Basics of Mechanical Engineering-3

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Week 04

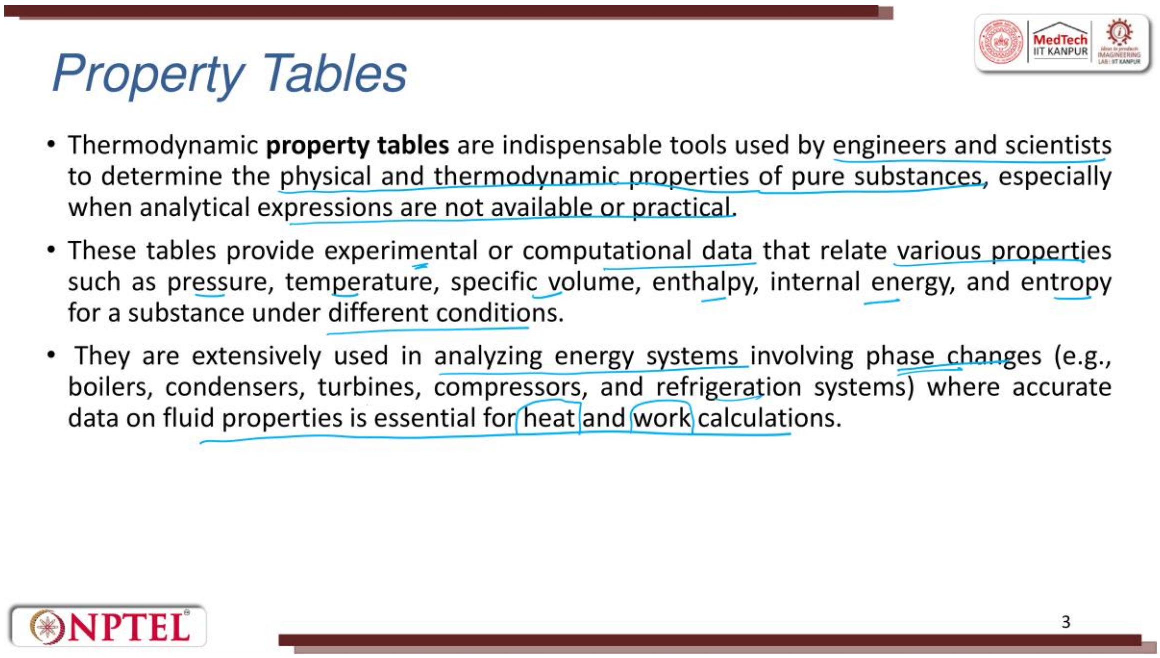
Lecture 18: Property Tables

Welcome to the next lecture of this course Property Table. In the last lecture, we learned about the different phases of a pure substance. Then we saw a PV diagram. Then we saw a PT diagram. Then we saw a VT diagram.

Then we saw a PVT diagram. Then we understood the need for a PV diagram. And then we moved on to defining specific volume. We discussed enthalpy. And then we also learned about supercritical fluids.

So these were the topics we covered in the last lecture. In this lecture, we will try to cover a very important topic, which is psychrometric charts or psychrometric tables. So we will see that. So that is very important. This is very useful while designing a system for specific requirements.

So these are the topics which we will cover in this lecture. All these topics are very important because you will have to understand each one of them. And then, while solving a problem in the examination, you have to extract it from the table and then solve the problem. However, in the examination, we will extract the values from the table and give them to you because it is an objective type. But in real time, you will have to go through the chart.



Thermodynamic Property Table. It is an indispensable tool used by engineers and scientists to determine the physical and thermodynamic properties of pure substances, especially when analytical expressions are not available or practical. These tables, the property tables, provide experimental or computational data that reveal various properties such as pressure, temperature, specific volume, enthalpy, internal energy, and entropy of a substance under various conditions or different conditions. So, what is this property table going to give? This is going to give me a relationship between P, T, specific volume, enthalpy H, internal energy U, and entropy S. So there is a relationship between all of them.

These relationships, if you can plot them in 2D, are between two variables. If you plot them in 3D, you get much more information. And it is also going to tell me under various conditions, not only at pressure at 1 atmosphere, it can talk about 10 atmospheres, it can talk about 0.1 atmosphere, temperatures: 100 degrees Celsius, 0 degrees, minus 273 degrees Celsius—all these things it can talk about. They are extensively used in analyzing energy systems involving phase changes. For example, in boilers, what we do is change from liquid to steam.

