

# Thermodynamics

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## Lecture 72

## Entropy Part 2

We will see how to find out entropy values of steam in a steam table.

(Refer Slide Time: 00:41)

Properties of Saturated Steam - Pressure Table									
Pressure	Temp.	Volume (lit/kg)	Specific Volume (m <sup>3</sup> /kg)	Enthalpy (kJ/kg)	Entropy (kJ/kgK)	Quality Factor	Enthalpy (kJ/kg)	Entropy (kJ/kgK)	Quality Factor
MPa	°C	v <sub>g</sub>	v <sub>f</sub>	h <sub>g</sub>	s <sub>g</sub>	x	h <sub>f</sub>	s <sub>f</sub>	x
0.01	5	0.000001	192.1	208.8	0.701	0.9999	0.0000	0.0000	0.0000
0.02	7	0.000001	187.7	208.2	0.702	0.9999	0.0000	0.0000	0.0000
0.03	9	0.000001	183.7	207.7	0.703	0.9999	0.0000	0.0000	0.0000
0.04	11	0.000001	180.1	207.3	0.704	0.9999	0.0000	0.0000	0.0000
0.05	13	0.000001	176.8	207.0	0.705	0.9999	0.0000	0.0000	0.0000
0.06	15	0.000001	173.8	206.7	0.706	0.9999	0.0000	0.0000	0.0000
0.07	17	0.000001	171.0	206.5	0.707	0.9999	0.0000	0.0000	0.0000
0.08	19	0.000001	168.4	206.3	0.708	0.9999	0.0000	0.0000	0.0000
0.09	21	0.000001	166.0	206.2	0.709	0.9999	0.0000	0.0000	0.0000
0.10	23	0.000001	163.8	206.1	0.710	0.9999	0.0000	0.0000	0.0000
0.12	27	0.000001	158.8	205.9	0.712	0.9999	0.0000	0.0000	0.0000
0.15	33	0.000001	151.9	205.7	0.715	0.9999	0.0000	0.0000	0.0000
0.20	41	0.000001	138.0	205.4	0.719	0.9999	0.0000	0.0000	0.0000
0.30	51	0.000001	110.2	205.0	0.725	0.9999	0.0000	0.0000	0.0000
0.40	61	0.000001	90.4	204.7	0.730	0.9999	0.0000	0.0000	0.0000
0.50	71	0.000001	76.7	204.5	0.734	0.9999	0.0000	0.0000	0.0000
0.60	81	0.000001	66.2	204.4	0.737	0.9999	0.0000	0.0000	0.0000
0.70	91	0.000001	58.0	204.3	0.740	0.9999	0.0000	0.0000	0.0000
0.80	101	0.000001	51.1	204.3	0.742	0.9999	0.0000	0.0000	0.0000
0.90	111	0.000001	45.2	204.3	0.744	0.9999	0.0000	0.0000	0.0000
1.00	121	0.000001	40.1	204.3	0.745	0.9999	0.0000	0.0000	0.0000
1.20	141	0.000001	32.5	204.3	0.747	0.9999	0.0000	0.0000	0.0000
1.50	171	0.000001	22.0	204.3	0.750	0.9999	0.0000	0.0000	0.0000
2.00	211	0.000001	13.2	204.3	0.753	0.9999	0.0000	0.0000	0.0000
3.00	271	0.000001	6.1	204.3	0.756	0.9999	0.0000	0.0000	0.0000
4.00	331	0.000001	3.6	204.3	0.757	0.9999	0.0000	0.0000	0.0000
5.00	391	0.000001	2.3	204.3	0.758	0.9999	0.0000	0.0000	0.0000
6.00	451	0.000001	1.6	204.3	0.759	0.9999	0.0000	0.0000	0.0000
7.00	511	0.000001	1.2	204.3	0.760	0.9999	0.0000	0.0000	0.0000
8.00	571	0.000001	0.9	204.3	0.761	0.9999	0.0000	0.0000	0.0000
9.00	631	0.000001	0.7	204.3	0.762	0.9999	0.0000	0.0000	0.0000
10.00	691	0.000001	0.5	204.3	0.763	0.9999	0.0000	0.0000	0.0000
12.00	811	0.000001	0.3	204.3	0.764	0.9999	0.0000	0.0000	0.0000
15.00	1011	0.000001	0.1	204.3	0.765	0.9999	0.0000	0.0000	0.0000
20.00	1411	0.000001	0.0	204.3	0.766	0.9999	0.0000	0.0000	0.0000
30.00	2111	0.000001	0.0	204.3	0.767	0.9999	0.0000	0.0000	0.0000
40.00	2911	0.000001	0.0	204.3	0.768	0.9999	0.0000	0.0000	0.0000
50.00	3711	0.000001	0.0	204.3	0.769	0.9999	0.0000	0.0000	0.0000
60.00	4511	0.000001	0.0	204.3	0.770	0.9999	0.0000	0.0000	0.0000
70.00	5311	0.000001	0.0	204.3	0.771	0.9999	0.0000	0.0000	0.0000
80.00	6111	0.000001	0.0	204.3	0.772	0.9999	0.0000	0.0000	0.0000
90.00	6911	0.000001	0.0	204.3	0.773	0.9999	0.0000	0.0000	0.0000
100.00	7711	0.000001	0.0	204.3	0.774	0.9999	0.0000	0.0000	0.0000
120.00	9111	0.000001	0.0	204.3	0.775	0.9999	0.0000	0.0000	0.0000
150.00	1111	0.000001	0.0	204.3	0.776	0.9999	0.0000	0.0000	0.0000
200.00	1511	0.000001	0.0	204.3	0.777	0.9999	0.0000	0.0000	0.0000
300.00	2211	0.000001	0.0	204.3	0.778	0.9999	0.0000	0.0000	0.0000
400.00	2911	0.000001	0.0	204.3	0.779	0.9999	0.0000	0.0000	0.0000
500.00	3611	0.000001	0.0	204.3	0.780	0.9999	0.0000	0.0000	0.0000
600.00	4311	0.000001	0.0	204.3	0.781	0.9999	0.0000	0.0000	0.0000
700.00	5011	0.000001	0.0	204.3	0.782	0.9999	0.0000	0.0000	0.0000
800.00	5711	0.000001	0.0	204.3	0.783	0.9999	0.0000	0.0000	0.0000
900.00	6411	0.000001	0.0	204.3	0.784	0.9999	0.0000	0.0000	0.0000
1000.00	7111	0.000001	0.0	204.3	0.785	0.9999	0.0000	0.0000	0.0000



