

*ENGR 292 Fluids and Thermodynamics*

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*Review of Last Class*

□ **Steam Power Plant**

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*Review of Last Class*

□ **Steam Power Plant**

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*Review of Last Class*

□ **Define the Properties**

State	T (°C)	P (MPa)	v (m³/kg)	h (kJ/kg)	s (kJ/(kgK))	Condition
1						
2						
3						
4						

□ *Note: The data given is labeled by \**

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*Review of Last Class*

□ **Energy Analysis**

Energy Analysis	Equations
Net Work	$\dot{W}_{net\ out} = \dot{W}_T - \dot{W}_P$ $W_{net\ out} = Q_{in} - Q_{out}$
Heat Input	$Q_{in} = Q_B = \dot{m}_s(h_1 - h_e)$
Thermal Efficiency	$\eta = \frac{\dot{W}_{net\ out}}{Q_{in}} = \frac{\dot{W}_T - \dot{W}_P}{Q_{in}}$
	$\eta = \frac{W_{net\ out}}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$

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*Review of Last Class*

□ **Energy Analysis**

Energy Analysis	Equations
Net Power	$P_{net} = \dot{m}\dot{W}_{net\ out}$
Back Work Ratio	$\frac{\dot{W}_P}{\dot{W}_T}$

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### Isentropic Efficiency

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### Isentropic Efficiency

- **Isentropic means:**
  - Ideal
  - Perfect
  - Reversible
- **Isentropic processes**
  - 1 to 2s
  - 3 to 4s

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### Isentropic Efficiency

- **For a less than perfect work process, some heat is generated by friction, imperfect compression / expansion, shock wave etc. Thus Entropy is generated.**
- **In Non-Isentropic process,  $S_{End} > S_{Start}$  or  $S_{Start} < S_{End}$**

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### Isentropic Efficiency

- **Isentropic Efficiency of Output device Turbine**

$$\eta_T = \frac{\dot{W}_{T\_Actual}}{\dot{W}_{T\_Ideal}} = \frac{h_1 - h_2}{h_1 - h_{2s}} < 1$$

- **A turbine produce a smaller work output**

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### Isentropic Efficiency

- **Isentropic Efficiency of Input device Pump**

$$\eta_P = \frac{\dot{W}_{P\_Ideal}}{\dot{W}_{P\_Actual}} = \frac{h_{4s} - h_3}{h_4 - h_3} < 1$$

- **A pump requires a greater work input**

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### Refrigeration

- **Refrigerators**

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### Refrigeration

□ **Refrigerators**

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### Refrigeration Cycle

□ **Process 1 – 2: Isentropic compression of a cold vapor refrigerant from state 1 to the condenser pressure at 2. Increases pressure of vapor, making it a hot vapor.**

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### Refrigeration Cycle

□ **Process 2 – 3: Heat is transferred from the refrigerant to the surroundings as it flows at constant pressure through the condenser. Hot compressed vapor now becomes a warm liquid at state 3.**

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### Refrigeration Cycle

□ **Process 3 – 4: Drop the pressure of the liquid using throttling process from state 3 to a cold two-phase liquid-vapor mixture at state 4.**

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### Refrigeration Cycle

□ **Process 4 – 1: Drop the pressure of the liquid using throttling process from state 3 to a cold two-phase liquid-vapor mixture at state 4.**

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### Energy Analysis

□ **Engineering Devices of Refrigeration**

Energy Analysis	Equations
Compressor	$W_c = \dot{m}(h_2 - h_1)$
Condenser	$\dot{Q}_{out} = \dot{m}(h_2 - h_3)$
Expansion Valve	$h_3 = h_4 = h_{f4} + x(h_{g4} - h_{f4})$
Evaporator	$\dot{Q}_{in} = \dot{m}(h_1 - h_4)$
Coefficient of Performance (COP)	$COP = \frac{\dot{Q}_{in}}{W_c} = \frac{h_1 - h_4}{h_2 - h_1}$

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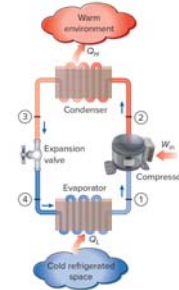
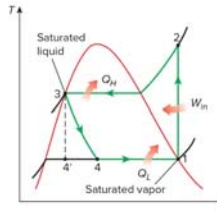
### Example 1

- An ideal vapor-compression refrigeration cycle operates at steady state with refrigerant R134a as the working fluid.
- Saturated vapor enters the compressor at  $-12^{\circ}\text{C}$ , and saturated liquid leaves the condenser at  $28^{\circ}\text{C}$ , The mass flow rate of refrigerant is  $5\text{ kg/min}$ .
- Determine:
  - The compressor power in kw
  - The refrigerant capacity
  - The coefficient of performance (COP)

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### Example 1

- Step 1. Draw the cycle
  - Fluid: Refrigerant R134a
  - $\dot{m} = 5\text{ kg/min}$



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### Example 1

- Step 2: Define the Properties

State	T (°C)	P(MPa)	v (m³/kg)	h (kJ/kg)	s (kJ/(kgK))	Condition
1	-12*					
2						
3	28*					
4						

