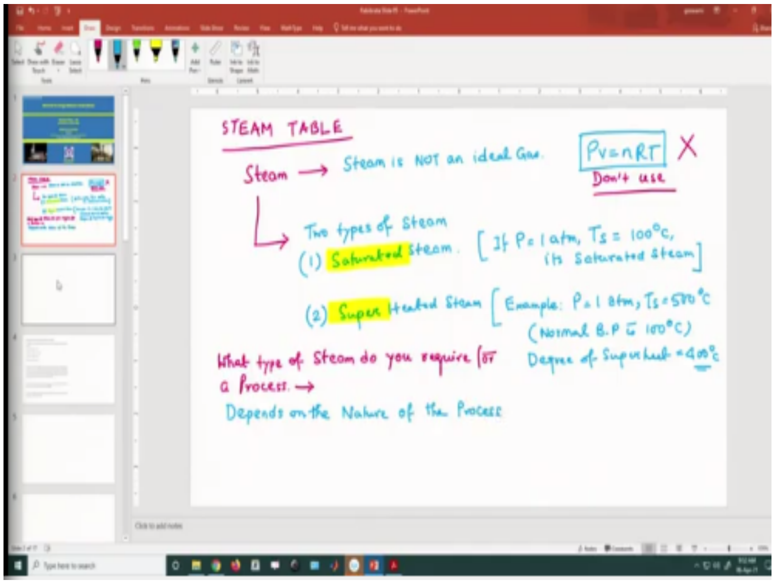

The second thing is, so essentially what we are going to talk today is about steam table. It is a very, very useful table; lot of information can be extracted from that. And before we move onto steam table certain words about steam, a word of caution I have seen many, many students making this mistake. Steam is not an ideal gas, so what does it mean? Please stay away from using this equation, do not use.

And this is a learning for life and now that you know it very specifically, lot of people have this doubt, after all it is a vapour, so what is the problem in using PV = nRT? Please do not forget PV = nRT is valid only for an ideal gas and now this class understands what is the meaning of an ideal gas? So, steam is not an ideal gas, so do not use it. Then the second thing, even before moving on to the table just the way we develop concepts for everything is to know that there can be 2 types of steams.

Number 1, you can have saturated steam like if p = 1 atm and steam temperature is 100°C, it is saturated steam. On the other hand, you can have super heated steam also. So, example again if p = 1 atm, of course these are all functions of pressure and Ts is 500°C. Of course, we know that the normal boiling point 100°C, therefore it is superheated, and degree of superheat is 400°C.

Now comes the question if I have to ask you which type of steam would you choose? These are questions one asks and typically people would commit, some will say I will go for superheated steam is more useful, some will say saturated steam is more useful, it is not like that. It depends on the application. So, a very, very important of particular question to ask is, do you require for a process? And please do not give any direct answer or commit yourself to an answer. The answer to this is, it depends on the nature of the process. So, what can be the nature of the process?

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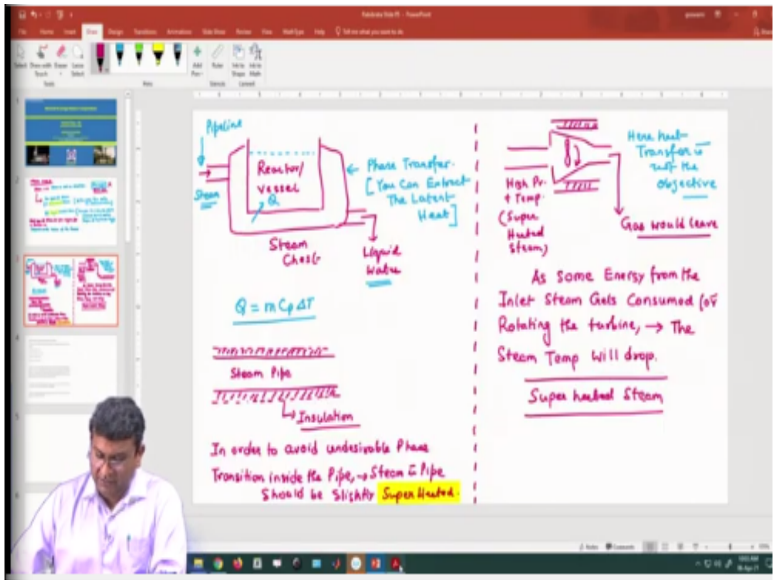

One very common application of steam is for heat transfer. So, you can have a reactor, or a vessel and it can be surrounded by what is known as the steam chest. So, what you do is you introduce steam here and maybe steam or typically you would extract, or liquid water leaves and heat is transferred. So, here what you are extracting is the amount of energy you would like to transfer from the steam side to this vessel, maybe it is a reaction that is going on, it requires high temperature or you want to maintain a vessel at a higher temperature or whatever it is.

