

ENGR 292 Fluids and Thermodynamics

Scott Li, Ph.D., P.Eng.
Mechanical Engineering Technology
Camosun College

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Midterm Exam Review

- **Good job !**

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Review of Last Class

- **Basic Concepts**
- **Work**
- **Energy**

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Basic Concepts

- **System**
- **Surrounding**
- **Boundary**
- **Closed system**
- **Open system**
- **Property**
 - **Mass**
- **Intensive Property**
- **Extensive Property**

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Basic Concepts

- **Property**
 - **Mass**
 - **Density**
 - **Specific Weight**
 - **Specific Gravity**
 - **Volume**
 - **Specific Volume**
- **Intensive Property**
- **Extensive Property**

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Basic Concepts

- **State**
- **Process**
- **Cycle**
- **Phases**
 - **Solid**
 - **Liquid**
 - **Gas**

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Energy

- **Energy: the ability to cause changes**
 - **Fundamental concept of thermodynamics**
 - **One of the most significant aspects of engineering analysis**

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Energy

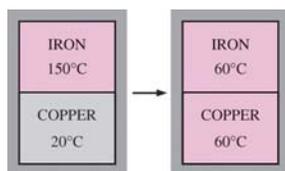
Zeroth Law of Thermodynamics

Two bodies are in thermal equilibrium if both have the same temperature reading even if they are not in contact.

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Energy

Zeroth Law of Thermodynamics



Two bodies reaching thermal equilibrium after being brought into contact in an isolated enclosure.

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Energy

First Law of Thermodynamics

The law of conservation of energy states that the total energy of an isolated system is constant; energy can be transformed from one form to another, but can not be created or destroyed.

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Forms of Energy

- **Kinetic Energy (KE)**
 - $KE = m \frac{v^2}{2}$
- **Potential Energy (PE)**
 - $PE = mgz$
- **Internal Energy (U)**

$$E = KE + PE + U$$

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Internal Energy

E denotes total energy, including kinetic, potential energy and others. These 'others' are considered internal energy, U.

Examples of internal energy:

1. Compress a spring
2. Charge a battery
3. Others?

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Work

Work:

Work done by the body can be considered a transfer of energy to the body, where it is stored as kinetic energy

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Work

$$W = \int_{s_1}^{s_2} F ds$$

A means of transferring energy

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Pure Substance

- Please note: a pure substance does not have to be of a single chemical element or compound. A mixture of various chemical elements or compounds also qualifies as a pure substance as long as the mixture is homogeneous.
- A mixture of two or more phases of a pure substance is still a pure substance as long as the chemical composition of all the phases is the same.

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Pure Substance

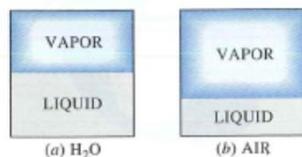
- Nitrogen and gaseous air are pure substances



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Pure Substance

- A mixture of liquid and gaseous water is a pure substance, but a mixture of liquid and gaseous air is not.



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Pure Substance

- Pure Substances? Yes
 - Water
 - Air
 - Water ice and liquid water
 - Liquid water and water vapor

Pure Substances? No:

- Liquid water and air
- Mix of Oil and Water

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Phase-Change Process of Pure Substances

FIGURE 3-5
The arrangement of atoms in different phases: (a) molecules are at relatively fixed positions in a solid, (b) clumps of molecules float about each other in the liquid phase, and (c) molecules move about at random in the gas phase.

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Phase-Change Process of Pure Substances

- **Compressed Liquid**
 - At 1 atm pressure and 20°C, water exists in the liquid phase

STATE 1
 $P = 1 \text{ atm}$
 $T = 20^\circ\text{C}$
Heat

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Phase-Change Process of Pure Substances

- **Saturated Liquid**
 - At 1 atm pressure and 100°C, water exists as a liquid that is ready to vaporize

STATE 2
 $P = 1 \text{ atm}$
 $T = 100^\circ\text{C}$
Heat

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Phase-Change Process of Pure Substances

- **Saturated Liquid-vapor Vapor**
 - As more heat is transferred, part of the saturated liquid vaporizes

