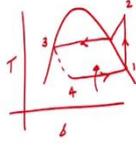


**Thermodynamics**  
**Professor Anand T N C**  
**Department of Mechanical Engineering**  
**Indian Institute of Technology, Madras**  
**Lecture 89**  
**Tutorial problem (1 number)**

(Refer Slide Time: 00:12)

In a vapour compression refrigeration cycle working with refrigerant R-134a, the evaporator and condenser temperatures are -5 °C and 30 °C respectively. Determine

- a) compression work
- b) refrigerating effect
- c) heat rejected in the condenser
- d) COP
- e) cycle efficiency

$$w_c = h_1 - h_2$$

$$q_L = h_1 - h_4$$

$$q_H = h_3 - h_2$$

$$COP = \frac{q_L}{|w_c|}$$

$$\eta = \frac{COP_{VCRS}}{COP_{Carnot}}$$



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Figure 1.

**Solution of the problem in Fig. 1.**

The VCRS cycle is shown on the T-S diagram in Fig. 1.

Compression work =  $w_c = h_1 - h_2$

Refrigerating effect = heat received by the refrigerant in the evaporator =  $q_L = h_1 - h_4$

Heat rejected in the condenser =  $h_3 - h_2$

$$COP_{VCRS} = \frac{q_L}{|w_c|}$$

Cycle efficiency =  $\eta = \frac{COP_{VCRS}}{COP_{Carnot}}$  ( $COP_{Carnot}$  is the COP of the reverse Carnot's cycle operating between the same two temperature reservoirs as the given VCRS cycle)

We can obtain enthalpy values in the above formulae from the tables for the refrigerant R134a. R134a stands for 1, 1, 1, 2- tetrafluoroethane.

Different tables have different fixed reference points. Properties at other conditions are measured with respect to this reference point. At the same condition, the properties may be different in different tables because the reference points are different for different tables. However, the difference between a property at two different conditions is the same irrespective of the table used. It is recommended that the students continue using one table throughout.

We need enthalpy values at states 1, 2, 3 and 4.

We have saturated vapor at state 1. Hence,  $h_g(at - 5^\circ\text{C}) = h_1 = 395.9 \frac{\text{kJ}}{\text{kg}}$

We know that states 2 and 3 lie on an isobar. State 2 is in superheated zone. At  $30^\circ\text{C}$ , the saturation pressure  $p_{\text{sat}}=771 \text{ kPa}$ . The process 1-2 is isentropic. Hence,  $s_2 = s_1 = s_g(at - 5^\circ\text{C}) = 1.7308 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$ . Now, we need enthalpy ( $h_2$ ) at the state where  $p=771 \text{ kPa}$  and  $s=1.7308 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$ .

If we have table with better resolution for pressure and temperature values, it would be easy to get enthalpy value at  $p=771 \text{ kPa}$  and  $s=1.7308 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$ , which is in the superheated zone. However, we do not have such table here. In such a case, we can do interpolation and calculate values at the required condition or use the value at the condition which is closest to the required condition and listed in the table. In the table we have for superheated refrigerant, at  $p=750 \text{ kPa}$  and  $T=35^\circ\text{C}$ , the entropy value is very close to  $s=1.7308 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$ . Hence, we will use enthalpy value at  $p=750 \text{ kPa}$  and  $T=35^\circ\text{C}$ , which is  $h_2 = 420.8 \text{ kJ/kg}$ .

At state 3, we have saturated liquid at  $30^\circ\text{C}$ . Hence,  $h_3 = h_f(at 30^\circ\text{C}) = 241.8 \frac{\text{kJ}}{\text{kg}}$

Throttling is an isenthalpic process. Hence,  $h_4 = h_3 = 241.8 \frac{\text{kJ}}{\text{kg}}$

Now, we have the values of enthalpy at all the states.

Hence, Compression work  $= w_c = h_1 - h_2 = -24.9 \frac{\text{kJ}}{\text{kg}}$

Refrigerating effect = heat received by the refrigerant in the evaporator =  $q_L = h_1 - h_4 = 154.1 \frac{kJ}{kg}$

Heat rejected in the condenser =  $h_3 - h_2 = -179 \frac{kJ}{kg}$

$$COP_{VCRS} = \frac{q_L}{|w_c|} = 6.2$$

For calculating cycle efficiency, we need  $COP_{Carnot}$ .

$$COP_{Carnot} = \frac{Q_L}{Q_H - Q_L} = \frac{1}{\frac{Q_H}{Q_L} - 1} = \frac{1}{\frac{T_H}{T_L} - 1} = \frac{T_L}{T_H - T_L} = \frac{268}{303 - 268} = 7.66$$

(This is the maximum COP achievable between the temperature reservoirs at -5 °C and 30 °C.)

$$\text{Hence, cycle efficiency } \eta = \frac{COP_{VCRS}}{COP_{Carnot}} = \frac{6.2}{7.66} = 0.81$$

Hence, the VCRS cycle in the problem is around 81 % as efficient as the Carnot's cycle. In reality, the COP of the VCRS cycle is even lower as the process in the compressor is also irreversible.

(Refer Slide Time 05:27)

Appendix C: Property Tables for R134a

Tables C-1 and C-2 present data for saturated liquid and saturated vapor. Table C-1 is presented information at regular intervals of temperature while Table C-2 is presented at regular intervals of pressure. Table C-3 presents data for superheated vapor over a matrix of temperatures and pressures. These tables were generated using EES with the substance R134a which implements the fundamental equation of state developed by R. Tillner-Roth and H.D. Bachr, An International Standard Formulation for the Thermodynamic Properties of 1,1,1,2-Tetrafluoroethane (HFC-134a) for Temperatures from 170 K to 455 K, and Pressures up to 70 MPa, J. Phys. Chem. Ref. Data, Vol. 23, No. 5, 1994.

Table C-1: Properties of Saturated R134a, Presented at Regular Intervals of Temperature