Figure 1.

Properties of Saturated Steam - Temperature Table									
Temp.	Pressure	Volume (lit/kg)	Specific Volume (m <sup>3</sup> /kg)	Enthalpy (kJ/kg)	Entropy (kJ/kgK)	Quality Factor	Enthalpy (kJ/kg)	Entropy (kJ/kgK)	Quality Factor
°C	MPa	v <sub>g</sub>	v <sub>f</sub>	h <sub>g</sub>	s <sub>g</sub>	x	h <sub>f</sub>	s <sub>f</sub>	x
5	0.01	0.000001	192.1	208.8	0.701	0.9999	0.0000	0.0000	0.0000
7	0.02	0.000001	187.7	208.2	0.702	0.9999	0.0000	0.0000	0.0000
9	0.03	0.000001	183.7	207.7	0.703	0.9999	0.0000	0.0000	0.0000
11	0.04	0.000001	180.1	207.3	0.704	0.9999	0.0000	0.0000	0.0000
13	0.05	0.000001	176.8	207.0	0.705	0.9999	0.0000	0.0000	0.0000
15	0.06	0.000001	173.8	206.7	0.706	0.9999	0.0000	0.0000	0.0000
17	0.07	0.000001	171.0	206.5	0.707	0.9999	0.0000	0.0000	0.0000
19	0.08	0.000001	168.4	206.3	0.708	0.9999	0.0000	0.0000	0.0000
21	0.09	0.000001	166.0	206.2	0.709	0.9999	0.0000	0.0000	0.0000
23	0.10	0.000001	163.8	206.1	0.710	0.9999	0.0000	0.0000	0.0000
27	0.12	0.000001	158.8	205.9	0.712	0.9999	0.0000	0.0000	0.0000
33	0.15	0.000001	151.9	205.7	0.715	0.9999	0.0000	0.0000	0.0000
41	0.20	0.000001	138.0	205.4	0.719	0.9999	0.0000	0.0000	0.0000
51	0.30	0.000001	110.2	205.0	0.725	0.9999	0.0000	0.0000	0.0000
61	0.40	0.000001	90.4	204.7	0.730	0.9999	0.0000	0.0000	0.0000
71	0.50	0.000001	76.7	204.5	0.734	0.9999	0.0000	0.0000	0.0000
81	0.60	0.000001	66.2	204.4	0.737	0.9999	0.0000	0.0000	0.0000
91	0.70	0.000001	58.0	204.3	0.740	0.9999	0.0000	0.0000	0.0000
101	0.80	0.000001	51.1	204.3	0.742	0.9999	0.0000	0.0000	0.0000
111	0.90	0.000001	45.2	204.3	0.744	0.9999	0.0000	0.0000	0.0000
121	1.00	0.000001	40.1	204.3	0.745	0.9999	0.0000	0.0000	0.0000
141	1.20	0.000001	32.5	204.3	0.747	0.9999	0.0000	0.0000	0.0000
171	1.50	0.000001	22.0	204.3	0.750	0.9999	0.0000	0.0000	0.0000
211	2.00	0.000001	13.2	204.3	0.753	0.9999	0.0000	0.0000	0.0000
271	3.00	0.000001	6.1	204.3	0.756	0.9999	0.0000	0.0000	0.0000
331	4.00	0.000001	3.6	204.3	0.757	0.9999	0.0000	0.0000	0.0000
391	5.00	0.000001	2.3	204.3	0.758	0.9999	0.0000	0.0000	0.0000
451	6.00	0.000001	1.6	204.3	0.759	0.9999	0.0000	0.0000	0.0000
511	7.00	0.000001	1.2	204.3	0.760	0.9999	0.0000	0.0000	0.0000
571	8.00	0.000001	0.9	204.3	0.761	0.9999	0.0000	0.0000	0.0000
631	9.00	0.000001	0.7	204.3	0.762	0.9999	0.0000	0.0000	0.0000
691	10.00	0.000001	0.5	204.3	0.763	0.9999	0.0000	0.0000	0.0000
771	12.00	0.000001	0.3	204.3	0.764	0.9999	0.0000	0.0000	0.0000
911	15.00	0.000001	0.1	204.3	0.765	0.9999	0.0000	0.0000	0.0000
1111	20.00	0.000001	0.0	204.3	0.766	0.9999	0.0000	0.0000	0.0000