Condenser, from steam to liquid. Turbine, where the pressure and temperature are lost. Compressor, where the pressure is increased, and temperature can increase or remain constant. Refrigeration, where it can suck out the hot air and blow in cold air. So, in all these things, these property tables will be used, where accurate data of fluid properties is essential for heat and work calculations.

Finally, friends, we will have to find out what is the heat you apply and what is the work you do. This is what you have been seeing in heat pumps and heat engines. So, apply heat, extract work, or apply work, extract heat. For this calculation, you need to have all these parameters: P, T, specific volume, enthalpy, internal energy, and entropy. All these values are required so that we can try to find out the efficiency of a system.

Property Tables

- The most commonly used property tables are:

1. *Saturated Properties Table:*

Lists properties of saturated liquid (subscript f) and saturated vapor (subscript g) at specific temperatures or pressures.

Useful when a substance exists in a two-phase mixture (liquid + vapor).

Includes:

$$T, P_{sat}, v_f, v_g, h_f, h_g, s_f, s_g$$

Also includes difference terms:

$$h_{fg} = h_g - h_f, v_{fg} = v_g - v_f, s_{fg} = s_g$$

Property Tables

- *Saturated Properties Table*

Saturated water—Temperature table

		Specific volume, m³/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K		
Temp., T °C	Sat. press., P_{sat} kPa	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556	9.1556
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.0249
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7803
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696	8.6661
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5	0.3672	8.1895	8.5567
30	4.2469	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6	0.4368	8.0152	8.4520
35	5.6291	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6	0.5051	7.8466	8.3517
40	7.3851	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5	0.5724	7.6832	8.2556
45	9.5953	0.001010	15.251	188.43	2247.7	2436.1	188.44	2394.0	2582.4	0.6386	7.5247	8.1633
50	12.352	0.001012	12.026	209.33	2233.4	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
55	15.763	0.001015	9.5639	230.24	2219.1	2449.3	230.26	2369.8	2600.1	0.7680	7.2218	7.9898
60	19.947	0.001017	7.6670	251.16	2204.7	2455.9	251.18	2357.7	2608.8	0.8313	7.0769	7.9082
65	25.043	0.001020	6.1935	272.09	2190.3	2462.4	272.12	2345.4	2617.5	0.8937	6.9360	7.8296
70	31.202	0.001023	5.0396	293.04	2175.8	2468.9	293.07	2333.0	2626.1	0.9551	6.7989	7.7540
75	38.597	0.001026	4.1291	313.99	2161.3	2475.3	314.03	2320.6	2634.6	1.0158	6.6655	7.6812
80	47.416	0.001029	3.4053	334.97	2146.6	2481.6	335.02	2308.0	2643.0	1.0756	6.5355	7.6111
85	57.868	0.001032	2.8261	355.96	2131.9	2487.8	356.02	2295.3	2651.4	1.1346	6.4089	7.5435
90	70.183	0.001036	2.3593	376.97	2117.0	2494.0	377.04	2282.5	2659.6	1.1929	6.2853	7.4782
95	84.609	0.001040	1.9808	398.00	2102.0	2500.1	398.09	2269.6	2667.6	1.2504	6.1647	7.4151
100	101.42	0.001043	1.6720	419.06	2087.0	2506.0	419.17	2256.4	2675.6	1.3072	6.0470	7.3542
105	120.90	0.001047	1.4186	440.15	2071.8	2511.9	440.28	2243.1	2683.4	1.3634	5.9319	7.2952
110	143.38	0.001052	1.2094	461.27	2056.4	2517.7	461.42	2229.7	2691.1	1.4188	5.8193	7.2382
115	169.18	0.001056	1.0360	482.42	2040.9	2523.3	482.59	2216.0	2698.6	1.4737	5.7092	7.1829
120	198.67	0.001060	0.89133	503.60	2025.3	2528.9	503.81	2202.1	2706.0	1.5279	5.6013	7.1292

https://www.researchgate.net/figure/Saturated-Water-Properties-as-a-Function-of-Temperature_tbl1_372515853

The most commonly used property tables are saturated properties tables. The lists properties of saturated liquid (suffix f) and saturated vapor (suffix g) at specific temperature or pressure. Useful when a substance coexists in two phases. When you are talking to a fluid expert or a thermal expert, He says single-phase, two-phase flow, and three-phase flow.