Now here you need to understand if you take super heated steam and even if there is a decrease in temperature. So, the Q that you are going to get if there is no phase change is m $C_p\Delta T$. Now for steam or for any gas for that matter C_p is very, very less. So, if you would like to have high amount of Q, reasonably high amount of heat, you need to have significant drop in temperature.

So, that means you need to introduce a steam, if you are using superheated steam you need to introduce steam at a very high temperature. And also, you need lot of mass, mass flow rate needs to be higher. On the other hand, if you now cleverly understand that my latent heat is much,

much higher than sensible heat, what you can do? You can take steam, which is very close to saturation, so in that case what will happen?

As the steam starts to cool down, it now goes to the phase transfer regime. So, the temperature does not drop but it goes to the phase transfer regime and it releases the entire heat of vapourization, the latent heat corresponding to the heat of vapourization or heat of condensation, so you get large amount of heat. And that is why I have shown that in such a case of course when I say that liquid water comes out and steam is introduced over here.

So, you actually want to have phase transfer here. And, so that you can extract the latent heat, so this is clear. So, there can be if there is a very, very major application of process steam if you have a heat transfer application then definitely you will go for saturated steam or steam that is very close to saturation. Of course, please also remember that ahead of this there has to be a pipeline.

And as steam is flowing through the pipeline of course steam is at high temperature; so, what would you do? You would definitely have insulation, all these things you will learn in your subsequent heat transfer this and then. But this much everybody understands that if you do not have insulation, what will happen? There will be a significant heat loss through the pipe which you do not want, so you would be having some insulation.

Now the issue is that if you have purely saturated steam, so we all know that despite having insulation there will be minor heat loss. So, if you just take for transportation through the pipe steam that is exactly saturated. And there is even minor heat loss through the insulation then condensation will start inside the pipe. So, instead of a gaseous flow of steam or high-pressure steam or whatever, you will now have a two phase flow.

And water and steam have different densities, so this becomes dangerous. And if it is at a high velocity this water drops can go and do some bombardment to the fittings, so it is known as pitting I think and so this is avoidable. So, in order to avoid undesirable phase transition inside the pipe, the steam in the pipe should be slightly superheated, I hope this is clear to all of you.

So, you take steam that is slightly superheated, so that you ensure that there is no undesirable condensation in the pipe.

Because you not only loose lot of heat in the pipe but also the problem is that this flow will get more complicated with 2 phase flow and droplets of water moving at very high velocity because of density difference and stuff like that, so that needs to be avoided. So, you essentially want your phase transition, transformation or phase transfer to take inside the steam chest where all the condensation should occur, so that you get the maximum amount of heat.

On the other hand, if you are looking at an application, for example many of you know about the thermal power plants. And in thermal power plants what actually happens is? You essentially burn coal to produce steam, actually what you do is? There is de-mineralized water that as it is called. That water is converted into steam by boiling, high pressure steam it is converted. And what is done? This steam is actually used as a high-pressure fluid to rotate the turbine. So, there the momentum of the steam is more important, so you do not want.

So, essentially when you have and most of the thermal power plants have different stages of this turbine. So, you have a high-pressure turbine, you have an intermediate pressure turbine, you have a low pressure turbine. So, essentially what happens is? Steam at very high pressure and temperature, so this is super heated steam, so it enters the turbine and rotates the blade, it rotates the blade. And what you have is this?

So, if this blade is rotating and you have electromagnetic coil outside electrical work gets done. So, essentially kinetic energy first getting converted to shaft work, we have discussed it all and that is getting converted to electrical energy. Now you do not want, so here heat transfer is not the objective, what is the objective? You would like actually to have a compressed gas; essentially steam is used as a compressed gas which is going to rotate the turbine.

And you would want again a gas to leave; now what will happen is? Since some amount of energy from this inlet steam is getting transferred to the shaft and the turbine. So, there is going to be, some energy from the inlet steam gets transferred or gets consumed for rotating the turbine, what will be the consequence? Consequence will be the steam temperature will drop.

Now as steam temperature drops if you are now close to saturation it will get converted to water, that is something you do not want. In fact, you would like to use, so therefore you would like to use highly superheated steam or the degree of superheat as we discussed in the previous slide should be adequately high. So, that it enters transfer significant part of the energy in rotating or consume significant part of it is internal energy in rotating the turbine.