1311	30.00	0.000001	0.0	204.3	0.767	0.9999	0.0000	0.0000	0.0000
1511	40.00	0.000001	0.0	204.3	0.768	0.9999	0.0000	0.0000	0.0000
1711	50.00	0.000001	0.0	204.3	0.769	0.9999	0.0000	0.0000	0.0000
1911	60.00	0.000001	0.0	204.3	0.770	0.9999	0.0000	0.0000	0.0000
2111	70.00	0.000001	0.0	204.3	0.771	0.9999	0.0000	0.0000	0.0000
2311	80.00	0.000001	0.0	204.3	0.772	0.9999	0.0000	0.0000	0.0000
2511	90.00	0.000001	0.0	204.3	0.773	0.9999	0.0000	0.0000	0.0000
2711	100.00	0.000001	0.0	204.3	0.774	0.9999	0.0000	0.0000	0.0000
2911	120.00	0.000001	0.0	204.3	0.775	0.9999	0.0000	0.0000	0.0000
3111	150.00	0.000001	0.0	204.3	0.776	0.9999	0.0000	0.0000	0.0000
3311	200.00	0.000001	0.0	204.3	0.777	0.9999	0.0000	0.0000	0.0000
3511	300.00	0.000001	0.0	204.3	0.778	0.9999	0.0000	0.0000	0.0000
3711	400.00	0.000001	0.0	204.3	0.779	0.9999	0.0000	0.0000	0.0000
3911	500.00	0.000001	0.0	204.3	0.780	0.9999	0.0000	0.0000	0.0000
4111	600.00	0.000001	0.0	204.3	0.781	0.9999	0.0000	0.0000	0.0000
4311	700.00	0.000001	0.0	204.3	0.782	0.9999	0.0000	0.0000	0.0000
4511	800.00	0.000001	0.0	204.3	0.783</				

We know how to find enthalpy, specific volume and internal energy of steam-water mixture and superheated steam using steam tables. However, we have not yet read values of entropy from the steam tables. Figure 1 shows a snippet of steam table. The last three columns list entropy of the saturated liquid ( $s_f$ ), entropy difference between saturated liquid and saturated vapor ( $s_{fg}$ ) and entropy of the saturated vapor ( $s_g$ ). For example, at 0.1 MPa, the entropy value of the saturated liquid  $s_f = 1.3028 \frac{kJ}{kg \cdot K}$ , the entropy value of the saturated vapor  $s_g = 7.3588 \frac{kJ}{kg \cdot K}$  and the difference between  $s_f$  and  $s_g$ , i.e.,  $s_{fg} = 6.056 \frac{kJ}{kg \cdot K}$ . Students are encouraged to find values of entropy at different conditions for the sake of practice. Also, the entropy of a steam-water mixture can be found out in the same usual way as we did for the other properties.  $s_{mixture} = s_f + x(s_g - s_f) = s_f + xs_{fg}$ , where  $x$  is the quality of the steam-water mixture. All the properties are calculated with respect to some datum values which can be found in a steam table. Some steam tables consider triple point of water as the datum point. While finding out properties from the steam tables, students should use only one steam table as the datum points may be different for different tables. The values of the properties could be different at the same pressure and temperature in different tables.