If you try to look at examples, single-phase means it is one fluid; it can be fully solid, fully liquid, or fully gas—single-phase, right? When you have two phases, water and air, steam and liquid, whatever it is, that is called two-phase, right? When we talk about three-phase, it will be air, water, and one more substance, or it can be three different fluids or three different states of a single thing. So, these things are called three-phase. Single-phase is very easy to solve the problem.

Generally, we convert three-phase into two-phase or two-phase into single-phase and try to solve the problem to understand the system. So, useful when substances exist in two phases, when it comes out of a boiler—liquid plus steam, liquid plus vapor—which includes temperature, p saturation, v saturated fluid. v saturated vapor, then hf is enthalpy, which is liquid. This is enthalpy in vapor. S is entropy for a liquid, entropy for a gas, which also includes terms like $hfg = hg - hf, vfg = vg - vf, sfg = sg - sf$.

So, this are the useful properties which you can extract from the table. So if you look at a typical table, it is like this. And friends, today there are so many softwares where in which you can try to just give some of the properties and get the further responses, whatever it is. So if you look at it, water at 45 degrees Celsius, we'll just discuss one point. Water at 45 degrees Celsius, saturation pressure will be around about 9.59 kPa.

The liquid saturation will happen will be at around about 0.0010. Then the saturation of vapor will be at 15.25 meter cube per kg for this units is given your specific volume. So then internal energy you will try to have is 188.43. Then the vapor will be 2247.7 and saturated vapor can be this. So all this internal energy will be represented as kilojoule per kg.

Units are very important because while solving the problem, you might have to convert. 10 to the power 3, 10 to the power minus 3. In the examination, there can be objective question where we can have something like this answer 1.0.01 or it can be 1.0.0 or it can be 0.001. So if you see the answer somewhere, it is 1 into 10 to the power minus whatever it is. So, you have to know the conversions properly.

Please keep that in mind. And there can be a factor multiplied by 10 while doing the unit conversion. Please take care of that. Then, enthalpy will be kilojoule per kg. So, internal energy is kilojoule per kg.

Enthalpy is also in kilojoules per kg. Keep that in mind. The units are the same. So here you will have 188.43, and then it is 2247—it is approximately the same. It is 2582; it is 2431—approximately the same with some approximation.

So it is very close. So enthalpy and internal energy values are very close. When we talk about entropy, you will see that you will have 0.063, 7.5, and 8.1 for saturated liquid Sf, saturated vapor Sfg, and then saturated vapor Sg—you will have these values. So here, if you see, the intermediate form is the two-phase flow. When in the problem examination, we give a two-phase flow, you are supposed to take this value.

But friends, this table will be converted into a unit, and we will give you the units directly for you to solve. We can give you more values, but you might ask, for example, I will give you for water—all these things are there. All these values I will give you in a table form and ask you to extract exactly what is required for you to solve the problem, and then you can solve.

Property Tables

2. Superheated Vapor Tables:

- Provide properties of vapor at temperatures above the saturation temperature for a given pressure. They are often referred to as Steam Tables.
- Used when steam or other vapor behaves like a gas.
- Typical entries: T, P, v, u, h, s

3. Compressed (Subcooled) Liquid Tables:

- Provide data for liquids **below the saturation temperature** at a given pressure.
- Often approximated by using saturated liquid values at the same temperature when data is scarce.

Superheated Table (PC Model), Nitrogen (N2)

K	m³/kg	kJ/kg	kJ/kg	kJ/kg·K	m³/kg	kJ/kg	kJ/kg	kJ/kg·K	m³/kg	kJ/kg	kJ/kg	kJ/kg·K
T	p = 0.10 MPa (T_{sat} = 77.24 K)				p = 0.20 MPa (T_{sat} = 83.62 K)				p = 0.50 MPa (T_{sat} = 93.98 K)			
	v	u	h	s	v	u	h	s	v	u	h	s
Sat.	0.21903	54.707	76.61	5.4059	0.11520	58.010	81.05	5.2673	0.04834	61.980	86.15	5.0802
100	0.29103	72.837	101.94	5.6944	0.14252	71.736	100.24	5.4775	0.05306	67.930	94.46	5.1660
120	0.35208	87.942	123.15	5.8878	0.17397	87.136	121.93	5.6753	0.06701	84.615	118.12	5.3821
140	0.41253	102.947	144.20	6.0501	0.20476	102.328	143.28	5.8399	0.08007	100.405	140.44	5.5541
160	0.47263	117.907	165.17	6.1901	0.23519	117.402	164.44	5.9812	0.09272	115.860	162.22	5.6996

https://energy.sdsu.edu/testhome/tablesModule/tablesPC/superN2.html

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Property Tables

- **Compressed Liquid Approximations:**

$$h_{subcooled} \approx h_{f@T,} u_{subcooled} \approx u_{f@T,} v_{subcooled} \approx v_{f@T}$$

This is accurate at low pressures and small temperature differences from saturation.