STATE 3
 $P = 1 \text{ atm}$
 $T = 100^\circ\text{C}$
Saturated vapor
Saturated liquid
Heat

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Phase-Change Process of Pure Substances

- **Saturated Vapor**
 - At 1 atm pressure, temperature remains at 100°C until the last drop of liquid vaporized

STATE 4
 $P = 1 \text{ atm}$
 $T = 100^\circ\text{C}$
Heat

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Phase-Change Process of Pure Substances

- **Superheated Vapor**
 - As more heat is transferred, the temperature of the vapor starts to rise

STATE 5
 $P = 1 \text{ atm}$
 $T = 300^\circ\text{C}$
Heat

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Specific Volume

- Density (ρ): mass per unit volume

$$\rho = \frac{m}{V}$$

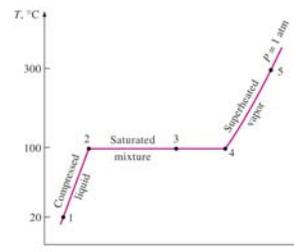
- A more frequently used property in thermodynamics is the specific volume. Volume per unit mass.

$$v = \frac{V}{m} = \frac{1}{\rho}$$

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Phase-Change Process of Pure Substances

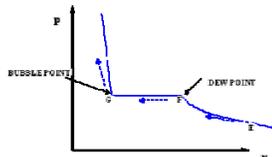
- T-v diagram for the heating process of water at constant pressure



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Phase-Change Process of Pure Substances

- P-v diagram for the compression process at constant temperature



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Phase-Change Process of Pure Substances

- Saturation Temperature (T_{sat})
 - At a given pressure, the temperature at which a pure substance changes phase is called Saturation Temperature
- Saturation Pressure (P_{sat})
 - At a given temperature, the pressure at which a pure substance changes phase is called Saturation Temperature

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Phase-Change Process of Pure Substances

TABLE 3-1
Saturation (boiling) pressure of water at various temperatures

Temperature, $T, ^\circ\text{C}$	Saturation pressure, P_{sat}, kPa
-10	0.26
-5	0.40
0	0.61
5	0.87
10	1.23
15	1.71
20	2.34
25	3.17
30	4.25
40	7.38
50	12.35
100	101.3 (1 atm)
150	475.8
200	1554
250	3973
300	8581

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Phase-Change Process of Pure Substances

TABLE 3-2
Variation of the standard atmospheric pressure and the boiling (saturation) temperature of water with altitude

Elevation, m	Atmospheric pressure, kPa	Boiling temperature, $^\circ\text{C}$
0	101.33	100.0
1,000	89.55	96.3
2,000	79.50	93.2
5,000	54.05	83.0
10,000	26.50	66.2
20,000	5.53	34.5

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Phase-Change Process of Pure Substances

□ **Liquid-Vapor Saturation Curve**

- T_{sat} increases with P_{sat}

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Vacuum Freezing

□ If the pressure in vacuum chamber is dropped below 0.6 kPa, the saturation pressure of water at 0°C.

□ The idea of making ice by using a vacuum pump is nothing new.

□ In 1775, Dr. William Cullen actually made ice in Scotland by evacuation the air in a water tank.

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Phase-Change Process of Pure Substances

□ **T-v diagram of constant pressure phase-change process of water at various pressures**

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Phase-Change Process of Pure Substances

□ **T-v diagram of a pure substance**

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Phase-Change Process of Pure Substances

□ **P-v diagram of constant Temperature phase-change process of water at various Temperature**

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Phase-Change Process of Pure Substances

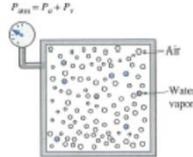
□ **P-v diagram of a pure substance**

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Vapor Pressure

- Atmospheric air can be viewed as a mixture of dry air (air with zero moisture content) and water vapor (also referred to as moisture), and the atmospheric pressure is the sum of the pressure of dry air P_a and the pressure of water vapor, called vapor pressure P_v .