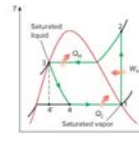
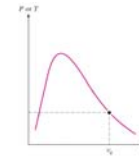
- Note: The data given is labeled by \*

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### Example 1

- Step 2 Define the Properties

- State (1)
- It is in the saturated vapor region at a specified temperature,  $T = -12^{\circ}\text{C}$ ;
- Use Table A-15a (with Interpolation method if needed)



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### Example 1

- A partial list of Table A-15a

TABLE A-15a  
Saturated refrigerant-134a—Temperature table

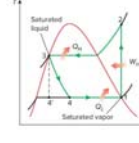
Temp. °C T	Press. MPa P <sub>sat</sub>	Specific volume m³/kg		Internal energy kJ/kg		Enthalpy kJ/kg		Entropy kJ/(kg·K)		
		Sat. liquid v <sub>f</sub>	Sat. vapor v <sub>g</sub>	Sat. liquid u <sub>f</sub>	Sat. vapor u <sub>g</sub>	Sat. liquid h <sub>f</sub>	Evap. h <sub>fg</sub>	Sat. vapor h <sub>g</sub>	Sat. liquid s <sub>f</sub>	Sat. vapor s <sub>g</sub>
-40	0.05164	0.0007055	0.3569	-0.04	204.45	0.00	222.88	222.88	0.0000	0.9560
-36	0.06332	0.0007113	0.2947	4.68	209.73	4.73	220.67	225.40	0.0201	0.9506
-32	0.07704	0.0007172	0.2451	9.47	209.01	9.52	218.37	227.90	0.0401	0.9456
-28	0.09305	0.0007233	0.2052	14.31	211.29	14.37	216.01	230.38	0.0600	0.9411
-24	0.12199	0.0007365	0.1682	16.75	212.43	16.82	214.80	231.62	0.0699	0.9390
-20	0.15660	0.0007566	0.1359	19.21	213.57	19.29	213.57	232.85	0.0798	0.9370
-16	0.19840	0.0007848	0.1068	24.17	215.84	24.26	211.05	235.31	0.0998	0.9352
-12	0.24940	0.0008219	0.0819	29.18	218.10	29.30	208.45	237.74	0.1192	0.9298
-8	0.31174	0.0008699	0.0581	34.25	220.36	34.39	205.77	240.15	0.1386	0.9267

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### Example 1

- Step 2 Define the Properties

- State (1)
- $x_1 = 1$
- $P_1 = P_{sat@-12^{\circ}\text{C}} = 0.1854\text{ MPa}$
- $v_1 = v_{g@-12^{\circ}\text{C}} = 0.1068\text{ m}^3/\text{kg}$
- $h_1 = h_{g@-12^{\circ}\text{C}} = 240.15\text{ kJ/kg}$
- $s_1 = s_{g@-12^{\circ}\text{C}} = 0.9267\text{ kJ/(kgK)}$



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### Example 1

□ **Step 2: Define the Properties**

State	T (°C)	P(MPa)	v (m³/kg)	h (kJ/kg)	s (kJ/(kgK))	Condition
1	-12*			240.15	0.9267	$x_1 = 1$
2						
3	28*					
4						

□ **Note:** The data given is labeled by \*

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### Example 1

□ **Step 2 Define the Properties**

- State (2)
- It is an isentropic process from state 1 to 2, so,  $s_2 = s_1 = 0.9267$
- It is obvious that the state (2) is in the superheated vapor region, however, the temperature and pressure are unknown.
- Not enough information to Use (Table A-16) (with interpolation method if needed)
- Let's work on State (3) first.

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### Example 1

□ **Step 2 Define the Properties**

- State (3)
- It is in the saturated liquid region at, at a specified temperature 28°C;
- Use Table A-15a (with Interpolation method if needed)

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### Example 1

□ **A partial list of Table A-15a**

TABLE A-15a  
Saturated refrigerant-134a—Temperature table

Temp. T °C	Press. P MPa	Specific volume m³/kg		Internal energy kJ/kg		Enthalpy kJ/kg		Entropy kJ/(kg·K)		
		Sat. liquid v <sub>f</sub>	Sat. vapor v <sub>g</sub>	Sat. liquid u <sub>f</sub>	Sat. vapor u <sub>g</sub>	Sat. liquid h <sub>f</sub>	Evap. h <sub>fg</sub>	Sat. vapor h <sub>g</sub>	Sat. liquid s <sub>f</sub>	Sat. vapor s <sub>g</sub>
26	0.68530	0.0008309	0.0298	85.18	241.05	85.75	175.73	261.48	0.3208	0.9082
28	0.72675	0.0008362	0.0281	88.00	242.08	88.61	173.89	262.50	0.3302	0.9076
30	0.77058	0.0008417	0.0265	90.84	243.10	91.49	172.00	263.50	0.3396	0.9070
32	0.81538	0.0008473	0.0250	93.70	244.12	94.39	170.09	264.48	0.3490	0.9064
34	0.86247	0.0008530	0.0236	96.58	245.12	97.31	168.14	265.45	0.3584	0.9058