Compressed liquid water

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
	P = 5 MPa (263.94°C)				P = 10 MPa (311.00°C)				P = 15 MPa (342.16°C)			
Sat.	0.0012862	1148.1	1154.5	2.9207	0.0014522	1393.3	1407.9	3.3603	0.0016572	1585.5	1610.3	3.6848
0	0.0009977	0.04	5.03	0.0001	0.0009952	0.12	10.07	0.0003	0.0009928	0.18	15.07	0.0004
20	0.0009996	83.61	88.61	0.2954	0.0009973	83.31	93.28	0.2943	0.0009951	83.01	97.93	0.2932
40	0.0010057	166.92	171.95	0.5705	0.0010035	166.33	176.37	0.5685	0.0010013	165.75	180.77	0.5666
60	0.0010149	250.29	255.36	0.8287	0.0010127	249.43	259.55	0.8260	0.0010105	248.58	263.74	0.8234
80	0.0010267	333.82	338.96	1.0723	0.0010244	332.69	342.94	1.0691	0.0010221	331.59	346.92	1.0659
100	0.0010410	417.65	422.85	1.3034	0.0010385	416.23	426.62	1.2996	0.0010361	414.85	430.39	1.2958
120	0.0010576	501.91	507.19	1.5236	0.0010549	500.18	510.73	1.5191	0.0010522	498.50	514.28	1.5148
140	0.0010769	586.80	592.18	1.7344	0.0010738	584.72	595.45	1.7293	0.0010708	582.69	598.75	1.7243
160	0.0010988	672.55	678.04	1.9374	0.0010954	670.06	681.01	1.9316	0.0010920	667.63	684.01	1.9259
180	0.0011240	759.47	765.09	2.1338	0.0011200	756.48	767.68	2.1271	0.0011160	753.58	770.32	2.1206
200	0.0011531	847.92	853.68	2.3251	0.0011482	844.32	855.80	2.3174	0.0011435	840.84	858.00	2.3100
220	0.0011868	938.39	944.32	2.5127	0.0011809	934.01	945.82	2.5037	0.0011752	929.81	947.43	2.4951
240	0.0012268	1031.6	1037.7	2.6983	0.0012192	1026.2	1038.3	2.6876	0.0012121	1021.0	1039.2	2.6774
260	0.0012755	1128.5	1134.9	2.8841	0.0012653	1121.6	1134.3	2.8710	0.0012560	1115.1	1134.0	2.8586
280					0.0013226	1221.8	1235.0	3.0565	0.0013096	1213.4	1233.0	3.0410
300					0.0013980	1329.4	1343.3	3.2488	0.0013783	1317.6	1338.3	3.2279
320									0.0014733	1431.9	1454.0	3.4263
340									0.0016311	1567.9	1592.4	3.6555
	P = 20 MPa (365.75°C)				P = 30 MPa				P = 50 MPa			
Sat.	0.0020378	1785.8	1826.6	4.0146								

https://coecs.ou.edu/Feng.Chyuan.Lai/thermoweb/Tables/A7/tablea7.htm

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The next property is the superheated vapor table. So the property—first, what did we see? It is the saturated property. We saw the saturated properties table—we saw it.

Next is the superheated vapor tables. It provides properties of vapor at temperatures above the saturated temperature for a given pressure. They are often referred to as steam tables. Like the periodic table, you have a steam table. So look at it.

It provides properties of vapor at temperatures above the saturation temperature for a given pressure. Used when steam or other vapor behaves like a gas. So they typically have entries like T, P, v, u, h, and s. The same thing: temperature, pressure, specific volume, internal energy, enthalpy, and entropy. The superheated vapor table is the compressed liquid table, which is otherwise called a subcooled liquid table, providing data for liquid below the saturation temperature at a given pressure. Above the saturation temperature is the superheated vapor table.