Temp T (°C)	Pressure P (kPa)	Specific volume v <sub>f</sub> (m <sup>3</sup> /kg)	Specific volume v <sub>g</sub> (m <sup>3</sup> /kg)	Specific internal energy (kJ/kg)	Specific enthalpy h <sub>f</sub> (kJ/kg)	Specific enthalpy h <sub>g</sub> (kJ/kg)	Specific entropy s <sub>f</sub> (kJ/kg·K)	Specific entropy s <sub>g</sub> (kJ/kg·K)	T (°C)
-40	51.25	0.00065	0.30684	-41.4	207.38	180	0.2256	0.6907	-40
-35	60.19	0.00072	0.26173	-32.5	210.25	162.9	0.2203	0.6619	-35
-30	64.43	0.00077	0.22577	-22.8	212.12	146.4	0.2150	0.6359	-30
-25	106.5	0.00080	0.18532	-12.9	213.99	130.9	0.2100	0.6120	-25
-20	133.9	0.00081	0.14715	-2.1	214.86	116.4	0.2053	0.5907	-20
-15	164.0	0.00081	0.11366	8.5	215.72	102.9	0.2010	0.5715	-15
-10	200.7	0.00080	0.08380	18.3	216.56	90.4	0.1970	0.5541	-10
-5	243.5	0.00078	0.05723	27.4	217.38	78.9	0.1933	0.5384	-5
0	292.0	0.00075	0.03344	35.8	218.18	68.4	0.1900	0.5243	0
5	346.9	0.00072	0.01940	43.6	218.96	58.9	0.1870	0.5116	5
10	408.9	0.00069	0.01047	50.9	219.72	50.4	0.1843	0.5001	10
15	477.8	0.00066	0.00511	57.8	220.46	42.9	0.1819	0.4896	15
20	554.1	0.00063	0.00260	64.3	221.18	36.4	0.1798	0.4801	20
25	638.5	0.00060	0.00139	70.5	221.88	30.9	0.1779	0.4715	25
30	731.8	0.00057	0.00076	76.4	222.56	26.4	0.1762	0.4637	30
35	834.8	0.00054	0.00046	82.1	223.22	22.9	0.1747	0.4566	35
40	948.4	0.00051	0.00027	87.6	223.86	19.4	0.1734	0.4501	40
45	1073.5	0.00048	0.00016	92.9	224.48	16.0	0.1722	0.4442	45
50	1210.1	0.00045	0.00009	98.0	225.08	12.6	0.1711	0.4389	50
55	1358.2	0.00042	0.00005	102.9	225.66	9.3	0.1701	0.4341	55
60	1517.8	0.00039	0.00003	107.6	226.22	6.0	0.1692	0.4297	60
65	1688.9	0.00036	0.00002	112.1	226.76	2.8	0.1684	0.4257	65
70	1871.6	0.00033	0.00001	116.4	227.28	-0.3	0.1677	0.4220	70
75	2066.0	0.00030	0.00000	120.5	227.78	-3.4	0.1671	0.4185	75
80	2272.2	0.00027	0.00000	124.4	228.26	-6.5	0.1666	0.4152	80
85	2490.2	0.00024	0.00000	128.1	228.72	-9.6	0.1661	0.4120	85
90	2720.9	0.00021	0.00000	131.6	229.16	-12.7	0.1657	0.4089	90
95	2964.4	0.00018	0.00000	134.9	229.58	-15.8	0.1653	0.4059	95
100	3321.7	0.00015	0.00000	138.0	230.00	-18.9	0.1650	0.4030	100
100.01	3321.7	0.00015	0.00000	138.0	230.00	-18.9	0.1650	0.4030	100.01



(Refer Slide Time 08:00)

Technical Information  
T-134a-SI

**DuPont™ Suva®**  
refrigerants

**Thermodynamic  
Properties  
of  
HFC-134a**

(1,1,1,2-tetrafluoroethane)

DuPont Product Names:  
 DuPont™ Suva® 134a Refrigerant  
 DuPont™ Formax® Z-4 Blowing Agent  
 DuPont™ Dymel® 134a Aerosol Propellant  
 DuPont™ Dymel® 134aP Aerosol Propellant (Pharmaceutical Grade)

  
The miracles of science™

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**TABLE 1**  
HFC-134a Saturation Properties—Temperature Table