And still it remains in a superheated state, high pressure and superheated state. In fact that is exactly what is meant by the high pressure turbine, intermediate pressure turbine and low pressure turbine. So, the first initial steam coming out from the boiler which is at high pressure and high temperature is first introduced to the high-pressure turbine. The output steam from the high-pressure turbine which is still superheated and at high pressure lower than the pressure at which it was introduced to the first stage is now introduced to the intermediate stage where it again rotates the turbine.

There is additional drop in temperature and pressure, still it remains super heated. So, you have to design it accordingly and that is introduced to the low-pressure turbine. Still you do not want steam to condense out there because again if it condenses the water that gets produced is going to heat your turbine and damage the blades. So, it comes out as steam, then you take it to the condenser and then you add further purification etcetera, etcetera.

You take it back to the dm plant recycle whatever you do. So, for this type of application of course you would like to go for superheated steam. I think this is an important understanding for all of you, that depending on process requirement where you should use saturated steam, where you should use superheated steam? Now with that let us now start talking about the steam table, so this is how a steam table typically looks like. **(Video Starts: 18:23)**

So, you essentially have different types of tables, so you can have, they are all very simple concepts. So, this is what it says is essentially the saturated water table, so this is what is known as the saturated water table. Typically the version of the steam table that I will be sharing with all of you, this will be termed as p 1. So, let me just go, so this is what is called the saturated water table.

So, what it means, so if you look at to the table it is very, very simple. See what is given is the temperature in degree centigrade, the first column. The corresponding saturation pressure is given. So, let us find out the easiest one or the easiest one is like we know if the temperature is 100°C, the atmospheric pressure it is 101.35 kilopascal or it is 0.10135 megapascal.

So, kindly take note that this pressure column is in kilopascal and megapascal, it is written like that. So, you have to use your wisdom to understand that these values, the initial part of the table the values are in kilopascal and how do you understand it has transferred to megapascal? See at 95°C, you have the saturation pressure is 84.554, at 100°C of course the saturation pressure has to be higher than that.

And you see the number has now reduced to 0.101. So, obviously now that at the top it is written kilopascal and megapascal, so you understand that up to 95, this is something that is no hard and fast rule for this. This is for this particular table and you just have to understand that for this particular table, this is the one we are going to use for all our purposes up to 95°C it is in kilopascal after that it becomes megapascal.

So, here for example you see if your saturation temperature is 100°C, then the saturation pressure or is at 0.10135 megapascal that is atmospheric pressure. There is actually a better way of looking into it is the other table. So, table b 1 is essentially the temperature table, saturated water temperature table. And remember saturated water means, for 1 atmospheric pressure for example this table will capture the condition of water at 100°C and steam at 100°C and it is all there I am coming to it.

Remember, this is saturated table, but you cannot use this table for superheated steam. So, similarly the table 2 that we have is the pressure table, this is even more convenient and convincing. So, when the pressure let us say is 0.101325, that is 1 atmospheric pressure very close to that you have this data over here. That actually shows your boiling temperature is 99.62°C.

So, depending on which condition is given and in most cases for a system the pressure will be given. So, and it will be mentioned that whether the steam is saturated or superheated. So, for example, for 4 megapascal if it is mentioned that you have steam at 4 megapascal which is saturated steam, then straight away what will happen? You simply go to this pressure table; find out what is the condition.

So, this is the data for 4 megapascal you can see over here, this is the data for 4 megapascal. And if it is said that you in a chamber you have saturated steam at 4 megapascal then immediately you know that the temperature of the vessel is 250.4°C, is it clear? So, I repeat again, suppose you are provided with a data that you have steam in a chest which has pressure of 3 megapascal and it is saturated.

So, immediately from the steam table you can get lot of information, what are the informations? So, for example straight away you see this is 3 megapascal over here and the corresponding, so it is told that it is a saturated steam. So, immediately you can say ok, the temperature is 233.90°C, so this immediately you can say. And is that all? No, there is much more you can actually say.

So, let us pick up a data I would like to show you the columns what they correspond to. So, let us say you are told that you have steam or water or whatever at let us say 10 kilopascal and which is saturated. So, 10 kilopascals, it is over here saturated, so temperature is 45.81°C. And what are the stuff you know what you know? What is the specific volume of the liquid, so if it is in liquid state this is the specific volume, what is specific volume?

It is opposite of density. So, just one by this and you will get the liquid density, this is the specific volume of vapour at that condition. So, kindly note, what are the stuff you have? You have vv which is the specific volume of liquid; you have vv which is the specific volume of the vapour. Then you have the specific internal energy of the liquid, specific enthalpy internal energy of the vapour.

