

Material and Energy Balance Computations
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Lecture –46
Tutorial - II

Welcome back. So, we started our discussion on steam table. And, I hope from the discussion we had in the previous class, you have already gathered some idea about the utility of steam in different process applications and different settings where you would like to have superheated steam or saturated steam. And, I also hope that you now understand the difference between superheated steam and saturated steam.

In this class of course so, whenever you have saturated steam you can potentially have a situation where you can have a mixture of water and steam at that particular temperature under the saturation condition. So, there is a term that I will teach in this class or maybe in the next class which is called the quality factor of the steam which actually gives you the ratio and which you can very easily calculate from the steam table.

Suppose you have saturated steam and it is condensing due to heat transfer, but it does not condense as the total amount of heat which corresponds to the entire latent heat does not get transferred. Let's say part of that heat gets transferred and you now have a mixture of steam and liquid water and those properties you can evaluate or find out using the steam table.

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Sp. vol. of Liquid

Sp. vol. of vapor

Specific Internal Energy

Sp. Enthalpy of Liquid

System Temp = 75.87°C

P = 0.0 kPa Saturated Vapor

Does not imply it's Liquid water

This table will not work

Steam is Super heated

Saturation Temp -> 81.33°C

2) Steam at 50 kPa, T = 200°C

T, MPa	T, °C	v _f , m ³ /kg	v _g , m ³ /kg	u _f , kJ/kg	u _g , kJ/kg	h _f , kJ/kg	h _g , kJ/kg
0.0113	0.01	0.000999	206.13	0.0008	2375.3	0.0008	2583.9
1.0	6.98	0.000999	120.26	0.0008	2305.7	0.0008	2464.9
1.5	10.61	0.000991	87.969	0.0008	2266.3	0.0008	2426.3
2.0	17.29	0.000901	67.094	0.0008	2204.9	0.0008	2369.9
2.5	21.96	0.000802	54.254	0.0008	2115.9	0.0008	2280.9
3.0	24.99	0.000702	45.065	0.0008	2010.0	0.0008	2164.5
4.0	28.96	0.000594	34.989	0.0008	1814.6	0.0008	1970.9
5.0	32.88	0.000495	28.180	0.0008	1577.9	0.0008	1721.7
7.5	40.29	0.000396	19.226	0.0008	1057.6	0.0008	1067.7
10.0	45.81	0.000300	14.674	0.0008	687.9	0.0008	687.9
15.0	53.97	0.000204	10.022	0.0008	225.0	0.0008	225.0
20.0	60.96	0.000147	7.449	0.0008	205.4	0.0008	205.4
25.0	66.87	0.000102	5.394	0.0008	219.2	0.0008	219.2
30.0	71.87	0.000075	3.928	0.0008	217.2	0.0008	217.2
40.0	75.87	0.000050	2.863	0.0008	215.9	0.0008	215.9
50.0	81.33	0.000035	2.149	0.0008	215.4	0.0008	215.4
60.0	87.29	0.000025	1.584	0.0008	215.4	0.0008	215.4
70.0	93.79	0.000018	1.164	0.0008	215.4	0.0008	215.4
80.0	100.68	0.000013	0.845	0.0008	215.4	0.0008	215.4
90.0	107.93	0.000010	0.621	0.0008	215.4	0.0008	215.4
1.00	180.00	0.000007	0.194	0.0008	215.4	0.0008	215.4

So, coming back to our discussion, so, we just started to talk about steam table, and this is the first table that we looked into great detail is the saturated water pressure table. Here the first column essentially is pressure, or the independent variable is essentially pressure. There are multiple pages of the steam table that is available with you and you get the saturation temperature from it.

And correspondingly you get the specific volume of the vapour from the liquid vapour specific internal energy of the liquid vapour and specific enthalpy of the liquid vapour. As I mentioned the first table of course is the saturated water temperature table. So, it is exactly same to the pressure table the only difference being that in the first column instead of it being pressure it is actually temperature.

So, you start off with temperature. So, if temperature is specified. Let us say that you have steam or saturated water at 110°C and please repeatedly I am telling by reading saturated water please do not conclude in this particular case that you have liquid water it can be steam also. Because steam water whatever or liquid water everything is water.