TEMP °C	PRESSURE kPa(a)	SUBLIME LINE		LIQUID LINE		CRITICAL POINT		SATURATED VAPOR		SATURATED LIQUID		TEMP °C
		TEMP °C	PRESSURE kPa(a)	TEMP °C	PRESSURE kPa(a)	TEMP °C	PRESSURE kPa(a)	TEMP °C	PRESSURE kPa(a)	TEMP °C	PRESSURE kPa(a)	
-100	0.01	0.006	0.000	10.69	0.006	13.2	20.2	0.01	0.01	0.006	0.006	-100
-90	0.01	0.006	0.000	10.70	0.006	13.2	20.2	0.01	0.01	0.006	0.006	-90
-80	0.01	0.006	0.000	10.71	0.006	13.2	20.2	0.01	0.01	0.006	0.006	-80
-70	0.01	0.006	0.000	10.72	0.006	13.2	20.2	0.01	0.01	0.006	0.006	-70
-60	0.01	0.006	0.000	10.73	0.006	13.2	20.2	0.01	0.01	0.006	0.006	-60
-50	0.01	0.006	0.000	10.74	0.006	13.2	20.2	0.01	0.01	0.006	0.006	-50
-40	0.01	0.006	0.000	10.75	0.006	13.2	20.2	0.01	0.01	0.006	0.006	-40
-30	0.01	0.006	0.000	10.76	0.006	13.2	20.2	0.01	0.01	0.006	0.006	-30
-20	0.01	0.006	0.000	10.77	0.006	13.2	20.2	0.01	0.01	0.006	0.006	-20
-10	0.01	0.006	0.000	10.78	0.006	13.2	20.2	0.01	0.01	0.006	0.006	-10
0	0.01	0.006	0.000	10.79	0.006	13.2	20.2	0.01	0.01	0.006	0.006	0
10	0.01	0.006	0.000	10.80	0.006	13.2	20.2	0.01	0.01	0.006	0.006	10
20	0.01	0.006	0.000	10.81	0.006	13.2	20.2	0.01	0.01	0.006	0.006	20
30	0.01	0.006	0.000	10.82	0.006	13.2	20.2	0.01	0.01	0.006	0.006	30
40	0.01	0.006	0.000	10.83	0.006	13.2	20.2	0.01	0.01	0.006	0.006	40
50	0.01	0.006	0.000	10.84	0.006	13.2	20.2	0.01	0.01	0.006	0.006	50
60	0.01	0.006	0.000	10.85	0.006	13.2	20.2	0.01	0.01	0.006	0.006	60
70	0.01	0.006	0.000	10.86	0.006	13.2	20.2	0.01	0.01	0.006	0.006	70
80	0.01	0.006	0.000	10.87	0.006	13.2	20.2	0.01	0.01	0.006	0.006	80
90	0.01	0.006	0.000	10.88	0.006	13.2	20.2	0.01	0.01	0.006	0.006	90
100	0.01	0.006	0.000	10.89	0.006	13.2	20.2	0.01	0.01	0.006	0.006	100
110	0.01	0.006	0.000	10.90	0.006	13.2	20.2	0.01	0.01	0.006	0.006	110
120	0.01	0.006	0.000	10.91	0.006	13.2	20.2	0.01	0.01	0.006	0.006	120
130	0.01	0.006	0.000	10.92	0.006	13.2	20.2	0.01	0.01	0.006	0.006	130
140	0.01	0.006	0.000	10.93	0.006	13.2	20.2	0.01	0.01	0.006	0.006	140
150	0.01	0.006	0.000	10.94	0.006	13.2	20.2	0.01	0.01	0.006	0.006	150
160	0.01	0.006	0.000	10.95	0.006	13.2	20.2	0.01	0.01	0.006	0.006	160
170	0.01	0.006	0.000	10.96	0.006	13.2	20.2	0.01	0.01	0.006	0.006	170
180	0.01	0.006	0.000	10.97	0.006	13.2	20.2	0.01	0.01	0.006	0.006	180
190	0.01	0.006	0.000	10.98	0.006	13.2	20.2	0.01	0.01	0.006	0.006	190
200	0.01	0.006	0.000	10.99	0.006	13.2	20.2	0.01	0.01	0.006	0.006	200
210	0.01	0.006	0.000	11.00	0.006	13.2	20.2	0.01	0.01	0.006	0.006	210
220	0.01	0.006	0.000	11.01	0.006	13.2	20.2	0.01	0.01	0.006	0.006	220
230	0.01	0.006	0.000	11.02	0.006	13.2	20.2	0.01	0.01	0.006	0.006	230
240	0.01	0.006	0.000	11.03	0.006	13.2	20.2	0.01	0.01	0.006	0.006	240
250	0.01	0.006	0.000	11.04	0.006	13.2	20.2	0.01	0.01	0.006	0.006	250
260	0.01	0.006	0.000	11.05	0.006	13.2	20.2	0.01	0.01	0.006	0.006	260
270	0.01	0.006	0.000	11.06	0.006	13.2	20.2	0.01	0.01	0.006	0.006	270
280	0.01	0.006	0.000	11.07	0.006	13.2	20.2	0.01	0.01	0.006	0.006	280
290	0.01	0.006	0.000	11.08	0.006	13.2	20.2	0.01	0.01	0.006	0.006	290
300	0.01	0.006	0.000	11.09	0.006	13.2	20.2	0.01	0.01	0.006	0.006	300
310	0.01	0.006	0.000	11.10	0.006	13.2	20.2	0.01	0.01	0.006	0.006	310
320	0.01	0.006	0.000	11.11	0.006	13.2	20.2	0.01	0.01	0.006	0.006	320
330	0.01	0.006	0.000	11.12	0.006	13.2	20.2	0.01	0.01	0.006	0.006	330
340	0.01	0.006	0.000	11.13	0.006	13.2	20.2	0.01	0.01	0.006	0.006	340
350	0.01	0.006	0.000	11.14	0.006	13.2	20.2	0.01	0.01	0.006	0.006	350
360	0.01	0.006	0.000	11.15	0.006	13.2	20.2	0.01	0.01	0.006	0.006	360
370	0.01	0.006	0.000	11.16	0.006	13.2	20.2	0.01	0.01	0.006	0.006	370
380	0.01	0.006	0.000	11.17	0.006	13.2	20.2	0.01	0.01	0.006	0.006	380
390	0.01	0.006	0.000	11.18	0.006	13.2	20.2	0.01	0.01	0.006	0.006	390
400	0.01	0.006	0.000	11.19	0.006	13.2	20.2	0.01	0.01	0.006	0.006	400
410	0.01	0.006	0.000	11.20	0.006	13.2	20.2	0.01	0.01	0.006	0.006	410
420	0.01	0.006	0.000	11.21	0.006	13.2	20.2	0.01	0.01	0.006	0.006	420
430	0.01	0.006	0.000	11.22	0.006	13.2	20.2	0.01	0.01	0.006	0.006	430
440	0.01	0.006	0.000	11.23	0.006	13.2	20.2	0.01	0.01	0.006	0.006	440
450	0.01	0.006	0.000	11.24	0.006	13.2	20.2	0.01	0.01	0.006	0.006	450
460	0.01	0.006	0.000	11.25	0.006	13.2	20.2	0.01	0.01	0.006	0.006	460
470	0.01	0.006	0.000	11.26	0.006	13.2	20.2	0.01	0.01	0.006	0.006	470
480	0.01	0.006	0.000	11.27	0.006	13.2	20.2	0.01	0.01	0.006	0.006	480
490	0.01	0.006	0.000	11.28	0.006	13.2	20.2	0.01	0.01	0.006	0.006	490
500	0.01	0.006	0.000	11.29	0.006	13.2	20.2	0.01	0.01	0.006	0.006	500



(Refer Slide Time 08:44)

**For IP units**  
 $T$  and  $T_m$  in  $^{\circ}\text{R}$ ;  $T = 459.67 + Y$  in  $^{\circ}\text{F}$ ;  $h$  in  $\text{Btu/lb}$  and  $P$  in  $\text{psia}$   
 $R = 0.0602 \text{ (psia}^2/\text{lb}^2)^{\circ}\text{R}$   
 $A, B, C, D, E, F$  are constants:  
 $A_1 = -3.13708 \text{ E-04}$   $A_2 = 1.687907 \text{ E-01}$   
 $B_1 = 9.115011 \text{ E-04}$   $B_2 = -2.131040 \text{ E-04}$   
 $C_1 = -7.222897 \text{ E-01}$   $C_2 = -2.843653 \text{ E-00}$   
 $A_3 = -6.061094 \text{ E-01}$   $A_4 = -1.144311 \text{ E-02}$   
 $B_3 = 6.526409 \text{ E-04}$   $B_4 = 1.493936 \text{ E-05}$   
 $C_3 = 1.277414 \text{ E-01}$   $C_4 = 1.921091 \text{ E-01}$   
 $b = 6.016014 \text{ E-03}$   $k = 4.599967 \text{ E-00}$

**Mod Gas Heat Capacity (at constant volume):**  
 $C_v^* = a + bT + cT^2 + dT^3 + eT^4$

**For SI units**  
 $C_v^*$  in  $\text{kJ/kg}\cdot\text{K}$   
 $T$  in  $\text{K}$ ;  $T = 273.15 + Y$  in  $^{\circ}\text{C}$   
 $a, b, c, d, e$  are constants:  
 $a = 1.151638 \text{ E-04}$   $d = -1.754491 \text{ E-04}$   
 $b = -1.658624 \text{ E-02}$   $f = -3.625199 \text{ E-04}$   
 $c = 4.153178 \text{ E-05}$

**For IP units**  
 $C_p^*$  in  $\text{Btu/lb}\cdot^{\circ}\text{R}$   
 $T$  in  $^{\circ}\text{R}$ ;  $T = 459.67 + Y$  in  $^{\circ}\text{F}$   
 $a, b, c, d, e$  are constants:  
 $a = 7.540297 \text{ E-01}$   $d = -1.133868 \text{ E-09}$   
 $b = -2.19025 \text{ E-03}$   $f = -2.344091 \text{ E-04}$   
 $c = 3.211685 \text{ E-06}$