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### Example 1

□ **Step 2 Define the Properties**

- State (3)
- $x_3 = 0$
- $P_3 = P_{sat@28°C} = 0.72675 \text{ MPa}$
- $v_3 = v_{@28°C} = 0.0008362 \text{ m}^3/\text{kg}$
- $h_3 = h_{f@28°C} = 88.61 \text{ kJ}/\text{kg}$
- $s_3 = s_{f@28°C} = 0.3302 \text{ kJ}/(\text{kgK})$

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### Example 1

□ **Step 2: Define the Properties**

State	T (°C)	P(MPa)	v (m³/kg)	h (kJ/kg)	s (kJ/(kgK))	Condition
1	-12*			240.15	0.9267	$x = 1$
2						
3	28*	0.727		88.61		$x = 0$
4						

□ **Note:** The data given is labeled by \*

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### Example 1

□ **Step 2 Define the Properties**

- State (2)
- Now we come back to state (2) It is in the superheated vapor region, because it is an isobaric process (constant pressure) from state 2 to 3, therefore,  $P_2 = P_3 = 0.72675 \text{ MPa}$
- It is an isentropic process from state 1 to 2, so,  $s_2 = s_1 = 0.9267$

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### Example 1

□ **Step 2: Define the Properties**

State	T (°C)	P(MPa)	v (m³/kg)	h (kJ/kg)	s (kJ/(kgK))	Condition
1	-12*			240.15	0.9267	$x_1 = 1$
2		0.727			0.9267	
3	28*	0.727		88.61		$x_3 = 0$
4						

□ Note: The data given is labeled by \*

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### Example 1

□ **Step 2 Define the Properties**

- State (2)
- Use (Table A-16) with interpolation method to get the temperature and enthalpy of state 2.
- $P_2 = 0.727 \text{ MPa}$  is between 0.7 MPa and 0.8 MPa
- $s_2 = 0.9267 \text{ (kJ)/(kg.K)}$ , which indicates that the temperature  $T_2$  is between 30°C – 40°C in 0.7 MPa table, and is between Sat temperate (31.33°C) to 40°C in 0.8 MPa table

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### Example 1

□ First to use the interpolation method to find  $h_{@31.33^\circ\text{C}}$  value and  $s_{@31.33^\circ\text{C}}$  at 31.33°C at pressure  $P=0.7 \text{ MPa}$  (temperature between 30°C to 40°C)

0.7 MPa		
T (°C)	h (kJ/kg)	s (kJ/(kgK))
30	265.37	0.9197
31.33	266.77	0.9242
40	275.93	0.9539

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### Example 1

□ A partial list of Table A-16

$P = 0.70 \text{ MPa } (T_{sat} = 26.72^\circ\text{C})$					
T (°C)	v (m³/kg)	h (kJ/kg)	s (kJ/(kg·K))	h <sub>f</sub> (kJ/kg)	
Sat.	0.02918	241.42	261.85	0.9080	
30	0.02979	244.51	265.37	0.9197	
40	0.03157	253.83	275.93	0.9539	

$P = 0.80 \text{ MPa } (T_{sat} = 31.33^\circ\text{C})$					
T (°C)	v (m³/kg)	h (kJ/kg)	s (kJ/(kg·K))	h <sub>f</sub> (kJ/kg)	
Sat.	0.02547	243.78	264.15	0.9096	
30	0.02592	247.04	268.19	0.9242	
40	0.02819	258.00	275.93	0.9539	

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### Example 1

□ Then to use the Double interpolation (pressure between 0.7 MPa to 0.8 MPa, Temperature between 31.33°C to 40°C) to determine the  $T_2, h_2$

0.7 MPa		
T (°C)	h (kJ/kg)	s (kJ/(kgK))
31.33	266.77(a)	0.9242 (b)
40	275.93 (c)	0.9539 (d)

0.8 MPa		
T (°C)	h (kJ/kg)	s (kJ/(kgK))
31.33	264.15 (a)	0.9066(b)
40	273.66 (c)	0.9374 (d)

0.727 MPa		
T (°C)	h (kJ/kg)	s (kJ/(kgK))
31.33	266.0.6 (a)	0.9194 (b)
34.04	268.95	0.9267*
40	275.32 (c)	0.9494 (d)

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### Example 1

- Then to use the Double interpolation (pressure between 0.7 Mpa to 0.8 Mpa, Temperature between 31.33°C to 40°C ) to determine the  $T_2, h_2$ 
  - $P_2 = P_3 = 0.72675 \text{ MPa}$
  - $s_2 = s_1 = 0.9267$
- $T_2 = 34.04^\circ\text{C}$ ;
- $h_2 = 268.95 \text{ kJ/kg}$

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### Example 1

- Step 2: Define the Properties

State	T (°C)	P(MPa)	v (m³/kg)	h (kJ/kg)	s (kJ/(kgK))	Condition
1	-12*			240.15	0.9267	$x_1 = 1$
2	34.04	0.727		268.95	0.9267	
3	28*	0.727		88.61		$x_3 = 0$
4						

- Note: The data given is labeled by \*

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### Example 1

- Step 2 Define the Properties
  - State (4)
  - It is inside the dome
  - Therefore, it is in a Saturated Liquid-Vapor Mixture at a specified because it is an Isothermal process (constant pressure) from state 4 to 1, therefore,  $T_4 = T_1 = -12^\circ\text{C}$
  - It is an Isenthalpic – constant enthalpy processes from state 3 to state 4 ,therefore,  $h_4 = h_3 = 88.61 \text{ kJ/kg}$