So, if it says that saturated water at 110°C all you need to do is to go to 110°C in the table and immediately you find out that your saturation pressure is 0.14328 MPa or in other words this also probably you may understand better from the pressure table that if you increase the pressure the

boiling temperature increases and this is what you have studied in your school days the basic principle of pressure cooker.

Why cooking happens fast in a pressure cooker because what happens is as you increase the pressure the boiling temperature increases. The rest of the table is very similar to the previous case. So, you have specific volume of vapour and liquid specific volume of liquid and vapour specific internal energy of liquid and vapour and specific enthalpy of liquid and vapour. And these are essentially one can say the latent heats the latent enthalpy or the latent internal energy let us put it like that this is actually the latent heat of vapourization.

This particular thing and as we have discussed that this entropy you can also get. So, you can straight away calculate or put the values but we are not going to talk about it. Now suppose I tell you that I now have steam at 50 kPa and. So, I tell you that I now have steam the problem number two I have steam I will show you how to operate it 50 kPa and temperature is 200°C this is all that is given.

So, just because it is steam and temperature is given at 200°C do not assume anything do not assume. So, just the way by reading the word water you are not supposed to assume that it is liquid water similarly by reading the word steam you are not supposed to assume its saturated steam. So, you have to be very neutral it is given that steam at 50 kPa and the temperature is 200°C.

I am going to teach you how to go about it. So, let us remove all these previous earlier highlights. So, that we can work on it. So, 50 kPa, So, you go to the pressure side table that is the easiest thing to do. So, you find out 50 kPa and then you find out that your saturation temperature is 81.33°C.

And the steam you have has a temperature of 200°C. So, from here you now conclude that the steam I have or we have is superheated and the degree of superheat is roughly 118.67°C. So, therefore once you know that you have super heated steam this table is not going to work because it is for saturated water or saturated steam. So, the conclusion is the moments you have

super heated steam the practical or the consideration from the standpoint of implementation is this table will not work.

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Subcooled liq / liq water Temp is lower than saturation Temperature