**3. Vapor Pressure**  
 $\ln(P_{\text{sat}} - A) + BT + C \ln(T + D) + E/(T - F) = \ln(P_{\text{sat}})$

**For SI units**  
 $T$  in  $\text{K}$ ;  $T = 273.15 + Y$  in  $^{\circ}\text{C}$   
 $A, B, C, D, E, F$  are constants:  
 $A = 4.606039 \text{ E-01}$   $D = 7.616085 \text{ E-03}$   
 $B = -2.362540 \text{ E-03}$   $E = 2.342844 \text{ E-01}$   
 $C = -1.30693 \text{ E-01}$   $F = 3.78111 \text{ E-02}$

**For IP units**  
 $T$  in  $^{\circ}\text{R}$ ;  $T = 459.67 + Y$  in  $^{\circ}\text{F}$   
 $A, B, C, D, E, F$  are constants:  
 $A = 4.252629 \text{ E-01}$   $D = 4.25114 \text{ E-03}$   
 $B = -4.26988 \text{ E-03}$   $E = 2.14264 \text{ E-01}$   
 $C = -1.26683 \text{ E-01}$   $F = 6.716009 \text{ E-02}$

**4. Density of the Saturated Liquid**  
 $\ln(\rho_{\text{sat}} - R_0(T - T_0)^2 + C_1(T - T_0)^3 + B_1(T - T_0)) = \ln(\rho_{\text{sat}})$

**For SI units**  
 $T_0 = T_0^*$  both in  $\text{K}$ ;  $T_0^* = 273.15$  and  $q_0$  in  $\text{kJ/kg}^{\circ}\text{C}$   
 $A_0, B_0, C_0, D_0, E_0$  are constants:  
 $A_0 = 2.52164 \text{ E-02}$   $D_0 = -9.49172 \text{ E-02}$   
 $B_0 = 7.55134 \text{ E-02}$   $E_0 = 5.915660 \text{ E-02}$   
 $C_0 = 1.02876 \text{ E-03}$

**For IP units**  
 $T_0 = T_0^*$  both in  $^{\circ}\text{R}$ ;  $T_0^* = 459.67$  and  $q_0$  in  $\text{Btu/lb}^{\circ}\text{F}$   
 $A_0, B_0, C_0, D_0, E_0$  are constants:  
 $A_0 = 1.29718 \text{ E-01}$   $D_0 = -5.52348 \text{ E-01}$   
 $B_0 = 4.71448 \text{ E-01}$   $E_0 = 3.76532 \text{ E-01}$   
 $C_0 = 6.42104 \text{ E-03}$



**MBWR coefficients for HFC-134a:**  
 $b_0 = -6.581 \text{ E-02}$   $b_1 = 5.809 \text{ E-01}$   $b_2 = -1.376 \text{ E-01}$   
 $b_3 = 2.289 \text{ E-01}$   $b_4 = -5.526 \text{ E-01}$   $b_5 = -1.932 \text{ E-01}$   
 $b_6 = -2.721 \text{ E-01}$   $b_7 = 1.629 \text{ E-01}$   $b_8 = 7.294 \text{ E-01}$   
 $b_9 = -1.172 \text{ E-01}$   $b_{10} = 8.880 \text{ E-01}$   $b_{11} = 3.966 \text{ E-01}$   
 $b_{12} = -2.566 \text{ E-01}$   $b_{13} = -2.438 \text{ E-01}$   $b_{14} = 3.166 \text{ E-01}$   
 $b_{15} = 1.432 \text{ E-01}$   $b_{16} = -1.015 \text{ E-01}$   $b_{17} = 1.171 \text{ E-01}$   
 $b_{18} = -2.728 \text{ E-01}$   $b_{19} = -0.613 \text{ E-01}$   $b_{20} = -6.475 \text{ E-01}$   
 $b_{21} = -3.729 \text{ E-01}$   $b_{22} = 1.261 \text{ E-01}$   $b_{23} = -0.474 \text{ E-01}$   
 $b_{24} = 1.226 \text{ E-01}$   $b_{25} = 1.468 \text{ E-01}$   $b_{26} = -5.184 \text{ E-01}$   
 $b_{27} = -8.139 \text{ E-01}$   $b_{28} = 3.032 \text{ E-01}$   $b_{29} = 1.139 \text{ E-01}$   
 $b_{30} = -1.385 \text{ E-01}$   $b_{31} = 9.067 \text{ E-01}$

**Mod Gas Heat Capacity Equation (at constant pressure):**  
 $C_p^* (\text{J/mole}\cdot\text{K}) = q_0 + q_1 T + q_2 T^2 + q_3 T^3$   
 $q_0 = 1.94000 \text{ E-01}$   $q_1 = -1.29665 \text{ E-04}$   
 $q_2 = 2.58331 \text{ E-08}$   $q_3 = 8.314417 \text{ J/mole}\cdot\text{K}^2$   
 $R = 192.0$

**Properties calculated in SI units from the equation and constants listed above can be converted to IP units using the conversion factors shown below. Please note that in converting enthalpy and entropy from SI to IP units, a change in reference states must be included (from  $h = 200$  and  $S = 1$  in  $^{\circ}\text{C}$  to  $h = 0$  and  $S = 0$  in  $^{\circ}\text{F}$  for IP units). Key conversion equation below.  $h$  (ref) and  $S$  (ref) are saturated liquid enthalpy and entropy at  $40^{\circ}\text{C}$ . For HFC-134a,  $h$  (ref) = 144.41 kJ/kg and  $S$  (ref) = 0.7607 kJ/kg $\cdot\text{K}$ .**

$P$  (psia)  $= P$  (kPa)  $\cdot 0.14504$   
 $T$  ( $^{\circ}\text{F}$ )  $= T$  ( $^{\circ}\text{C}$ )  $\cdot 1.8 + 32$   
 $D$  (lb/lb $^3$ )  $= D$  (kg/m $^3$ )  $\cdot 0.062428$   
 $v$  (ft $^3$ /lb)  $= v$  (m $^3$ /kg)  $\cdot 16.018$   
 $h$  (Btu/lb)  $= h$  (kJ/kg)  $\cdot 0.41868$   
 $S$  (Btu/lb $\cdot^{\circ}\text{R}$ )  $= S$  (kJ/kg $\cdot\text{K}$ )  $\cdot 0.41868$   
 $C_p$  (Btu/lb $\cdot^{\circ}\text{F}$ )  $= C_p$  (kJ/kg $\cdot\text{K}$ )  $\cdot 0.23901$   
 $C_v$  (Btu/lb $\cdot^{\circ}\text{F}$ )  $= C_v$  (kJ/kg $\cdot\text{K}$ )  $\cdot 0.23901$   
 $\rho$  (lb/ft $^3$ )  $= \rho$  (kg/m $^3$ )  $\cdot 1.9403$

**2. Martin-Huo Equation of State (SI from MBWR data)**  
 As previously stated, the thermodynamic properties presented in these tables are based on the MBWR equation of state. Coefficients for the Martin-Huo equation of state are presented below for the convenience of those who may have existing computer programs based on this equation of state. While as accurate as the data from the MBWR equation of state, particularly in the supercritical region, data calculated using these Martin-Huo coefficients should be sufficient for most engineering calculations.