$$P_{atm} = P_a + P_v$$



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Vapor Pressure

- Air can hold a certain amount of moisture only, and the ratio of the actual amount of moisture in the air at a given temperature to the maximum amount air can hold at that temperature is called the relative humidity ϕ
- 0 for dry air
- 100 for saturated air

$$P_v = \phi P_{sat@T}$$

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Phase Equilibrium

- For liquid water that is open to the atmosphere, the criterion for phase equilibrium can be expressed as follows:

The vapor pressure in the air must be equal to the saturation pressure of water at the water temperature.

$$P_v = P_{sat@T}$$

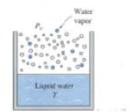
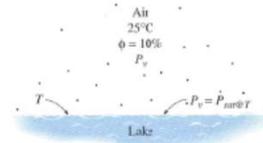


FIGURE 3-30 When open to the atmosphere, water is in phase equilibrium with the vapor in the air if the vapor pressure is equal to the saturation temperature of water.

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Example 1

- On a summer day, the air temperature over a lake is measured to be 25 °C. Determine water temperature of the lake when phase equilibrium conditions are established between the water in the lake and the vapor in the air for relative humidities of 10, 80, 100 percentage for the air.



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Example 1

- A partial list of Table A-4

Temp., T °C	Specific volume, m³/kg			Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg·K		
	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	9.1564	9.1564
5	0.8725	0.001000	147.03	21.019	2369.8	2388.8	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	0.001003	77.865	62.980	2322.5	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

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Example 1

- Solution:**
The saturation pressure of water 25 °C, from Table A-4, is 3.17 kPa. Then the vapor pressures at relative humidities of 10, 80 and 100 percent are determined from following equation:

$$P_{atm} = P_a + P_v$$

$$\phi_1 = 10\%; P_{v1} = \phi_1 P_{sat@25^\circ C} = 0.1 \times 3.17 kPa = 0.317 kPa$$

$$\phi_2 = 80\%; P_{v2} = \phi_2 P_{sat@25^\circ C} = 0.8 \times 3.17 kPa = 2.536 kPa$$

$$\phi_3 = 100\%; P_{v3} = \phi_3 P_{sat@25^\circ C} = 1.0 \times 3.17 kPa = 3.17 kPa$$

The saturation temperature corresponding to these pressure are determined from Table A-4 by interpolation to be:

$$T_1 = -8.0^\circ C; \quad T_2 = 21.2^\circ C; \quad T_3 = 25^\circ C$$

Therefore, water will freeze in the first case even though the surrounding air is hot. In the last case the water temperature will be the same as the surrounding air temperature.

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Example 1

□ **Solution:**

Discussion:

You probably skeptical about the lake freezing when the air is at 25 , and you are right. The water temperature will drop to -8 in the limiting case of no heat transfer to the water surface. In practice the water temperature will drop below the air temperature, but it will not drop to -8 because (1) it is very unlikely for the air over the lake to be so dry (a relative humidity of just 10 percent) and (2) as the water temperature near the surface drops, heat transfer from the air and the lower parts of the water body will tend to make up for the this heat loss and prevent the water temperature from dropping too much.

Example 1

□ **Solution:**

Discussion:

The water temperature will stabilize when the heat gain from the surrounding air and water body equals the heat loss by evaporation, that is, when a dynamic balance is established between heat the mass transfer instead of phase equilibrium. If you try this experiment using a shallow layer of water in a well-insulated pan, you can actually freeze the water if the air is really dry and relatively cool.

Property Table

□ For most substances, the relationships among thermodynamics properties are too complex to be expressed in simple equations.

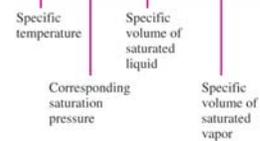
□ Therefore, properties are frequently presented in the form of tables.

□ Tables of the properties of saturated liquid and saturated vapor.

- Temperature Table (when the temperature is given)
- Pressure Table (when the pressure is given)

Property Table

Temp. T °C	Sat. press. P_{sat} kPa	Specific volume m^3/kg	
		Sat. liquid v_f	Sat. vapor v_g
85	57.868	0.001032	2.8261
90	70.183	0.001036	2.3593
95	84.609	0.001040	1.9808



Property Table

□ A partial list of Table A-4

Temp. T °C	Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, $kJ/kg \cdot K$			
	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	0.8175	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.1026
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	8.5509	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

Property Table

□ A partial list of Table A-5

Press. P kPa	Temp. T °C	Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, $kJ/kg \cdot K$		
		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
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2608	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765

Enthalpy and Entropy

Enthalpy

Total Enthalpy

$$H = U + PV$$

Specific Enthalpy (per unit mass):

$$h = u + Pv$$

Entropy (s)

- Entropy is a property associated with the second law of thermodynamics. It will be introduced later.