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### Example 1

- Step 2: Define the Properties

State	T (°C)	P(MPa)	v (m³/kg)	h (kJ/kg)	s (kJ/(kgK))	Condition
1	-12*			240.15	0.9267	$x = 1$
2	34.04	0.727		268.95	0.9267	
3	28*	0.727		88.61		$x = 0$
4	-12			88.61		

- Note: The data given is labeled by \*

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### Energy Analysis

- Engineering Devices of Refrigeration

Energy Analysis	Equations
Compressor	$W_c = \dot{m}(h_2 - h_1)$
Condenser	$\dot{Q}_c = \dot{Q}_{out} = \dot{m}(h_2 - h_3)$
Expansion Valve	$h_3 = h_4 = h_{f4} + x(h_{g4} - h_{f4})$
Evaporator	$\dot{Q}_E = \dot{Q}_{in} = \dot{m}(h_1 - h_4)$
Coefficient of Performance (COP)	$COP = \frac{\dot{Q}_{in}}{W_c} = \frac{h_1 - h_4}{h_2 - h_1}$

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### Example 1

- Step 3: Energy Analysis
  - (a) The compressor power in kw

$$\dot{m} = 5 \text{ kg/min}$$

$$W_c = \dot{m}(h_2 - h_1)$$

$$= \frac{5}{60} (268.95 - 240.15) = 2.4 \text{ kw}$$

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### Example 1

□ **Step 3: Energy Analysis**  
 (b) **The refrigerant capacity**  
 $\dot{m} = 5 \text{ kg/min}$   
 $\dot{Q}_E = \dot{m}(h_1 - h_4) = \frac{5}{60} (240.15 - 88.61) = 12.63 \text{ kW}$   
 The refrigerant capacity is  $\frac{12.63}{3.516} = 3.6 \text{ tons}$ .  
 Note: 1 air conditioning ton = 3.516 kw.

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### Example 1

□ **Step 3: Energy Analysis**  
 (c) **The coefficient of performance (COP)**  

$$\text{COP} = \frac{\dot{Q}_E}{W_c} = \frac{12.63}{2.4} \cong 5.3$$

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### Heat Pumps

□ A Heat Pump operates in exactly the same way as a refrigerator.  
 □ Energy is extracted from a cold place and deliver to a hot place.  
 □ The only thing that changes, from a thermodynamic point of view, is what the user wants:

- A Refrigerator: Cold is desired
- A Heat Pump: Heat is desired.

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### Heat Pumps

□ Household heat pump can often supply both cooling and heating thanks to a valve inside the system that switches the function of the heat exchange coils.

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### Heat Pumps

□ **Heating mode and Cooling mode**

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### Heat Pumps

□ **Heating mode**

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### Heat Pumps

□ **Cooling mode**

HEAT PUMP - COOLING MODE (REFRIG.)

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### Heat Pumps

□ **Note:**  
That's all it takes to reverse the function of the device by turning the reversing valve 90 degree and reverse the flow through each coil and the expansion valve.

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### Heat Pumps

□ **T-S Diagram**

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### Heat Pumps

□ **Coefficients of Performance (COP)**

$$COP = \frac{\text{Desired Output}}{\text{Required Input}}$$

□ **Refrigerator**

$$COP = \frac{\text{Cooling Effect}}{\text{Work Input}} = \frac{\dot{Q}_{in}}{W_{in}}$$

□ **Heat Pump**

$$COP = \frac{\text{Heating Effect}}{\text{Work Input}} = \frac{\dot{Q}_{out}}{W_{in}}$$

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### Example 2

□ A small scale heat pump setup uses R-134a and operates as an ideal vapor-compression refrigeration cycle between 0.14 Mpa and 0.8 Mpa. The mass flow rate of refrigerant is 0.05kg/s.

□ **Determine:**

- The rate of heat removal from the outdoor air
- The rate of heat delivery to the indoor space
- The coefficient of performance (COP) of Heat Pump ( $COP_{HP}$ )

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### Example 2

□ **Step 1. Draw cycle**

- Fluid: Refrigerant R134a
- $\dot{m} = 0.05\text{kg/s}$

① T-S DIAGRAM.

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Example 2

□ Step 2: Define the Properties

State	T (°C)	P(MPa)	v (m³/kg)	h (kJ/kg)	s (kJ/(kgK))	Condition
1		0.14*				$x_1 = 1^*$
2		0.8*				
3		0.8*				$x_3 = 0^*$
4		0.14*				

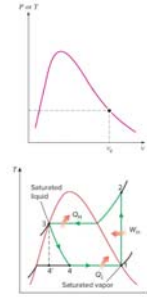
□ Note: The data given is labeled by \*

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Example 2

□ Step 2 Define the Properties

- State (1)
- It is in the saturated vapor region at a specified pressure,  $P = 0.14\text{Mpa}$ ;
- Use Table A-15b