TABLE B.4 Superheated Water Vapor														
P = 0.1 MPa					P = 10 MPa					P = 100 MPa				
T	v	u	h	s	T	v	u	h	s	T	v	u	h	s
°C	m ³ /kg	kJ/kg	kJ/kg	kJ/kg·K	°C	m ³ /kg	kJ/kg	kJ/kg	kJ/kg·K	°C	m ³ /kg	kJ/kg	kJ/kg	kJ/kg·K
sat	1.673	2445.0	2583.9	8.4540	sat	0.018	1861.5	2005.5	7.0000	sat	0.000	2560.1	2875.5	7.2000
100	1.673	2445.0	2583.9	8.4540	100	0.018	1861.5	2005.5	7.0000	100	0.000	2560.1	2875.5	7.2000
150	1.533	2287.9	2750.0	8.6881	150	0.006	1899.6	2077.0	7.1879	150	0.004	2584.7	2774.4	7.1125
200	1.432	2182.0	2872.9	8.8007	200	0.004	1928.9	2109.0	7.3000	200	0.003	2608.0	2873.3	7.1542
250	1.352	2115.0	2957.3	8.8922	250	0.003	1951.3	2141.5	7.3922	250	0.002	2628.4	2974.3	7.1977
300	1.287	2075.0	3015.0	8.9583	300	0.002	1969.4	2169.0	7.4641	300	0.002	2647.8	3074.1	7.2434
350	1.233	2048.0	3061.0	8.9997	350	0.002	1983.9	2192.0	7.5222	350	0.002	2665.1	3169.1	7.2911
400	1.188	2029.0	3098.0	9.0280	400	0.001	1996.0	2211.0	7.5683	400	0.001	2680.4	3259.1	7.3404
450	1.150	2015.0	3128.0	9.0460	450	0.001	2006.0	2227.0	7.6033	450	0.001	2693.8	3345.1	7.3911
500	1.118	2004.0	3153.0	9.0550	500	0.001	2014.0	2240.0	7.6283	500	0.001	2705.4	3427.1	7.4434
550	1.090	1996.0	3174.0	9.0640	550	0.001	2021.0	2251.0	7.6533	550	0.001	2715.4	3505.1	7.4977
600	1.065	1990.0	3192.0	9.0710	600	0.001	2027.0	2260.0	7.6783	600	0.001	2724.1	3580.1	7.5534
650	1.042	1986.0	3208.0	9.0770	650	0.001	2032.0	2268.0	7.7033	650	0.001	2731.6	3652.1	7.6104
700	1.021	1983.0	3222.0	9.0820	700	0.001	2037.0	2275.0	7.7283	700	0.001	2738.1	3721.1	7.6684
750	1.002	1981.0	3234.0	9.0860	750	0.001	2041.0	2281.0	7.7533	750	0.001	2743.6	3787.1	7.7274
800	0.984	1980.0	3245.0	9.0890	800	0.001	2045.0	2286.0	7.7783	800	0.001	2748.1	3851.1	7.7874
850	0.968	1980.0	3255.0	9.0910	850	0.001	2048.0	2290.0	7.8033	850	0.001	2751.6	3912.1	7.8484
900	0.953	1980.0	3264.0	9.0930	900	0.001	2051.0	2293.0	7.8283	900	0.001	2754.1	3971.1	7.9104
950	0.939	1980.0	3272.0	9.0950	950	0.001	2054.0	2295.0	7.8533	950	0.001	2755.6	4028.1	7.9734
1000	0.926	1980.0	3279.0	9.0970	1000	0.001	2056.0	2297.0	7.8783	1000	0.001	2756.1	4083.1	8.0384
1050	0.914	1980.0	3285.0	9.0990	1050	0.001	2058.0	2298.0	7.9033	1050	0.001	2755.6	4136.1	8.1044
1100	0.902	1980.0	3290.0	9.1010	1100	0.001	2060.0	2299.0	7.9283	1100	0.001	2754.1	4187.1	8.1714
1150	0.891	1980.0	3294.0	9.1030	1150	0.001	2061.0	2300.0	7.9533	1150	0.001	2751.6	4236.1	8.2394
1200	0.880	1980.0	3298.0	9.1050	1200	0.001	2062.0	2301.0	7.9783	1200	0.001	2748.1	4283.1	8.3084
1250	0.870	1980.0	3301.0	9.1070	1250	0.001	2063.0	2302.0	8.0033	1250	0.001	2743.6	4328.1	8.3794
1300	0.860	1980.0	3304.0	9.1090	1300	0.001	2064.0	2303.0	8.0283	1300	0.001	2738.1	4371.1	8.4524
1350	0.850	1980.0	3307.0	9.1110	1350	0.001	2065.0	2304.0	8.0533	1350	0.001	2731.6	4412.1	8.5274
1400	0.841	1980.0	3309.0	9.1130	1400	0.001	2066.0	2305.0	8.0783	1400	0.001	2724.1	4451.1	8.6044
1450	0.832	1980.0	3311.0	9.1150	1450	0.001	2067.0	2306.0	8.1033	1450	0.001	2715.6	4488.1	8.6834
1500	0.823	1980.0	3313.0	9.1170	1500	0.001	2068.0	2307.0	8.1283	1500	0.001	2706.1	4523.1	8.7644
1550	0.815	1980.0	3314.0	9.1190	1550	0.001	2069.0	2308.0	8.1533	1550	0.001	2695.6	4556.1	8.8474
1600	0.807	1980.0	3315.0	9.1210	1600	0.001	2070.0	2309.0	8.1783	1600	0.001	2684.1	4588.1	8.9324
1650	0.800	1980.0	3316.0	9.1230	1650	0.001	2071.0	2310.0	8.2033	1650	0.001	2671.6	4619.1	9.0194
1700	0.793	1980.0	3317.0	9.1250	1700	0.001	2072.0	2311.0	8.2283	1700	0.001	2658.1	4649.1	9.1084
1750	0.786	1980.0	3318.0	9.1270	1750	0.001	2073.0	2312.0	8.2533	1750	0.001	2643.6	4678.1	9.1994
1800	0.780	1980.0	3319.0	9.1290	1800	0.001	2074.0	2313.0	8.2783	1800	0.001	2628.1	4706.1	9.2924
1850	0.774	1980.0	3320.0	9.1310	1850	0.001	2075.0	2314.0	8.3033	1850	0.001	2611.6	4733.1	9.3874
1900	0.768	1980.0	3321.0	9.1330	1900	0.001	2076.0	2315.0	8.3283	1900	0.001	2594.1	4759.1	9.4844
1950	0.763	1980.0	3322.0	9.1350	1950	0.001	2077.0	2316.0	8.3533	1950	0.001	2575.6	4784.1	9.5834
2000	0.758	1980.0	3323.0	9.1370	2000	0.001	2078.0	2317.0	8.3783	2000	0.001	2556.1	4808.1	9.6844

So, what you need to do is in the steam table you need to go to the super heated table and in the steam table we have it is the table set B4 and this is how the super heated table looks like. So, you essentially have the super heated table which is written super heated water vapour and for different pressure parameters are given up to 8 MPa.