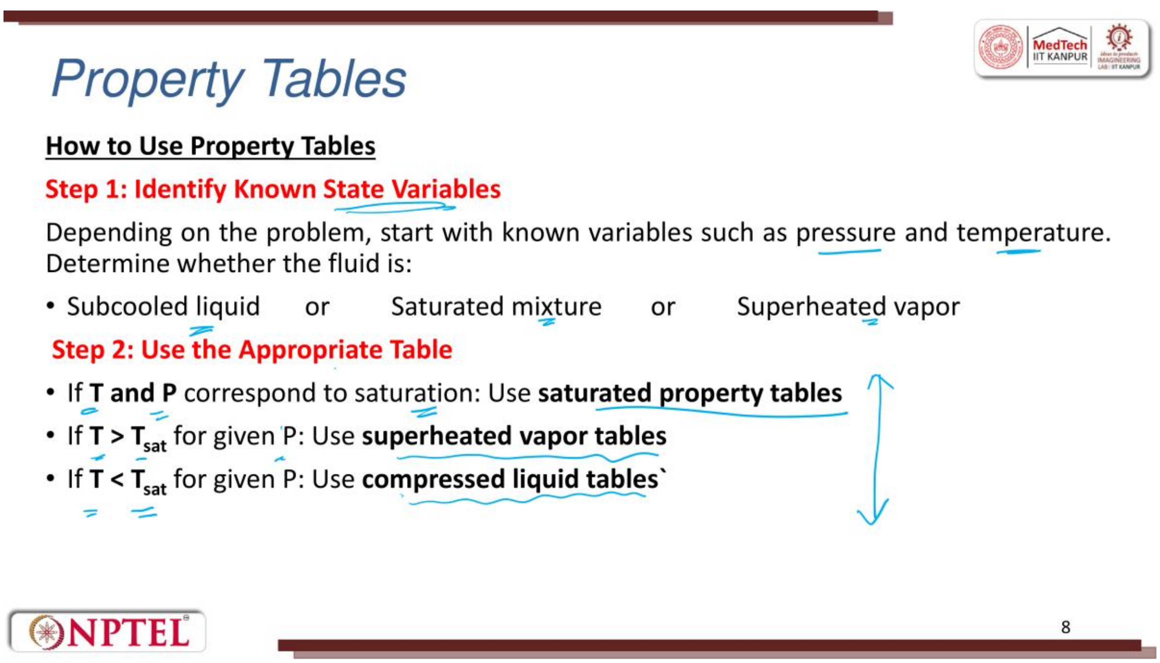
Below the saturation temperature is the compressed liquid table. Below the saturation: superheated and subcooled. So often approximated by using saturated liquid values at the same temperature when the data is scarce. So when the data is not available for a particular fluid, then you can use this. So the same table is given here very clearly.

So then it is compressed liquid approximation. What is compressed liquid approximation? Compressed liquid approximation is below the saturation temperature at a given pressure. So this was above the saturation temperature. So the values are given where saturation temperature is given, then v, u, h, s. Here we have when pressures are constant: P = 5 MPa, P = 10 MPa, P = 15 MPa.

You can see how the values change for a liquid. So, it is given. So, this is given for water. You can see this is given only for 5, 10, and 15. So, when you are trying to develop a system and then you are trying to see with a pressure what the values are, you can try to get it from this table.

So, h subcooled is approximated to hf at the rate of T, unsubcooled which is approximated to uf at the rate T, v subcooled which is equal to vf at the rate of T. So, this is the approximation which is used. This is accurate at low pressures and small temperature differences from saturation. We hold this equation. h cool, h subcooled, what is it? Enthalpy.

So, F at the rate of T, it is under subcooled. So, it is u, internal energy subcooled. Then it is v, subcooled, and vapor is formed.