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Example 2

□ A partial list of Table A-15b

TABLE A-15a  
Saturated refrigerant-134a—Pressure table

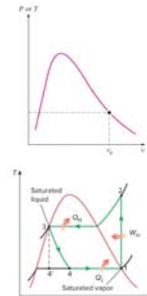
Press. MPa P	Temp. °C T <sub>sat</sub>	Specific volume m³/kg		Internal energy kJ/kg			Enthalpy kJ/kg		Entropy kJ/(kg·K)	
		Sat. liquid v <sub>f</sub>	Sat. vapor v <sub>g</sub>	Sat. liquid u <sub>f</sub>	Sat. vapor u <sub>g</sub>	Sat. liquid u <sub>fg</sub>	Sat. vapor h <sub>g</sub>	Sat. liquid h <sub>f</sub>	Sat. vapor h <sub>g</sub>	Sat. liquid s <sub>f</sub>
0.06	-37.07	0.0007097	0.3100	3.41	206.12	3.46	221.27	224.72	0.0147	0.9520
0.08	-31.21	0.0007184	0.2366	10.41	209.46	10.47	217.92	228.39	0.0440	0.9447
0.10	-26.43	0.0007258	0.1817	16.22	212.18	16.29	215.06	231.35	0.0678	0.9395
0.12	-22.36	0.0007323	0.1414	21.23	214.50	21.32	212.54	233.86	0.0879	0.9354
0.14	-18.80	0.0007381	0.1095	25.66	216.52	25.77	210.27	236.04	0.1055	0.9322

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Example 2

□ Step 2 Define the Properties

- State (1)
- $x_1 = 1$
- $T_1 = T_{sat@0.14\text{Mpa}} = -18.8^\circ\text{C}$
- $v_1 = v_{g@0.14\text{Mpa}} = \text{m}^3/\text{kg}$
- $h_1 = h_{g@0.14\text{Mpa}} = 236.04\text{kJ}/\text{kg}$
- $s_1 = s_{g@0.14\text{Mpa}} = 0.9322\text{kJ}/(\text{kgK})$



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Example 2

□ Step 2: Define the Properties

State	T (°C)	P(MPa)	v (m³/kg)	h (kJ/kg)	s (kJ/(kgK))	Condition
1	-18.8	0.14*		236.04	0.9332	$x_1 = 1^*$
2		0.8*				
3		0.8*				$x_3 = 0^*$
4		0.14*				

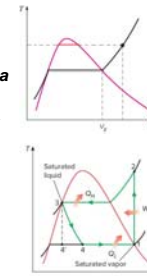
□ Note: The data given is labeled by \*

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Example 2

□ Step 2 Define the Properties

- State (2)
- It is in the superheated vapor region, at a specific pressure 0.8 Mpa
- And from State 1 to State 2 is Isentropic process,  $s_2 = s_1 = 0.9322\text{ (kJ/(kgK))}$
- Use (Table A-16) (with interpolation method if needed)



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### Example 2

□ A partial list of Table A-16

T °C	v m <sup>3</sup> /kg	u kJ/kg	h kJ/kg	s kJ/(kg·K)
<b>P = 0.80 MPa (P<sub>s</sub> = 31.33°C)</b>				
5at.	0.0547	243.79	264.15	0.9096
60	0.02891	252.13	273.06	0.9374
70	0.02062	271.04	294.98	1.0034
80	0.01564	289.89	316.00	1.0647
90	0.01219	308.93	336.52	1.0940
100	0.00959	328.09	357.06	1.1227
110	0.00742	348.57	377.71	1.1508
120	0.00576	369.31	398.43	1.1784
130	0.00431	390.14	419.19	1.2055
140	0.00307	411.09	439.97	1.2321
150	0.00213	432.15	460.75	1.2584
160	0.001427	453.32	481.54	1.2843
170	0.000940	474.61	502.33	1.3098
180	0.000632	496.02	523.13	1.3351

s<sub>1</sub> = 0.9322

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### Example 2

□ Step 2: Define the Properties

State	T (°C)	P(MPa)	v (m <sup>3</sup> /kg)	h (kJ/kg)	s (kJ/(kgK))	Condition
1	-18.8	0.14*		236.04	0.9332	x <sub>1</sub> = 1
2	38.54	0.8*		272.05	0.9322	
3		0.8*				x <sub>3</sub> = 0
4		0.14*				

□ Note: The data given is labeled by \*

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### Example 2

□ Step 2 Define the Properties

- State (3)
- It is in the saturated liquid region at a specified pressure 0.8 MPa.
- Use Table A-15b (with Interpolation method if needed)

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### Example 2

□ A partial list of Table A-15b

Press. MPa P	Temp. °C T <sub>sat</sub>	Specific volume m <sup>3</sup> /kg		Internal energy kJ/kg		Enthalpy kJ/kg		Entropy kJ/(kg·K)		
		Sat. liquid v <sub>f</sub>	Sat. vapor v <sub>g</sub>	Sat. liquid u <sub>f</sub>	Sat. vapor u <sub>g</sub>	Sat. liquid h <sub>f</sub>	Evap. h <sub>fg</sub>	Sat. vapor h <sub>g</sub>	Sat. liquid s <sub>f</sub>	Sat. vapor s <sub>g</sub>
0.7	26.72	0.0008328	0.0292	86.19	241.42	86.78	175.07	261.85	0.3249	0.9080
0.8	31.33	0.0008454	0.0255	92.76	243.78	93.42	170.73	264.15	0.3459	0.9056
0.9	35.53	0.0008576	0.0225	99.79	245.88	99.56	166.62	266.18	0.3656	0.9054
1.0	39.39	0.0008695	0.0202	104.42	247.77	105.29	162.68	267.97	0.3838	0.9043
1.2	46.32	0.0008928	0.0166	114.69	251.03	115.76	155.23	270.99	0.4164	0.9023