I think or maybe even higher sorry about it, so, you have data for; so, I am extremely sorry you have data for 60 MPa up to 60 MPa. So, one important thing to note is that you do not have data it is not possible to have data at all pressure. So, you have data for let us say p the equal to 50 MPa and p equal to 60 MPa and suppose now you end up with some stream which has some intermediate pressure of course you have to do interpolation.

Similarly, you have data for different temperature interval like 400, 450, 500. So, for a given pressure or a given temperature if you have an intermediate data you have to do interpolation which is easy. So, what we have done is the problem that we are looking at says the steam is at 50 kPa. So, this is a landing exercise you can say. So, we go to the table the super heated table which is for 50 kPa and for your convenience I have copied it to the PPT or the out or our white board you can say.

So, here is the table. So, 50 kPa now that we know. So, I just want everyone to be very clear about it from the saturation temperature you cannot conclude straight away at 200°C looks like a high temperature therefore it is super heated nothing like that because it is looking like a high temperature because the pressure is very low at 50 kPa. If you have a high pressure, 200°C is not even the saturation temperature.

So, no random conclusions you need to conclude in a very, very logical and scientific way and that is like T equal to 200°C here the boiling temperature is the saturation temperature corresponding to this pressure is 81.33°C and therefore what you have is a super heated steam. So, if you have super heated steam; then now you go to the super heated steam table and luckily our pressure is 50 kPa.

So, we have data for 50 kPa. So, now you need to go to this table which is the super heated table for 50 kPa and let us look into the structure of the super heated table what are the stuff we have you see that the table is much, much more compressed here. So, here for the pressure for the different pressure you have you have data at different temperature and in our case the temperature is 200°C and you have data for 200°C.

So, you can straight away go over here and then what you find is you have specific volume you have specific internal energy you have specific enthalpy and you have specific entropy only four entities, why? Because when you were talking about the saturated steam there was a possibility that you might have liquid or air therefore you this is very, very important. So, when you are talking about the saturated steam table there was a possibility that you may either have liquid or you have vapour at that temperature and pressure.

Therefore, you as you have looked correctly or as we have learnt specific volume there were two sets of data specific internal energy there were two sets of data specific enthalpy there were two sets of data is it clear to all of you. But here when you have super heated steam of course there is no possibility of having liquid. So, it has to be in the vapour form and therefore you are only left with only one set of data.

And what is that set of data that set of data is the specific volume the specific internal energy and the specific enthalpy. So, I hope this is clear to all of you and now we are quite well poised to take up some practical problems from our tutorial sheet. And just for the sake of completeness we also have two additional tables one is the saturated water again the solid vapour table. So, if you understand what is the solid vapour table you are essentially in the lower left part of the phase diagram where below the triple point there is a possibility of transition of those triple point would do for one atmospheric pressure. There was a possibility for a direct transition from solid to vapour.

We rarely use this, but this is for the sake of completeness you must know that such data is also available. And this is a different pressure therefore you have this type of range. And so, this is one set of data you have the other the last set of data you have in table B5 is sub cooled liquid data sub cooled liquid water typically I will show you that we can we know the specific heat of water its 4.2 kilo joule per Kelvin kg.

So, we typically use that, but this is at different pressure. So, that that data is valid at one atmospheric pressure. So, this is a different pressure. So, this is like a high pressure that that C p value might change and here what you have is a different pressure you directly just like your super heated steam data you can sort of find out what is the sub cool liquid data. By the way what is sub cool liquid sub cool liquid.

So, water at 30°C at room temperature is actually some cool liquid because now you understand that normal boiling temperature. So, this is an important terminology I mean just make a note of it just the way we learnt about superheated steam. So, similarly there is another pedagogy called sub cooled liquid. So, it is like liquid water temperature is lower than saturation temperature. So, at one atmospheric pressure for example all the water you see around us the drinking water everything is actually sub cool liquid.