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$s = \text{const}$   
 $ds = 0$   
 $ds = \frac{\delta Q_{rev}}{T}$   
 isentropic process  
 ↓  
 adiabatic & reversible

$p = c; v = c; T = c; h = c;$   
 $Q = 0 \rightarrow \text{adiabatic}$

$p = c$   
 $p v^\gamma = c$   
 $p v = c$  isotherm for ideal gas  
 $p v^\gamma = c$

Ideal gas  
 $T ds = du + p dv$   
 $T ds = C_v dT$   
 $\frac{dT}{ds} = \frac{T}{C_v}$   
 $T ds = dh - v dp$   
 $T ds = C_p dT$   
 $\Rightarrow \left( \frac{dT}{ds} \right)_{p=c} = \frac{T}{C_p}$

liq + vapour  
 $p, T$

NPTEL

Figure 2.

We have come across processes for a system where some property remains constant during the process, e.g., isobaric process ( $p=\text{constant}$ ), isochoric process ( $v=\text{constant}$ ), isothermal process ( $T=\text{constant}$ ), isenthalpic process ( $h=\text{constant}$ ). For adiabatic process, heat transfer  $Q=0$ .

Let's look at an isentropic process for a system. In this process,  $s = \text{constant}$  or  $\Delta s = 0$ . We know that, for a reversible process,  $dS_{rev} = \frac{\delta Q_{rev}}{T}$  or  $dS_{rev} = \frac{\delta q_{rev}}{T}$ . For the process to be isentropic,  $ds$  should be 0, which leads to  $\delta q = 0$ . Hence, the isentropic process is reversible and adiabatic.

Let's recap how different processes for a system look on a p-v diagram.

An isobaric process (a constant pressure process,  $p = c$ ) is represented by a line parallel to the  $v$  axis. Similarly, an isochoric process (a constant volume process,  $v = c$ ) is represented by a line parallel to the  $p$  axis. An adiabatic process for an ideal gas ( $pv^\gamma = c$ ) is represented by a curve which is steeper than the curve representing an isothermal process for an ideal gas ( $pv = c$ ) as shown in Fig. 2. If the adiabatic process is also reversible, then the same curve ( $pv^\gamma = c$ ) represents isentropic process ( $s = c$ ) for an ideal gas. For two-phase mixtures, isobars and isotherms are lines parallel to the  $v$  axis inside liquid-vapor dome. Hence, the nature of the curve representing a process on a p-v diagram depends on the nature of the substance.

Let's see how different processes look on a T-s diagram.

A line parallel to the  $s$  axis represents an isothermal process on a T-s diagram. Similarly, a line parallel to the  $T$  axis represents an isentropic process on T-s diagram. For two-phase mixtures, isobars and isotherms are lines parallel to the  $s$  axis inside a liquid-vapor dome. For an ideal gas, we have a relation,  $Tds = dh - vdp$ . For a constant pressure process,  $dp=0$ . Hence,  $Tds = dh = C_p dT \rightarrow \frac{dT}{ds} = \frac{T}{C_p}$ . Hence, the slope of a curve representing a constant pressure process on a T-s diagram is  $\frac{T}{C_p}$ . For a perfect gas, as  $C_p$  is constant, the slope increases with increase in temperature. A curve representing a constant pressure process for a perfect gas at low temperatures is less steeper than the curve representing a constant pressure process for a perfect gas at higher temperatures as the slope  $\frac{dT}{ds} \propto T$ .

For an ideal gas, we also have  $Tds = du + pdv$ . For a constant volume process,  $dv=0$ . Hence,  $Tds = du = C_v dT \rightarrow \frac{dT}{ds} = \frac{T}{C_v}$ . Hence, the slope of a curve representing a constant volume process on a T-s diagram is  $\frac{T}{C_v}$ . For a perfect gas, as  $C_v$  is constant, the slope increases with increase in temperature. A curve representing a constant volume process for a perfect gas at low temperatures less steeper than the curve representing a constant volume process for a perfect gas at higher temperatures as the slope  $\frac{dT}{ds} \propto T$ .

For an ideal gas (and perfect gas),  $C_p > C_v \rightarrow \frac{T}{C_p} < \frac{T}{C_v}$ . Hence, if a constant volume and a constant pressure process starts at the same point on a T-s diagram, the curve representing the constant volume process would be steeper compared to that representing the constant pressure process (see Fig. 2).