64

### Example 2

□ Step 2 Define the Properties

- State (3)
- x<sub>3</sub> = 0
- P<sub>3</sub> = P<sub>sat@0.8MPa</sub> = 31.33°C
- h<sub>3</sub> = h<sub>f@0.8MPa</sub> = 93.42 kJ/kg

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### Example 2

□ Step 2: Define the Properties

State	T (°C)	P(MPa)	v (m <sup>3</sup> /kg)	h (kJ/kg)	s (kJ/(kgK))	Condition
1	-18.8	0.14*		236.04	0.9332	x <sub>1</sub> = 1
2	38.54	0.8*		272.05	0.9322	
3	31.33	0.8*		93.42		x <sub>3</sub> = 0
4		0.14*				

□ Note: The data given is labeled by \*

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### Example 2

□ **Step 2 Define the Properties**

- State (4)
- It is inside the dome
- Therefore, it is in a Saturated Liquid-Vapor Mixture at a specified temperature,  $T = -18.8^\circ\text{C}$ ; and a specified pressure  $P = 0.14\text{MPa}$
- It is an Isenthalpic – constant enthalpy processes from state 3 to state 4 ,therefore,  $h_4 = h_3 = 93.42\text{kJ/kg}$

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### Example 2

□ **Step 2: Define the Properties**

State	T (°C)	P(MPa)	v (m³/kg)	h (kJ/kg)	s (kJ/(kgK))	Condition
1	-18.8	0.14*		236.04	0.9332	$x_1 = 1$
2	38.54	0.8*		272.05	0.9322	
3	31.33	0.8*		93.42		$x_3 = 0$
4	-18.8	0.14*		93.42		

□ Note: The data given is labeled by \*

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### Energy Analysis

□ **Refrigeration and Heat Pump**

Energy Analysis	Equations
Compressor	$W_c = \dot{m}(h_2 - h_1)$
Condenser	$\dot{Q}_c = \dot{Q}_{out} = \dot{m}(h_2 - h_3)$
Expansion Valve	$h_3 = h_4 = h_{f4} + x(h_{g4} - h_{f4})$
Evaporator	$\dot{Q}_E = \dot{Q}_{in} = \dot{m}(h_1 - h_4)$
COP of Refrigeration	$COP_R = \frac{\dot{Q}_{in}}{W_c} = \frac{h_1 - h_4}{h_2 - h_1}$
COP of Heat Pump	$COP_{HP} = \frac{\dot{Q}_{out}}{W_c} = \frac{h_2 - h_3}{h_2 - h_1}$

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### Example 2

□ **Step 3: Energy Analysis**

(a) The rate of heat removal from the outdoor air  
 $\dot{m} = 0.05\text{kg/s}$   
 $\dot{Q}_{in} = \dot{m}(h_1 - h_4) = 0.05(236.04 - 93.42) = 7.31\text{kw}$

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### Example 2

□ **Step 3: Energy Analysis**

(b) The rate of heat delivery to the indoor space  
 $\dot{m} = 0.05\text{kg/s}$   
 $\dot{Q}_{out} = \dot{m}(h_2 - h_3) = 0.05(272.05 - 93.42) = 8.93\text{kw}$

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### Example 2

□ **Step 3: Energy Analysis**

(c) The coefficient of performance (COP) of Heat Pump ( $COP_{HP}$ )  
 $\dot{m} = 0.05\text{kg/s}$   
 $W_{in} = \dot{m}(h_2 - h_1) = 0.05(272.05 - 236.04) = 1.8\text{kw}$   
 $COP_{HP} = \frac{\dot{Q}_{out}}{W_{in}} = \frac{8.93}{1.8} = 4.96$

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### Example 3

□ **Refrigeration System – Ideal**

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### Example 3

□ **Determine:**

- Quality  $x_4$
- Mass rate
- Compressor Power
- The coefficient of performance (COP) -  $COP_R$

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### Example 3

□ **Step 1. Draw cycle**

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### Example 3

□ **Step 2: Define the Properties**

State	T (°C)	P(MPa)	v (m³/kg)	h (kJ/kg)	s (kJ/(kg·K))	Condition
1		0.14*				$x_1 = 1$
2		0.8*				Super
3		0.8*				$x_3 = 0$
4		0.14*				$x_4 = ?$

□ **Note:** The data given is labeled by \*

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### Example 3

□ **Step 2 Define the Properties**

- State (1)
- It is in the saturated vapor region at a specified pressure,  $P = 0.14\text{MPa}$ ;
- Use Table A-15b (with Interpolation method if needed)