And then this is essentially corresponding to the latent internal energy you can say, the delta U l. So, for every condition if you subtract from this one U v cap to U l cap, so let me just show you this in a slightly better way by marking, so that we all understand. I have my own ways for doing this, so let us have this data in the power point, so that we can mark one it in our powerpoint slide. **(Video Ends: 25:08)**

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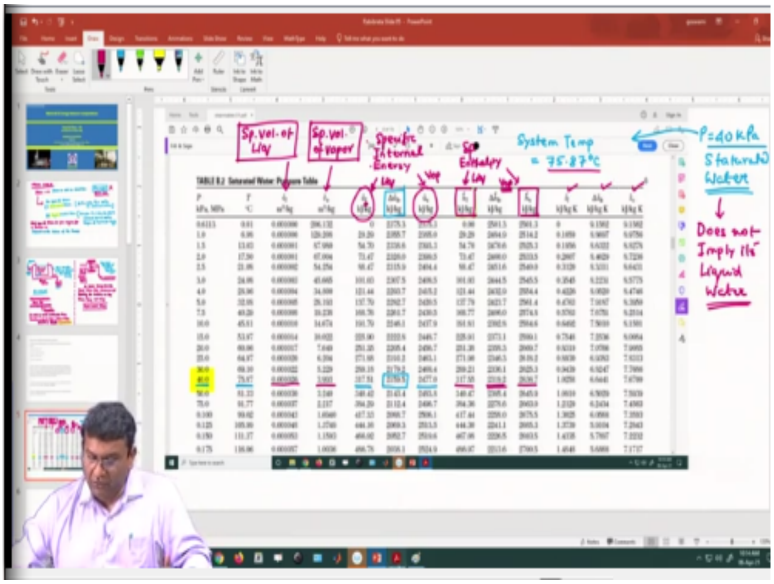

So, let us say this is the data, so this will be much more convenient now for us to work. So, you see let us say, it says that you have condition is pressure = 40 kPa and it is mentioned that you have saturated water. So, be careful about one particular thing, saturated water does not imply it is liquid water because steam, waters, ice everything is water, so be careful about that particular thing.

So, if that is mentioned that you have saturated water at 40 kPa then what it means? Here is 40 kPa, so straightaway you now know that the system temperature. From here straightaway you know the system temperature = 75.87°C, this is something comes out straight away. Then I was telling what are the additional informations you can get. And this is please note down of course the slides will be there, this is the specific volume of liquid, this is the specific volume of vapour.

So, these 2 things are known. So, now you know that if the system is in the liquid state this is going to be the specific volume, if it is in the vapour state this is going to be the specific volume. There are problems which we will show how useful these can be. Then you essentially have the specific internal energy, so these 2 are specific internal. And now your conversant when it is L, it is liquid and it is vapour.

So and this delta is nothing but you subtract this term from this term, so this 2159.5 is you actually get by subtracting 2477.0 - 317.5, so this you can say is equivalent to latent heat. So, there is a latent internal energy you can say, there is a change in internal energy for phase transition per 1 kg of liquid at this condition. If it undergoes a phase transition at this condition, this is how it will be.

So, the next column gives us the specific enthalpy. So, this one and this one gives the again this is for liquid and this is for vapour. And this is the change again this 2636.7 - 317.55 will give you this value. So, this is again corresponding to the latent heat you can say. This particular version of steam table also comes with specific entropy but that is something at least in this context we will not use.

In future when you learn entropy because entropy is a critical concept and I do not want to talk about entropy right now, so when it comes we will see. So, this is how what are the informations you can get? **(Video Starts: 29:47)** So, maybe a quick relook and what now we understand that the same data can be given in 2 forms either the temperature is given and correspondingly the saturation pressure you find out which is rare actually most of the cases.

So, if it is says that water at 170°C is saturated, so in that case you know that your pressure is 0.7917 megapascal. In most cases what will be specified? And also, you see that this data stops at 374.14°C, there is a reason for that, that is actually the triple point. Also, you need to know we are running out of time, so you need to know the basis of the steam table.

Steam table is actually calculated the basis of the steam table is the specific internal energy of a liquid at 0.01°C and 0.6113 kilopascal = 0. Not too many people will tell you this, this is the basis. So, based on which all the calculations or the number of steam table are shown. So, in the next class I will teach you how to handle the superheated table and then we will take up some practical problems, thank you very much. **(Video Ends: 30:53)**