$P = RT/(V - b) + \frac{a}{V^2} (A + B_1/T + C_1 \exp(-k_1 T/V)) (V - b)^{-1}$

**For SI units**  
 $T$  and  $T_m$  in  $\text{K}$ ;  $T = 273.15 + Y$  in  $^{\circ}\text{C}$ ;  $h$  and  $P$  in  $\text{kJ/kg}$  and  $\text{Pa}$  respectively  
 $R = 0.08314 \text{ kJ/kg}\cdot\text{K}$   
 $A, B_1, C_1, k_1$  are constants:  
 $A_1 = -8.99483 \text{ E-02}$   $A_2 = 1.77071 \text{ E-05}$   
 $B_1 = 4.60848 \text{ E-01}$   $B_2 = -6.89979 \text{ E-01}$   
 $C_1 = -2.07434 \text{ E-00}$   $C_2 = -2.97761 \text{ E-04}$   
 $A_3 = -1.01682 \text{ E-01}$   $A_4 = -1.40440 \text{ E-01}$   
 $B_3 = 2.74257 \text{ E-04}$   $B_4 = 1.67835 \text{ E-10}$   
 $C_3 = 2.14259 \text{ E-02}$   $C_4 = 1.25922 \text{ E-06}$   
 $k = 3.75887 \text{ E-04}$   $k_1 = 4.99967$



(Refer Slide Time: 09:03)

**Thermodynamic Properties of HFC-134a Refrigerant  
(1,1,1,2-tetrafluoroethane)**  
SI Units

New tables of the thermodynamic properties of HFC-134a have been developed and are presented here. These tables are based on experimental data from the Database at the National Institute of Standards and Technology (NIST). Equations have been developed, based on the Modified Benedict-Webb-Rubin (MBWR) equation of state, which represent the data with accuracy and consistency throughout the entire range of temperature, pressure, and density.

**Physical Properties**

Chemical Formula	CH <sub>2</sub> FCF <sub>3</sub>
Molecular Weight	102.03
Boiling Point at One Atmosphere	-26.06°C (-14.9°F)
Critical Temperature	101.06°C (213.9°F)
Critical Pressure	4063.1 kPa (abs) (588.9 psia)
Critical Density	515.3 kg/m <sup>3</sup> (32.17 lb/ft <sup>3</sup> )
Critical Volume	0.00194 m <sup>3</sup> /kg (0.011 ft <sup>3</sup> /lb)

**Units and Factors**

- T = temperature in °C
- T = temperature in K = °C + 273.15
- P = pressure in kilopascals absolute (kPa (abs))
- v<sub>l</sub> = volume of saturated liquid in m<sup>3</sup>/kg
- v<sub>v</sub> = volume of saturated vapor in m<sup>3</sup>/kg
- v<sub>l</sub> = volume of superheated vapor in m<sup>3</sup>/kg
- d<sub>l</sub> = 1/v<sub>l</sub> = density of saturated liquid in kg/m<sup>3</sup>
- d<sub>v</sub> = 1/v<sub>v</sub> = density of saturated vapor in kg/m<sup>3</sup>
- h<sub>l</sub> = enthalpy of saturated liquid in kJ/kg
- h<sub>v</sub> = enthalpy of saturated vapor in kJ/kg
- h = enthalpy of superheated vapor in kJ/kg
- s<sub>l</sub> = entropy of saturated liquid in kJ/kg(K)
- s<sub>v</sub> = entropy of saturated vapor in kJ/kg(K)
- s = entropy of superheated vapor in kJ/kg(K)
- C<sub>p</sub> = heat capacity at constant pressure in kJ/kg(°C)
- C<sub>v</sub> = heat capacity at constant volume in kJ/kg(°C)
- v = velocity of sound in m/s
- The gas constant R = 0.1414 kJ/kg(K) for HFC-134a, R = 0.08314 kJ/kg·K. One atmosphere = 101.325 kPa. Reference point for enthalpy and entropy: h<sub>o</sub> = 261 kJ/kg at 0°C, s<sub>o</sub> = 1.5 kJ/kg·K at 0°C.

**Equations**  
The Modified Benedict-Webb-Rubin (MBWR) equation of state was used to calculate the tables of thermodynamic properties. It was chosen as the preferred equation of state because it provided the most accurate fit of the thermodynamic data over the entire range of temperature and pressure presented in these tables. The data fit and values of constants for HFC-134a were performed for the First at the National Institute of Standards and Technology (NIST) under the supervision of Dr. Mark O. McLinden.

The constants were calculated in SI units. For conversion of thermodynamic properties to Engineering (EP) units, properties must be calculated in SI units and converted to EP units. Conversion factors are provided for each property derived from the MBWR equation of state.