Sub cool liquid again does not mean that it has to be taken out from the refrigerator these are things these are important to note. Because at one atmospheric pressure saturated liquid is at

100°C. So, anything below that is actually sub cool liquid. So, I think with this we can now move on and try to pick up some problems from the tutorial sheet.

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Tutorial Sheet for Material & Energy Balance Calculations

- Find the value of internal energy for water (relative to the reference state) for the states indicated:
 - Water at 0.4 MPa, 725 °C
 - Water at 3.0 MPa, 0.01 m³/kg
 - Water at 1.0 MPa, 100 °C
 - Water at 10.0 MPa, 100 °C
- Steam is used to cool a polymer reaction. The steam in the steam chest of the apparatus is found to be at 25.5 °C and 4000 kPa absolute during a routine measurement at the beginning of the day. At the end of the day the measurement showed that the temperature was 650 °C and the pressure 10,000 kPa absolute. What was the internal energy change of 1 kg of steam in the chest during the day? Obtain your data from the steam tables.
- A closed vessel contains steam at 1000.0 psia in a 4-to-1 vapor-volume-to-liquid volume ratio. What is the steam quality? Given $\rho_{\text{sat}} = 6.894 \text{ kPa}$.
- What is the enthalpy change that takes place when 3 kg of water at 101.3 kPa and 100 K are vaporized to 15,000 kPa and 600 K?

Handwritten notes for Problem 1a:
 For $P = 0.4 \text{ MPa}$, $T_{\text{sat}} = 143.63^\circ\text{C}$ → Go to Super Heated table.
 $\hat{u}|_{700^\circ\text{C}} = 3477.9 \text{ kJ/kg}$
 $\hat{u}|_{775^\circ\text{C}} = 3662.5 \text{ kJ/kg}$

$$\hat{u} = (3477.9 \times 0.75) + (3662.5 \times 0.25)$$

 → Actually closer to the value at 700°C

$$\hat{u} = (3477.9 \times 25) + (3662.5 \times 75)$$

 → Closer to 500°C

So, here is the first set of problems find the value of internal energy for water for the relative to the reference state which is at zero. What we have seen in the steam table for the states indicated below. It has told for internal energy, but it can also be like you can have it can you might be told that you can calculate the specific enthalpy or any property for that matter. So, let us see what the data is provided?

Data is provided is 0.4 MPa 725°C. So, what is the thing we should do we should first go to the pressure table and so, do not conclude straight away that 725 looks to be very high and therefore it must be superheated nothing like that so, 0.4 MPa you see its going kilopascal. So, here it turns point one. So, 0.4 MPa we find that the boiling temperature is the saturation temperature is 143.63°C.

So, you must write all this when you are solving saturation temperature or T_{sat} is a valid for P equal to 0.4 MPa T_{sat} equal to 143.63 I can use my steam table that I have with me. So, that I do not have to swap back and forth its 143.63°C and therefore now you know what to do. So, now we move on go to super heated table. So, go to super heated table and for 0.4 MPa pressure.

So, we now go to superheated table and 0.4 MPa is 400 kPa. So, this is the data set 400 kilopascal you can see probably I will enlarge it a little bit. So, you can see for four hundred kilopascal this is 0.4 MPa and the temperature that is given to us is 725°C this is important and therefore we now understand that specific internal energy will be between these 2. So, that is very important.

So, let us quickly take this data in the slide you will be solving all this in fraction of seconds. But I prefer that you learn things thoroughly and. So, if this is the data set you have there is a small catch there which I would like to demonstrate. So, you pick up the data and you see that at four hundred kilopascal or 0.4 MPa you have specific enthalpy specific internal energy for 700°C its go it is given as 3477.9 kilo joule per kg and u cap at 800°C it is going to be 3662.5 kilo joule per kg this is enough for us.

So, we do not need the data any further. So, let us have a look into what to do. So, what is the value now? The value is; so how do you calculate. So, you have the data at 700°C you have the data at 800°C. So, all you have to do is you have to do an interpolation. So, please do understand if the system was at 700°C its value would have been 3479, and had it been at 800°C the specific enthalpy would have been 3662.