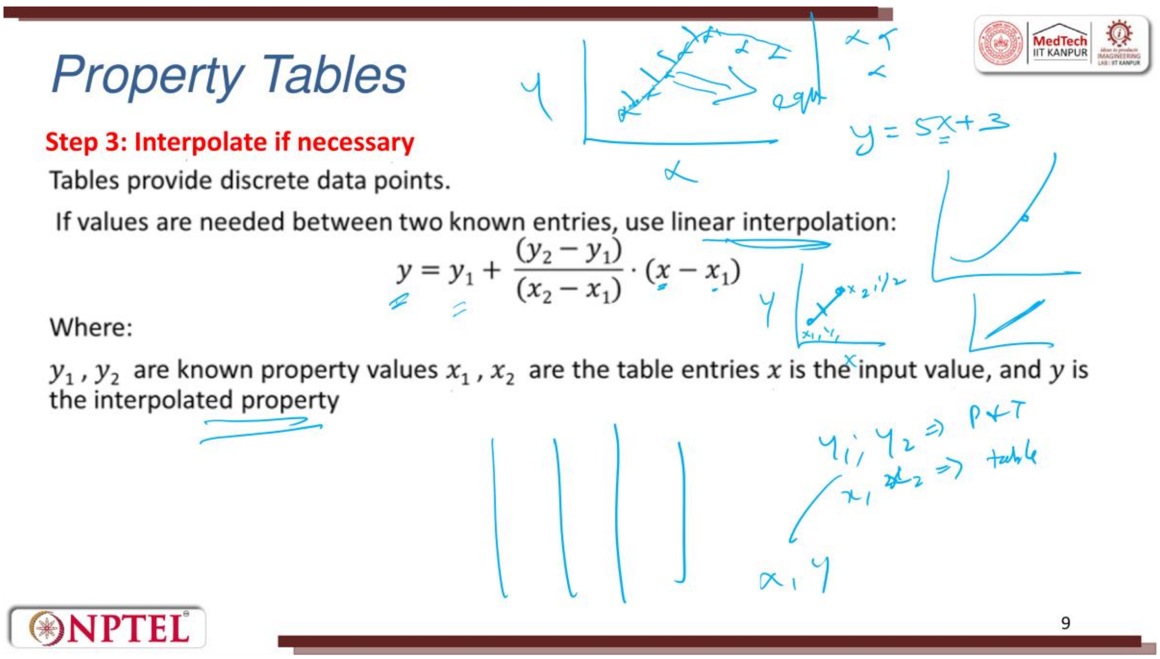
How to use a property table? We have seen the table now, but now we will see how to use the table. Step one is to identify known state variables. Friends, you would have gone through what a state variable is. So, identify known state variables. Depending on the problem, start with known variables such as pressure and temperature. Why are we saying known variables, pressure and temperature?

Because these two are easy to measure; enthalpy, entropy, these are all difficult to measure. So, pressure and temperature are straightforward; you put a gauge and measure it. So, depending on the problem, start with the known variables such as pressure and temperature. Determine whether the fluid is subcooled, a saturated mixture, or superheated vapor. You see subcooled liquid, saturated mixture, and superheated vapor. So, this we saw here.

Superheated vapor, subcooled liquid table, and saturated mixture. We said the first table. So now, step 2 is going to be using the appropriate table. If T and P correspond to saturation, use the saturated property table. If T is greater than T saturation for a given P, then use the superheated vapor table.

If T saturated is more than T for a given P, then use the compressed liquid table. So these are the three things which you should remember. If T and P correspond to saturation, saturation means up to the brim. Now you can have at the top, at the bottom, up to the brim. So you use the saturated property table. Superheated, go up.

Then you use a superheated vapor table where T is greater than T saturation. When T is less than T saturation, then go for the compressed liquid table. So then, what have you done? First, you have identified the states, then you have determined the fluid, whatever is there. Then you have taken the appropriate table. From the table, you have extracted data.



So, interpolate if necessary. See if you have a y-axis and an x-axis, and you have points like this. So, you try to draw a straight line, something like this, and now you have an equation for this line. Now, if you want to find intermediate points, that is called interpolation.

For example, y equals 5x + 3—you have found some equation. Now, what will you do? You will try to substitute various x-values and try to get the values of y. That is called interpolation. The other extreme end is I have data points outside the line. Now, if I wanted to do interpolation or talk about this, it is called extrapolation, which is outside these data points. My equation is valuable only to, or valid only for, the points I have considered.

This is called interpolation—intermediate points where the equation is applied. Extrapolation is generally something we try to avoid. Interpolate if necessary. Tables provide discrete data points. If I want to make it continuous, then what I do is linear interpolation.

Friends, you might have exponential data points or equations. What we do is, we convert this exponential into a linear form so that we can try to do the interpolation easily. There will be approximations, right? So, if values are needed between two entities, because in a table, what you get are discrete values. So, discrete values are here.

So, now I want to get small values in between. So, if values are needed between two known entities, use linear interpolation. In linear interpolation, we write it as

$$y = y_1 + \frac{(y_2 - y_1)}{(x_2 - x_1)} \cdot (x - x_1)$$

So finally, what you get is a point called y. So now from y, you can try to find out x also. So where y1, y2 are known property values, x1, x2 are the table entries data. And y1, y2 are the property values which are known property values which are done.

Table x is the input value, and y is the interpolated property. So it is very clear now. You see, y1 and y2 are known properties. So that is with respect to P and T. And x1, x2 are taken from tables. So now, you try to find out x and y in the third step. So, with these three steps, you try to figure out the values and solve.

And thank you very much.