**1. Equation of State (MBWR)**

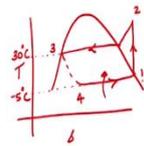
$$\frac{P}{RT} = \frac{1}{1 - b_1 \frac{v}{V_m}} + \frac{a_1}{v^2} + \frac{a_2}{v^3} + \frac{a_3}{v^4} + \frac{a_4}{v^5} + \frac{a_5}{v^6} + \frac{a_6}{v^7} + \frac{a_7}{v^8} + \frac{a_8}{v^9} + \frac{a_9}{v^{10}} + \frac{a_{10}}{v^{11}} + \frac{a_{11}}{v^{12}} + \frac{a_{12}}{v^{13}} + \frac{a_{13}}{v^{14}} + \frac{a_{14}}{v^{15}} + \frac{a_{15}}{v^{16}} + \frac{a_{16}}{v^{17}} + \frac{a_{17}}{v^{18}} + \frac{a_{18}}{v^{19}} + \frac{a_{19}}{v^{20}} + \frac{a_{20}}{v^{21}} + \frac{a_{21}}{v^{22}} + \frac{a_{22}}{v^{23}} + \frac{a_{23}}{v^{24}} + \frac{a_{24}}{v^{25}} + \frac{a_{25}}{v^{26}} + \frac{a_{26}}{v^{27}} + \frac{a_{27}}{v^{28}} + \frac{a_{28}}{v^{29}} + \frac{a_{29}}{v^{30}} + \frac{a_{30}}{v^{31}} + \frac{a_{31}}{v^{32}} + \frac{a_{32}}{v^{33}} + \frac{a_{33}}{v^{34}} + \frac{a_{34}}{v^{35}} + \frac{a_{35}}{v^{36}} + \frac{a_{36}}{v^{37}} + \frac{a_{37}}{v^{38}} + \frac{a_{38}}{v^{39}} + \frac{a_{39}}{v^{40}} + \frac{a_{40}}{v^{41}} + \frac{a_{41}}{v^{42}} + \frac{a_{42}}{v^{43}} + \frac{a_{43}}{v^{44}} + \frac{a_{44}}{v^{45}} + \frac{a_{45}}{v^{46}} + \frac{a_{46}}{v^{47}} + \frac{a_{47}}{v^{48}} + \frac{a_{48}}{v^{49}} + \frac{a_{49}}{v^{50}} + \frac{a_{50}}{v^{51}} + \frac{a_{51}}{v^{52}} + \frac{a_{52}}{v^{53}} + \frac{a_{53}}{v^{54}} + \frac{a_{54}}{v^{55}} + \frac{a_{55}}{v^{56}} + \frac{a_{56}}{v^{57}} + \frac{a_{57}}{v^{58}} + \frac{a_{58}}{v^{59}} + \frac{a_{59}}{v^{60}} + \frac{a_{60}}{v^{61}} + \frac{a_{61}}{v^{62}} + \frac{a_{62}}{v^{63}} + \frac{a_{63}}{v^{64}} + \frac{a_{64}}{v^{65}} + \frac{a_{65}}{v^{66}} + \frac{a_{66}}{v^{67}} + \frac{a_{67}}{v^{68}} + \frac{a_{68}}{v^{69}} + \frac{a_{69}}{v^{70}} + \frac{a_{70}}{v^{71}} + \frac{a_{71}}{v^{72}} + \frac{a_{72}}{v^{73}} + \frac{a_{73}}{v^{74}} + \frac{a_{74}}{v^{75}} + \frac{a_{75}}{v^{76}} + \frac{a_{76}}{v^{77}} + \frac{a_{77}}{v^{78}} + \frac{a_{78}}{v^{79}} + \frac{a_{79}}{v^{80}} + \frac{a_{80}}{v^{81}} + \frac{a_{81}}{v^{82}} + \frac{a_{82}}{v^{83}} + \frac{a_{83}}{v^{84}} + \frac{a_{84}}{v^{85}} + \frac{a_{85}}{v^{86}} + \frac{a_{86}}{v^{87}} + \frac{a_{87}}{v^{88}} + \frac{a_{88}}{v^{89}} + \frac{a_{89}}{v^{90}} + \frac{a_{90}}{v^{91}} + \frac{a_{91}}{v^{92}} + \frac{a_{92}}{v^{93}} + \frac{a_{93}}{v^{94}} + \frac{a_{94}}{v^{95}} + \frac{a_{95}}{v^{96}} + \frac{a_{96}}{v^{97}} + \frac{a_{97}}{v^{98}} + \frac{a_{98}}{v^{99}} + \frac{a_{99}}{v^{100}}$$



(Refer Slide Time 09:57)

In a vapour compression refrigeration cycle working with refrigerant R-134a, the evaporator and condenser temperatures are -5 °C and 30 °C respectively. Determine

- compression work
- refrigerating effect
- heat rejected in the condenser
- COP
- cycle efficiency



$$\begin{aligned}
 w_c &= h_1 - h_2 \\
 q_L &= h_1 - h_4 \\
 q_H &= h_3 - h_2 \\
 COP &= \frac{q_L}{|w_c|} \\
 \eta &= \frac{COP_{VCS}}{COP_{Carnot}}
 \end{aligned}$$



(Refer Slide Time 10:38)

Appendix C: Property Tables for R134a

Tables C-1 and C-2 present data for saturated liquid and saturated vapor. Table C-1 is presented at regular intervals of temperature while Table C-2 is presented at regular intervals of pressure. Table C-3 presents data for superheated vapor over a matrix of temperatures and pressures. These tables were generated using EES with the substance R134a which implements the fundamental equation of state developed by B. Tillner-Roth and H.E. Becker. An International Standard Formulation for the Thermodynamic Properties of 1,1,1,2-Tetrafluoroethane (HFC-134a) for Temperatures from 170 K to 455 K and Pressures up to 70 MPa. J. Phys. Chem. Ref. Data, Vol. 23, No. 5, 1994.

Temp T (°C)	Pressure P (MPa)	Specific volume v <sub>f</sub> (m <sup>3</sup> /kg)	Specific internal energy u <sub>f</sub> (kJ/kg)	Specific enthalpy h <sub>f</sub> (kJ/kg)	Specific entropy s <sub>f</sub> (kJ/kg·K)	Temp T (°C)	
-40	0.5126	0.0004	-2.01	20.09	0.10	0.000	0.5061
-30	0.6119	0.0004	-2.01	20.09	0.10	0.000	0.5061
-20	0.7170	0.0004	-2.01	20.09	0.10	0.000	0.5061
-10	0.8280	0.0004	-2.01	20.09	0.10	0.000	0.5061
0	0.9449	0.0004	-2.01	20.09	0.10	0.000	0.5061
10	1.0678	0.0004	-2.01	20.09	0.10	0.000	0.5061
20	1.1967	0.0004	-2.01	20.09	0.10	0.000	0.5061
30	1.3316	0.0004	-2.01	20.09	0.10	0.000	0.5061
40	1.4725	0.0004	-2.01	20.09	0.10	0.000	0.5061
50	1.6194	0.0004	-2.01	20.09	0.10	0.000	0.5061
60	1.7723	0.0004	-2.01	20.09	0.10	0.000	0.5061
70	1.9312	0.0004	-2.01	20.09	0.10	0.000	0.5061
80	2.0961	0.0004	-2.01	20.09	0.10	0.000	0.5061
90	2.2670	0.0004	-2.01	20.09	0.10	0.000	0.5061
100	2.4439	0.0004	-2.01	20.09	0.10	0.000	0.5061
110	2.6268	0.0004	-2.01	20.09	0.10	0.000	0.5061
120	2.8147	0.0004	-2.01	20.09	0.10	0.000	0.5061
130	3.0076	0.0004	-2.01	20.09	0.10	0.000	0.5061
140	3.2055	0.0004	-2.01	20.09	0.10	0.000	0.5061
150	3.4084	0.0004	-2.01	20.09	0.10	0.000	0.5061
160	3.6163	0.0004	-2.01	20.09	0.10	0.000	0.5061
170	3.8292	0.0004	-2.01	20.09	0.10	0.000	0.5061
180	4.0471	0.0004	-2.01	20.09	0.10	0.000	0.5061
190	4.2700	0.0004	-2.01	20.09	0.10	0.000	0.5061
200	4.4979	0.0004	-2.01	20.09	0.10	0.000	0.5061
210	4.7308	0.0004	-2.01	20.09	0.10	0.000	0.5061
220	4.9687	0.0004	-2.01	20.09	0.10	0.000	0.5061
230	5.2116	0.0004	-2.01	20.09	0.10	0.000	0.5061
240	5.4595	0.0004	-2.01	20.09	0.10	0.000	0.5061
250	5.7124	0.0004	-2.01	20.09	0.10	0.000	0.5061
260	5.9703	0.0004	-2.01	20.09	0.10	0.000	0.5061
270	6.2332	0.0004	-2.01	20.09	0.10	0.000	0.5061
280	6.5011	0.0004	-2.01	20.09	0.10	0.000	0.5061
290	6.7740	0.0004	-2.01	20.09	0.10	0.000	0.5061
300	7.0519	0.0004	-2.01	20.09	0.10	0.000	0.5061
310	7.3348	0.0004	-2.01	20.09	0.10	0.000	0.5061
320	7.6227	0.0004	-2.01	20.09	0.10	0.000	0.5061
330	7.9156	0.0004	-2.01	20.09	0.10	0.000	0.5061
340	8.2135	0.0004	-2.01	20.09	0.10	0.000	0.5061
350	8.5164	0.0004	-2.01	20.09	0.10	0.000	0.5061
360	8.8243	0.0004	-2.01	20.09	0.10	0.000	0.5061
370	9.1372	0.0004	-2.01	20.09	0.10	0.000	0.5061
380	9.4551	0.0004	-2.01	20.09	0.10	0.000	0.5061
390	9.7780	0.0004	-2.01	20.09	0.10	0.000	0.5061
400	10.1059	0.0004	-2.01	20.09	0.10	0.000	0.5061
410	10.4388	0.0004	-2.01	20.09	0.10	0.000	0.5061
420	10.7767	0.0004	-2.01	20.09	0.10	0.000	0.5061
430	11.1196	0.0004	-2.01	20.09	0.10	0.000	0.5061
440	11.4675	0.0004	-2.01	20.09	0.10	0.000	0.5061
450	11.8204	0.0004	-2.01	20.09	0.10	0.000	0.5061