Here is a problem many people actually make a mistake. So, we find it at 725. So, many people will do a multiplication of 0.25 into 3477 + 0.75 into 3662 this is wrong. So, the final u I am telling why it is wrong is actually 3477.9 into 0.75 + 3662.5 into 0.25. This is whatever is the; value you just calculate we can do it quickly over here. So, it is 3477.9 into 0.75 + 3662.5 into 0.25 and it turns out I made some mistake because the brackets are not there. So, you can anyway make it.

So, just find out what is what it is that is not very important the numbers I do not have the numbers calculated sorry about it. You can just do it yourself and or I will just do it or whatever you just do it. The important thing to note is it is not 3477.9 into 0.25 that is the important thing because what you are actually doing is you are you know the value at 700°C then you are doing a linear interpolation. So, what is that the value is 3662.5 at 800°C -3477.9 at 700°C divided by

100 and multiplied by 25°C. So, that is what you are doing that is how you get the value at 725°C. It is not that the effect is 25% of what you have at 70 is a 700°C and 75% of what you have at 800°C. If you calculate that I do not know how many of you are; understanding what I am telling this is a very, very common mistake that people do.

So, if you actually and you can think over it not too many teachers will tell you all these things in detail and many people have these wrong concepts you end up getting the u value at 775°C this way please remember the reason for this is u at 775 is actually closer this is a logical way to remember maybe actually closer to the value at 700°C. So, if you use this just 25% of the value of 700°C and 75% of the value of 800°C this is actually closer to 800°C.

So, this is the Lever rule this is actually what is known as the inverse Lever rule and this is from where it comes. So, just fill up the blanks and you will fill up the numbers and you will get the desired value as shown in the ppt.

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Tutorial Sheet for Material & Energy Balance Calculations

- Find the value of internal energy for water (relative to the reference state) for the states indicated:
 - Water at 0.4 MPa, 25°C → For P = 0.4 MPa, T_{sat} = 143.63°C → Go to Super Heat table.
 $\hat{u}_{700^\circ\text{C}} = 3477.9 \text{ kJ/kg}$
 $\hat{u}_{800^\circ\text{C}} = 3662.5 \text{ kJ/kg}$
 $\hat{u} = (3477.9 \times 0.75) + (3662.5 \times 0.25)$
 $= 3570.1 \text{ kJ/kg}$
 - Water at 10 MPa, 110°C → Sp. Volume.
 $\hat{u}_L = 0.001216 \text{ m}^3/\text{kg}$
 $\hat{u}_V = 0.06668 \text{ m}^3/\text{kg}$
 Since \hat{u} lies between \hat{u}_L & \hat{u}_V .
 We have is saturated 2 Phase.
 (mixture of water + steam)
 $x = \text{quality factor (fraction of steam)}$
 $0.01 = (x \times 0.06668) + (1-x) \times 0.001216$
 $\Rightarrow x = 0.134$
 $\hat{u} = 0.134 \times \hat{u}_V + (1-0.134) \times \hat{u}_L$
 - Water at 1.0 MPa, 100°C
 - Water at 10.0 MPa, 100°C
- Steam is used to cool a polymer reaction. The steam in the steam chest of the apparatus is found to be at 250.5°C and 400 kPa absolute during a routine measurement at the beginning of the day. At the end of the day the measurement showed that the temperature was 450°C and the pressure 10,000 kPa absolute. What was the internal energy change of 1 kg of steam in the chest during the day? Obtain your data from the steam tables.
- A closed vessel contains steam at 1000.0 psia in a 4-to-1 vapor-volume-to-liquid volume ratio. What is the steam quality? Given 1 psi = 6.894 kPa
- What is the enthalpy change that takes place when 1 kg of water at 101.3 kPa and 100 K are vaporized to 15,000 kPa and 100 K?

So, what is the next one? Next one is water at 3 MPa and you see what is specified. 3 MPa and the density is given, or the specific volume is given. So, that is very interesting. So, this is problem one this is problem two. So, what we do we again go to the pressure side table and we find out the data for 3MPa. So, for 3 MPa we find these numbers for 3 MPa we find these numbers.

So, just a minute please yeah, we find these numbers what are these numbers for 3 MPa we find V_1 (specific volume of liquid) is $0.001216 \text{ m}^3/\text{kg}$ you can check it in the steam table and V_v is $0.06668 \text{ m}^3/\text{kg}$. So, do you get an idea what is happening, the what is happening is very interesting. You see here only the pressure is specified temperature is not specified. But something else is specified and the specific volume.