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Example 2

Finding the Pressure of Saturated Liquid

A rigid tank contains 50 kg of saturated liquid water at 90 °C. Determine the pressure in the tank and the volume of the tank.

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Example 2

Solution:

The state of the saturated liquid water is shown on a T-v diagram in Fig below. Since saturation condition exist in the tank, the pressure must be the saturation pressure at 90°C.

$$P = P_{\text{sat}@90^\circ\text{C}} = 70.183 \text{ kPa (Table A-4)}$$

The specific volume of the saturation liquid at 90°C is:

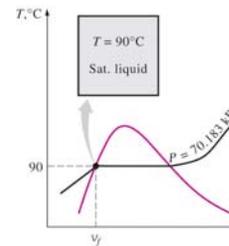
$$v = v_{f@90^\circ\text{C}} = 0.001036 \text{ m}^3/\text{kg (Table A-4)}$$

Then the total volume of the tank is determined to be:

$$V = mv = (50\text{kg})(0.001036\text{m}^3/\text{kg}) = 0.0518\text{m}^3$$

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Example 2



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Example 2

A partial list of Table A-4

Temp. T, °C	Specific volume, m ³ /kg			Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg·K		
	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	9.1506	9.1506
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
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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	8.2566
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	7.9868
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

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Example 3

Finding the Temperature of Saturated Vapor

A piston-cylinder device contains 2 ft³ of saturated water vapor at 50 psig pressure. Determine the temperature of the vapor and the mass of the vapor inside the cylinder.

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Example 3

□ Solution:

The state of the saturated water vapor is shown on a P-v diagram in the Fig below. Since the cylinder contains saturated vapor at 50 psig, the temperature inside must be the saturation temperature at this pressure:

$$T = T_{sat@50psig} = 281.99^\circ\text{F} \quad (\text{Table A-5E})$$

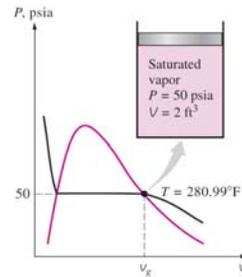
The specific volume of the saturation vapor at 50 psig is:

$$v = v_{g@50psig} = 8.518 \text{ ft}^3/\text{lbm} \quad (\text{Table A-5E})$$

Then the mass of water vapor inside the cylinder is determined to be:

$$m = \frac{V}{v} = \frac{2 \text{ ft}^3}{8.518 \text{ ft}^3/\text{lbm}} = 0.235 \text{ lbm}$$