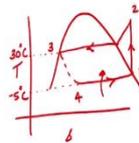


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In a vapour compression refrigeration cycle working with refrigerant R-134a, the evaporator and condenser temperatures are -5 °C and 30 °C respectively.

Determine

- a) compression work
- b) refrigerating effect
- c) heat rejected in the condenser
- d) COP
- e) cycle efficiency



$$w_c = h_1 - h_2$$

$$q_L = h_1 - h_4$$

$$q_H = h_3 - h_2$$

$$COP = \frac{q_L}{|w_c|}$$

$$\eta = \frac{COP_{VCR}}{COP_{Carnot}}$$

$$h_1 = 247.55 \frac{kJ}{kg}$$

$$q_1 = 0.9345 \frac{kJ}{kg \cdot K}$$

$$p_2 = p_3 = 770.6 \text{ kPa}$$





Appendix C: Property Tables for R134a

Tables C-1 and C-2 present data for saturated liquid and saturated vapor. Table C-1 is presented in regular intervals of temperature while Table C-2 is presented at regular intervals of pressure. Table C-3 presents data for superheated vapor over a range of temperatures and pressures. These tables were generated using EES with the substance R134a which implements the fundamental equation of state developed by R. Tillner-Roth and H.D. Baehr, An International Standard Formulation for the Thermodynamic Properties of 1,1,1,2-Tetrafluoroethane (HFC-134a) for Temperatures from 170 K to 455 K and Pressures up to 70 MPa, J. Phys. Chem. Ref. Data, Vol. 23, No. 5, 1994.

Table C-1: Properties of Saturated R134a, Presented at Regular Intervals of Temperature. Columns include Temp (C), P (kPa), Specific volume (m^3/kg), Specific internal energy (kJ/kg), Specific enthalpy (kJ/kg), and Specific entropy (kJ/kg-K).



(Refer Slide Time 12:39)

Table C-3: Properties of Superheated R134a, Presented from 0.01 MPa to 400 kPa. Columns include P (kPa), Temp (C), v (m^3/kg), u (kJ/kg), h (kJ/kg), and s (kJ/kg-K).





Table C-3 (Continued): Properties of Superheated Vapor: Propane from 500 kPa to 1.3 MPa

P (kPa)	Temperature (°C)										
	20	30	40	50	60	70	80	90	100	110	120
500	$v$	0.001446	0.001450	0.001454	0.001458	0.001462	0.001466	0.001470	0.001474	0.001478	0.001482
	$u$	262.4	263.1	263.7	264.3	264.9	265.5	266.1	266.7	267.3	267.9
	$h$	262.1	273.1	282.1	292.1	301.1	310.1	319.1	328.1	337.1	346.1
	$s$	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
600	$v$	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009
	$u$	264.7	275.7	284.7	293.7	302.7	311.7	320.7	329.7	338.7	347.7
	$h$	264.4	275.4	284.4	293.4	302.4	311.4	320.4	329.4	338.4	347.4
	$s$	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
700	$v$	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
	$u$	267.0	278.0	287.0	296.0	305.0	314.0	323.0	332.0	341.0	350.0
	$h$	266.7	277.7	286.7	295.7	304.7	313.7	322.7	331.7	340.7	349.7
	$s$	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
800	$v$	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
	$u$	269.3	280.3	289.3	298.3	307.3	316.3	325.3	334.3	343.3	352.3
	$h$	269.0	280.0	289.0	298.0	307.0	316.0	325.0	334.0	343.0	352.0
	$s$	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

$$\frac{700-700}{800-700} = \delta = 0.9345 \frac{kJ}{kg \cdot K}$$



(Refer Slide Time: 15:47)

Thermodynamic Properties of HFC-134a Refrigerant (1,1,1,2-tetrafluoroethane)

SI Units

New tables of the thermodynamic properties of HFC-134a have been developed and are presented here. These tables are based on experimental data from the database at the National Institute of Standards and Technology (NIST). Equations have been developed based on the Modified Benedict-Webb-Rubin (MBWR) equation of state, which represent the data with accuracy and consistency throughout the entire range of temperature, pressure, and density.