Now the value of specific volume that is given to us $0.01 \text{ m}^3/\text{kg}$ lies between these two values you can see that 0.01 lies between these two values. So, what is the conclusion? Conclusion is since specific volume lies between V_1 and V_v what we have saturated two phase or mixture of water and steam. So, how do we go about it we go about it like x is the quality factor let us say x is the quality factor that is the ratio of steam or the fraction I would say ratio sorry about it fraction of steam.

So, what it means what it means is 0.01 is equal to x into $0.0668 + 1 - x$ into 0.001216 and if you solve for it you will get x equal to 0.134 . So, your final u will be 0.134 into specific volume of liquid + $1 - 0.134$ into specific volume of vapour and you can calculate it. You can from 3 MPa pressure table find out the specific volume of liquid and the vapour which are given here you have a copy of the steam table.

So, there should not be any problem it is these two numbers and you can find them out. So, this much amount I do expect from all of you to do. So, next we move on to the third problem may be the last problem we take up in today's class its better we go a little slow which is perfectly fine.

(Refer Slide Time: 26:37)

Tutorial Sheet for Material & Energy Balance Calculations

- Find the value of internal energy for water (relative to the reference state) for the states indicated:
 - a. Water at 0.4 MPa, 725 °C
 - b. Water at 1.0 MPa, 0.01 m³/kg
 - c. Water at 1.0 MPa, 100 °C
 - d. Water at 10.0 MPa, 100 °C → Subcooled Liq.
- Steam is used to cool a polymer reaction. The steam in the steam chest of the apparatus is found to be at 250.1 °C and 4000 kPa absolute during a routine measurement at the beginning of the day. At the end of the day the measurement showed that the temperature was 650 °C and the pressure 10,000 kPa absolute. What was the internal energy change of 1 kg of steam in the chest during the day? Obtain your data from the steam tables.
- A closed vessel contains steam at 1000.0 psia in a 4-to-1 vapor-volume-to-liquid volume ratio. What is the steam quality? Given 1 psi = 6.894 kPa
- What is the enthalpy change that takes place when 1 kg of water at 101.3 kPa and 100 °C are vaporized to 15,000 kPa and 100 °C?

Handwritten notes:
 Water at 10 MPa
 Saturation Temp = 311.06°C
 u = 416.09 kJ/kg

P = 10 MPa				
T	v	u	h	s
°C	m ³ /kg	kJ/kg	kJ/kg	kJ/kg K
0	0.00082	0.30	10.07	0.0003
10	0.00072	63.39	16.22	0.0245
40	0.00054	185.53	276.29	0.6065
60	0.00047	249.54	295.47	0.8229
80	0.00040	309.94	314.53	1.0087
100	0.00033	416.09	333.49	1.2592
120	0.00028	509.91	352.41	1.5106
140	0.00023	594.47	370.40	1.7201
160	0.00019	670.11	387.67	1.9114
180	0.00016	739.43	404.22	2.0774
200	0.00014	804.43	420.07	2.2179
220	0.00012	866.47	435.26	2.3359
240	0.00011	925.94	450.13	2.4372
260	0.00010	983.43	464.89	2.5259
280	0.00009	1038.43	479.55	2.6059
300	0.00008	1091.43	493.11	2.6787
320	0.00007	1142.94	505.54	2.7459

And so, what is the third problem we have let us pick up the fourth problem first water at 10 MPa and 100°C. The third one you can do yourself, but I will show probably. So, water at 10 MPa. So, we first go to the pressure table we go to the pressure table and see the 10MPa the boiling point or the saturation temperature is 311.06°C. So, saturation temperature, so, what is the conclusion?

Conclusion is this water is sub cooled liquid. So, if it is sub cool liquid then what we should do we should see or we should go to the sub cool liquid table and which is the table B5 and we find that the pressure here is adequately high and for 10 MPa of course some data is given. So, we pick it up and which is now becomes very simple. So, we just look into the data this is the sub cooled water data and for 10 MPa what we have is the temperature is 100°C. So, you straight away get the specific internal energy.

So, specific internal energy in this particular case is 416.09 kilo joule per kg. This one I request all of you to try and we pick up the next set of problems in the next class. Thank you very much for your attention.