Example 3



Example 3

□ A partial list of Table A-5E

H ₂ O	Press., psia	Sat. temp., °F	Specific volumes, ft ³ /lbm			Internal energies, Btu/lbm			Enthalpies, Btu/lbm			Entropies, Btu/lbm·R		
			sat. liq., v _f	sat. vapor, v _g	sat. liq., v _f	sat. vapor, v _g	sat. liq., u _f	sat. vapor, u _g	sat. liq., h _f	sat. vapor, h _g	sat. liq., s _f	sat. vapor, s _g		
35	140.38	0.21632	0.0206	208.44	0.7639	1080.3	208.52	922.2	1360.7	0.30365	1.3602	1.7142		
40	152.24	0.21724	0.0206	218.24	0.8029	1080.0	218.50	940.4	1354.3	0.30521	1.3714	1.6936		
45	165.26	0.21825	0.0207	227.03	0.8424	1080.0	228.54	959.3	1347.4	0.30693	1.3784	1.6723		
50	179.46	0.21936	0.0209	234.03	0.8823	1080.0	238.16	979.0	1340.0	0.30874	1.3845	1.6512		
55	194.86	0.22057	0.0212	239.37	0.9227	1080.0	247.51	999.5	1332.3	0.31065	1.3897	1.6302		
60	211.53	0.22187	0.0216	243.08	0.9635	1080.0	256.24	1020.8	1324.4	0.31266	1.3949	1.6093		
65	229.43	0.22326	0.0221	245.18	1.0047	1080.0	264.46	1042.9	1316.3	0.31476	1.3999	1.5885		
70	248.53	0.22474	0.0227	245.68	1.0463	1080.0	272.19	1065.8	1308.0	0.31694	1.4047	1.5678		
75	268.89	0.22631	0.0234	244.68	1.0883	1080.0	279.42	1089.5	1299.5	0.31920	1.4093	1.5472		
80	290.56	0.22797	0.0242	242.18	1.1307	1080.0	286.15	1114.0	1290.9	0.32154	1.4137	1.5267		
85	313.60	0.22972	0.0251	238.28	1.1735	1080.0	292.48	1139.2	1282.2	0.32396	1.4179	1.5063		
90	338.07	0.23156	0.0261	233.00	1.2167	1080.0	298.31	1165.0	1273.4	0.32646	1.4219	1.4860		
95	364.03	0.23349	0.0272	226.34	1.2603	1080.0	303.64	1191.4	1264.5	0.32903	1.4257	1.4658		
100	391.54	0.23551	0.0284	218.30	1.3043	1080.0	308.47	1218.4	1255.6	0.33167	1.4293	1.4457		
110	450.33	0.24163	0.0317	198.50	1.3907	1080.0	312.70	1266.4	1236.7	0.33539	1.4329	1.4056		
120	519.26	0.24875	0.0361	168.27	1.4813	1080.0	316.33	1315.4	1216.8	0.33919	1.4364	1.3655		

Example 4

□ The Volume and Energy Change during Evaporation

A mass of 200 g of saturated liquid water is completely vaporized at a constant pressure 100 kPa. Determine

- (a) The volume change
- (b) The amount of energy added to the water

Example 4

□ Solution:

(a) The process described is illustrated on a P-v diagram in Fig below. The volume change per unit mass during a vaporization process is v_{fg} , which is the difference between v_g and v_f . Reading these values from Table A-5 at 100 kPa and substituting yield:

$$v_{fg} = v_g - v_f = (1.6940 - 0.001043) \text{ m}^3/\text{kg} = 1.6930 \text{ m}^3/\text{kg}$$

Thus,

$$\Delta V = m v_{fg} = (0.2 \text{ kg})(1.6930 \text{ m}^3/\text{kg}) = 0.3386 \text{ m}^3$$

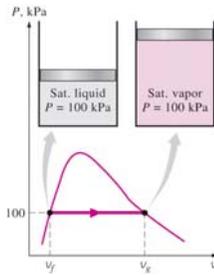
Example 4

□ Solution:

(b) The amount of energy needed to vaporize the unit mass of a substance at a given pressure is the enthalpy of vaporization at that pressure, which, at 100 kPa, is $h_{fg} = 2258.0 \text{ kJ/kg}$. Thus the amount of energy added is