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### Example 3

□ **A partial list of Table A-15b**

TABLE A-15b  
Saturated refrigerant-134a—Pressure table

Press. MPa $P$	Temp. °C $T_{sat}$	Specific volume m³/kg		Internal energy kJ/kg		Enthalpy kJ/kg		Entropy kJ/(kg·K)		
		Sat. liquid $v_f$	Sat. vapor $v_g$	Sat. liquid $u_f$	Sat. vapor $u_g$	Sat. liquid $h_f$	Evap. $h_{fg}$	Sat. vapor $h_g$	Sat. liquid $s_f$	Sat. vapor $s_g$
0.06	-37.07	0.0007097	0.3100	3.41	206.12	3.46	221.27	224.72	0.0147	0.9520
0.08	-31.21	0.0007164	0.2566	10.41	209.46	10.47	217.92	228.39	0.0440	0.9447
0.10	-26.43	0.0007258	0.1917	16.22	212.18	16.29	215.06	231.35	0.0679	0.9366
0.12	-22.36	0.0007323	0.1614	21.23	214.50	21.32	212.54	233.86	0.0879	0.9284
0.14	-18.80	0.0007361	0.1365	25.66	216.52	25.77	210.27	236.04	0.1055	0.9222

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### Example 3

□ **Step 2 Define the Properties**

- **State (1)**

$$x_1 = 1$$

$$T_1 = T_{sat@0.14Mpa} = -18.8^\circ C$$

$$h_1 = h_{g@0.14Mpa} = 236.04 kJ/kg$$

$$s_1 = s_{g@0.14Mpa} = 0.9322 kJ/(kgK)$$

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### Example 3

□ **Step 2: Define the Properties**

State	T (°C)	P(MPa)	v (m³/kg)	h (kJ/kg)	s (kJ/(kgK))	Condition
1	-18.8	0.14*		236.04	0.9332	$x_1 = 1$
2		0.8*				
3		0.8*				$x_3 = 0$
4		0.14*				

□ **Note: The data given is labeled by \***

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### Example 3

□ **Step 2 Define the Properties**

- **State (2)**
- **It is in the superheated vapor region, at a specific pressure 0.8 Mpa**
- **And from State 1 to State 2 is Isentropic process,  $s_2 = s_1 = 0.9322$  (kJ/(kgK))**
- **Use (Table A-16) (with interpolation method if needed)**

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### Example 3

□ **A partial list of Table A-16**

T °C	v m³/kg	h kJ/kg	s kJ/(kg·K)
<b>P = 0.80 MPa (T<sub>sat</sub> = 31.33°C)</b>			
Sat.	0.0547	243.79	264.15
	0.02891	252.13	273.66
50	0.02846	261.62	284.39
60	0.02802	271.04	294.98
70	0.02759	280.45	305.50
80	0.02716	289.89	316.00
90	0.02673	299.37	326.52
100	0.02630	308.89	337.08
110	0.02587	318.37	347.71
120	0.02544	327.81	358.40
130	0.02501	337.24	369.19
140	0.02458	346.65	379.97
150	0.02415	356.05	390.75
160	0.02372	365.44	401.54
170	0.02329	374.82	412.33
180	0.02286	384.20	423.13

$s_2 = 0.9322$

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### Example 3

□ **Step 2: Define the Properties**

State	T (°C)	P(MPa)	v (m³/kg)	h (kJ/kg)	s (kJ/(kgK))	Condition
1	-18.8	0.14*		236.04	0.9332	$x_1 = 1$
2	38.54	0.8*		272.05	0.9322	
3		0.8*				$x_3 = 0$
4		0.14*				

□ **Note: The data given is labeled by \***

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### Example 3

□ **Step 2 Define the Properties**

- **State (3)**
- **It is in the saturated liquid region at a specified pressure, at a specified pressure 0.8 Mpa.**
- **Use Table A-15b (with Interpolation method if needed)**

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### Example 3

□ A partial list of Table A-15b

TABLE A-15b  
Saturated refrigerant-134a—Pressure table

Press. MPa <i>P</i>	Temp. °C <i>T<sub>sat</sub></i>	Specific volume m <sup>3</sup> /kg		Internal energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/(kg·K)	
		Sat. liquid <i>v<sub>f</sub></i>	Sat. vapor <i>v<sub>g</sub></i>	Sat. liquid <i>u<sub>f</sub></i>	Sat. vapor <i>u<sub>g</sub></i>	Sat. liquid <i>h<sub>f</sub></i>	Evap. <i>h<sub>fg</sub></i>	Sat. vapor <i>h<sub>g</sub></i>	Sat. liquid <i>s<sub>f</sub></i>	Sat. vapor <i>s<sub>g</sub></i>
0.7	26.72	0.000 832 8	0.0292	86.19	241.42	86.78	175.07	261.85	0.3242	0.9080
0.8	31.33	0.000 845 4	0.0355	92.75	243.78	93.42	170.73	264.15	0.3459	0.9066
0.9	35.53	0.000 857 6	0.0426	96.79	245.98	99.56	166.92	266.15	0.3656	0.9054
1.0	39.39	0.000 869 5	0.0502	104.42	247.77	105.29	162.68	267.97	0.3838	0.9043
1.2	46.32	0.000 892 6	0.0766	114.69	251.03	115.76	155.23	270.99	0.4164	0.9023