$$m h_{fg} = (0.2 \text{ kg})(2258 \text{ kJ/kg}) = 451.6 \text{ kJ}$$

Example 4



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Example 4

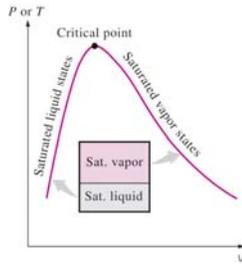
□ A partial list of Table A-5

TABLE A-5 Saturated water—Pressure table													
Press., P/MPa	Temp., T _{sat} /°C	Specific volume, m ³ /kg		Internal energy, kJ/kg		Enthalpy, kJ/kg		Entropy, kJ/kg·K		Quality		Enthalpy	
		Sat. liquid, v _f	Sat. vapor, v _g	Sat. liquid, u _f	Sat. vapor, u _g	Sat. liquid, h _f	Sat. vapor, h _g	Sat. liquid, s _f	Sat. vapor, s _g	Sat. liquid, h _f	Sat. vapor, h _g		
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749	
1.5	13.02	0.001001	87.964	54.686	2381.1	2392.8	54.688	2470.1	2524.7	0.1956	8.8114	8.8270	
2.0	17.50	0.001001	66.990	73.431	2375.5	2396.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227	
2.5	21.08	0.001002	54.242	88.422	2370.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421	
3.0	24.08	0.001003	45.644	100.98	2366.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765	
4.0	28.96	0.001004	34.791	121.39	2363.1	2414.5	121.39	2432.3	2553.7	0.4224	8.0510	8.4734	
5.0	32.87	0.001005	28.185	137.75	2360.1	2419.8	137.75	2423.0	2560.7	0.4762	7.8176	8.3938	
7.5	40.29	0.001008	19.233	168.74	2351.1	2429.8	168.75	2405.3	2574.0	0.5763	7.6738	8.2501	
10	45.81	0.001010	14.670	191.79	2345.4	2437.2	191.81	2392.1	2583.9	0.6490	7.4996	8.1488	
15	53.97	0.001014	10.020	225.93	2332.1	2448.0	225.94	2372.8	2598.3	0.7499	7.2532	8.0071	
20	60.06	0.001017	7.6481	251.40	2324.6	2456.0	251.42	2357.5	2608.9	0.8320	7.0752	7.9073	
25	64.96	0.001020	6.2034	271.93	2318.4	2462.4	271.96	2345.5	2617.5	0.8932	6.9170	7.8022	
30	69.09	0.001022	5.2087	289.24	2314.5	2467.7	289.27	2335.3	2624.6	0.9441	6.8234	7.7475	
40	75.86	0.001026	3.9933	317.58	2308.8	2476.3	317.62	2318.4	2636.1	1.0261	6.6430	7.6691	
50	81.32	0.001030	3.2403	340.49	2305.7	2483.2	340.54	2304.7	2645.2	1.0912	6.5019	7.6031	
75	91.76	0.001037	2.2172	384.36	2311.8	2496.1	384.44	2278.0	2662.4	1.2132	6.2426	7.4558	
100	99.61	0.001043	1.6941	417.40	2308.2	2505.6	417.51	2257.5	2675.0	1.3028	6.0562	7.3589	

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Saturated Liquid-Vapor Mixture

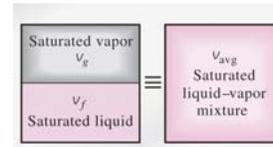
□ The relative amounts of liquid and vapor phases in a saturated mixture are specified by the quality x



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Saturated Liquid-Vapor Mixture

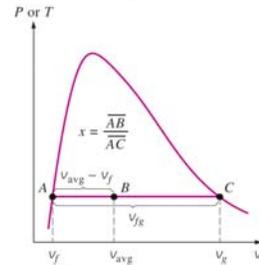
□ A two-phase system can be treated as a homogenous mixture for convenience



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Saturated Liquid-Vapor Mixture

□ Quality is related to the horizontal distances on P-v and T-v diagrams.



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Saturated Liquid-Vapor Mixture

□ Consider a tank that contains a saturated liquid-vapor mixture. The volume occupied by saturated liquid is V_f , and the volume occupied by saturated vapor is V_g . The total volume V is the sum of these two:

$$V = V_f + V_g$$

$$V = mv \rightarrow m_t v_{av} = m_f v_f + m_g v_g$$

$$m_f = m_t - m_g \rightarrow m_t v_{ave} = (m_t - m_g) v_f + m_g v_g$$

Dividing by m_t , yields:

$$v_{av} = (1 - x) v_f + x v_g \text{ where } x = m_g / m_t$$

$$v_{av} = v_f + x v_{fg} \text{ where } v_{fg} = v_g - v_f$$

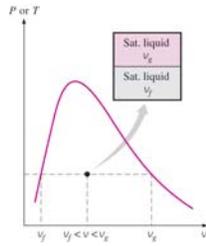
Then:

$$x = \frac{v_{av} - v_f}{v_{fg}}$$

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Saturated Liquid-Vapor Mixture

- The v value of a saturated liquid-vapor mixture lies between the v_f and v_g values at the specific T or P



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What is next?

- Any Questions?
- Continue on with Thermodynamics

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