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### Example 3

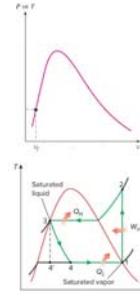
□ Step 2 Define the Properties

• State (3)

$$x_3 = 0$$

$$P_3 = P_{sat@0.8MPa} = 31.33^\circ\text{C}$$

$$h_3 = h_f@0.8MPa = 93.42\text{kJ/kg}$$



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### Example 3

□ Step 2: Define the Properties

State	T (°C)	P(MPa)	v (m <sup>3</sup> /kg)	h (kJ/kg)	s (kJ/(kgK))	Condition
1	-18.8	0.14*		236.04	0.9332	$x_1 = 1$
2	38.54	0.8*		272.05	0.9322	
3	31.33	0.8*		93.42		$x_3 = 0$
4		0.14*				

□ Note: The data given is labeled by \*

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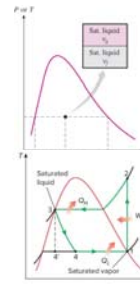
### Example 3

□ Step 2 Define the Properties

• State (4)

• It is inside the dome  
• Therefore, it is in a Saturated Liquid-Vapor Mixture at a specified temperature,  $T = -18.8^\circ\text{C}$ ; and a specified pressure  $P = 0.14\text{MPa}$

• It is an Isenthalpic – constant enthalpy processes from state 3 to state 4, therefore,  $h_4 = h_3 = 93.42\text{kJ/kg}$



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### Example 3

□ Step 2: Define the Properties

State	T (°C)	P(MPa)	v (m <sup>3</sup> /kg)	h (kJ/kg)	s (kJ/(kgK))	Condition
1	-18.8	0.14*		236.04	0.9332	$x_1 = 1$
2	38.54	0.8*		272.05	0.9322	
3	31.33	0.8*		93.42		$x_3 = 0$
4	-18.8	0.14*		93.42		

□ Note: The data given is labeled by \*

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### Energy Analysis

□ Refrigeration and Heat Pump

Energy Analysis	Equations
Compressor	$W_c = \dot{m}(h_2 - h_1)$
Condenser	$\dot{Q}_c = \dot{Q}_{out} = \dot{m}(h_2 - h_3)$
Expansion Valve	$h_3 = h_4 = h_{f4} + x(h_{g4} - h_{f4})$
Evaporator	$\dot{Q}_E = \dot{Q}_{in} = \dot{m}(h_1 - h_4)$
COP of Refrigeration	$COP_R = \frac{\dot{Q}_{in}}{W_c} = \frac{h_1 - h_4}{h_2 - h_1}$
COP of Heat Pump	$COP_{HP} = \frac{\dot{Q}_{out}}{W_c} = \frac{h_2 - h_3}{h_2 - h_1}$

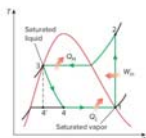
90

### Example 3

#### □ Step 3: Energy Analysis

(a)  $x_4$  ?

$$x_4 = \frac{h_4 - h_g}{h_g - h_f} = 0.322$$



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### Example 3

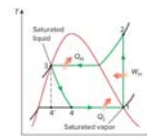
#### □ Step 3: Energy Analysis

(b) Mass rate

$$\dot{Q}_{in} = 300 \text{ kJ/min}$$

$$\dot{Q}_{in} = \dot{m}(h_1 - h_4)$$

$$\dot{m} = \frac{\dot{Q}_{in}}{h_1 - h_4} = 0.035 \text{ kg/s}$$



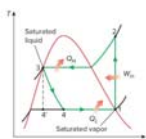
92

### Example 3

#### □ Step 3: Energy Analysis

(c) Compressor Power

$$\dot{W}_c = \dot{m}(h_2 - h_1) = 0.035(272.05 - 236.04) = 1.26 \text{ kW}$$



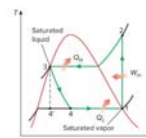
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### Example 3

#### □ Step 3: Energy Analysis

(d) The coefficient of performance (COP)

$$COP_R = \frac{\dot{Q}_{in}}{\dot{W}_c} = \frac{5}{1.26} = 3.97$$



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### Efficiency vs COP

- There are two type of devices, energy converters and energy transferring devices.
- The energy efficiency energy conversion devices is the ratio of Energy Output to the Energy Input like the energy efficiency.
- In an energy converter, the output will be a portion of the energy input and it may be less than the energy input. Therefore, the efficiency will be less than 100% by the laws of thermodynamics.

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### Efficiency vs COP

- The efficiency of a heat (energy) transferring devices is called the coefficient of performance (COP) unlike the energy conversion devices
- In an energy transfer device, the energy output is the amount of heat extracted from the heat source (Space to be cooled-in case of refrigeration).
- The extracted energy is not a portion of the input energy. The extracted energy can exceed the input energy. Therefore, the efficiency of an energy transferring devices can be higher than 100% without violating the first law of thermodynamics. Therefore, the name coefficient of performance.

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*What is next?*

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- **Continue on with Thermodynamics**
  - *Heat Transfer*

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