**Physical Properties**

Chemical formula: C<sub>2</sub>H<sub>2</sub>F<sub>4</sub>

Molecular Weight: 102.03

Boiling Point at 0.101325 MPa: -26.06°C (4.14 R°)

Critical Temperature: 101.06°C (213.97 R°)

Critical Pressure: 37.213 kPa (0.27183 atm)

Critical Density: 4863.1 kg/m<sup>3</sup> (303.9 lbm/ft<sup>3</sup>)

Critical Volume: 0.02029 m<sup>3</sup>/kg (0.001187 ft<sup>3</sup>/lb)

**Units and Factors**

T = temperature in °C, °F, 273.15

P = pressure in kilopascals absolute (kPa abs)

v = volume of saturated liquid in m<sup>3</sup>/kg

v<sub>g</sub> = volume of saturated vapor in m<sup>3</sup>/kg

v<sub>l</sub> = density of saturated liquid in kg/m<sup>3</sup>

v<sub>g</sub> = density of saturated vapor in kg/m<sup>3</sup>

h<sub>l</sub> = enthalpy of saturated liquid in kJ/kg

h<sub>g</sub> = enthalpy of saturated vapor in kJ/kg

h = enthalpy of superheated vapor in kJ/kg

h<sub>l</sub> = enthalpy of saturated liquid in kJ/kg

h<sub>g</sub> = enthalpy of saturated vapor in kJ/kg

h = enthalpy of superheated vapor in kJ/kg

s = entropy of saturated liquid in kJ/kg·K

s<sub>g</sub> = entropy of saturated vapor in kJ/kg·K

S = entropy of superheated vapor in kJ/kg·K

C<sub>p</sub> = heat capacity at constant pressure in kJ/kg·K

C<sub>v</sub> = heat capacity at constant volume in kJ/kg·K

v<sub>∞</sub> = velocity of sound in m/s

The gas constant, R = 0.0815 kJ/kg·K for HFC-134a, R = 0.0815 kJ/kg·K One atmosphere = 101.325 kPa Reference point for enthalpy and entropy: h<sub>l</sub> = 266.16 kJ/kg at 0°C v<sub>l</sub> = 0.000714 m<sup>3</sup>/kg at 0°C

**Equations**

The Modified Benedict-Webb-Rubin (MBWR) equation of state was used to calculate the values of thermodynamic properties. It was chosen as the preferred equation of state because it provided the most accurate fit of the thermodynamic data over the entire range of temperatures and pressures presented in these tables. The data fit and calculation of constants for HFC-134a were performed for the P-T form at the National Institute of Standards and Technology (NIST) under the supervision of Dr. Mark O. McLinden.

The constants were calculated in SI units. For conversion of thermodynamic properties to Engineering (E-PT) units, properties must be calculated in SI units and converted to E-PT units. Conversion factors are provided for each property derived from the MBWR equation of state.

**1. Equation of State (MBWR)**

$$P = \frac{R T}{v - b} + \frac{a}{v^2} + \frac{c}{v^3} + \frac{d}{v^4} + \frac{e}{v^5} + \frac{f}{v^6} + \frac{g}{v^7} + \frac{h}{v^8} + \frac{i}{v^9} + \frac{j}{v^{10}}$$

where the temperature dependence of the coefficients is given by:

$$a = RT$$

$$b = b_1 + b_2 T^{1/2} + b_3 T + b_4 T^2$$

$$c = c_1 + c_2 T + c_3 T^2 + c_4 T^3$$

$$d = d_1 + d_2 T + d_3 T^2$$

$$e = e_1 + e_2 T + e_3 T^2$$

$$f = f_1 + f_2 T + f_3 T^2$$

$$g = g_1 + g_2 T + g_3 T^2$$

$$h = h_1 + h_2 T + h_3 T^2$$

$$i = i_1 + i_2 T + i_3 T^2$$

$$j = j_1 + j_2 T + j_3 T^2$$

where T is in K, V is in m<sup>3</sup>/kg, P is in Pa, and R = 0.0815 kJ/kg·K



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TABLE 2 (continued)  
**HFC-134a Superheated Vapor—Constant Pressure Tables**  
h = Enthalpy in kJ/kg    s = Entropy in kJ/kgK    v = Specific Volume in m³/kg  
 Cp = Heat Capacity in kJ/kgK    Cpv = Heat Capacity Ratio (Dimensionless)

P, MPa	Subcooled Liquid					Saturated Vapor				
	T, °C	h, kJ/kg	s, kJ/kgK	v, m³/kg	h <sub>g</sub> , kJ/kg	s <sub>g</sub> , kJ/kgK	v <sub>g</sub> , m³/kg	h <sub>g</sub> , kJ/kg	s <sub>g</sub> , kJ/kgK	v <sub>g</sub> , m³/kg
0.06	-10	25.49	0.101	0.0007	250.96	0.922	0.0007	250.96	0.922	0.0007
0.06	0	29.32	0.107	0.0007	251.93	0.925	0.0007	251.93	0.925	0.0007
0.06	10	33.29	0.113	0.0007	252.90	0.928	0.0007	252.90	0.928	0.0007
0.06	20	37.40	0.119	0.0007	253.87	0.931	0.0007	253.87	0.931	0.0007
0.06	30	41.65	0.125	0.0007	254.84	0.934	0.0007	254.84	0.934	0.0007
0.06	40	46.04	0.131	0.0007	255.81	0.937	0.0007	255.81	0.937	0.0007
0.06	50	50.57	0.137	0.0007	256.78	0.940	0.0007	256.78	0.940	0.0007
0.06	60	55.24	0.143	0.0007	257.75	0.943	0.0007	257.75	0.943	0.0007
0.06	70	60.05	0.149	0.0007	258.72	0.946	0.0007	258.72	0.946	0.0007
0.06	80	64.99	0.155	0.0007	259.69	0.949	0.0007	259.69	0.949	0.0007
0.06	90	70.06	0.161	0.0007	260.66	0.952	0.0007	260.66	0.952	0.0007
0.06	100	75.26	0.167	0.0007	261.63	0.955	0.0007	261.63	0.955	0.0007
0.06	110	80.59	0.173	0.0007	262.60	0.958	0.0007	262.60	0.958	0.0007
0.06	120	86.04	0.179	0.0007	263.57	0.961	0.0007	263.57	0.961	0.0007
0.06	130	91.61	0.185	0.0007	264.54	0.964	0.0007	264.54	0.964	0.0007
0.06	140	97.30	0.191	0.0007	265.51	0.967	0.0007	265.51	0.967	0.0007
0.06	150	103.11	0.197	0.0007	266.48	0.970	0.0007	266.48	0.970	0.0007
0.06	160	109.04	0.203	0.0007	267.45	0.973	0.0007	267.45	0.973	0.0007
0.06	170	115.09	0.209	0.0007	268.42	0.976	0.0007	268.42	0.976	0.0007
0.06	180	121.26	0.215	0.0007	269.39	0.979	0.0007	269.39	0.979	0.0007
0.06	190	127.55	0.221	0.0007	270.36	0.982	0.0007	270.36	0.982	0.0007
0.06	200	133.96	0.227	0.0007	271.33	0.985	0.0007	271.33	0.985	0.0007
0.06	210	140.49	0.233	0.0007	272.30	0.988	0.0007	272.30	0.988	0.0007
0.06	220	147.14	0.239	0.0007	273.27	0.991	0.0007	273.27	0.991	0.0007
0.06	230	153.91	0.245	0.0007	274.24	0.994	0.0007	274.24	0.994	0.0007
0.06	240	160.80	0.251	0.0007	275.21	0.997	0.0007	275.21	0.997	0.0007
0.06	250	167.81	0.257	0.0007	276.18	0.999	0.0007	276.18	0.999	0.0007
0.06	260	174.94	0.263	0.0007	277.15	1.002	0.0007	277.15	1.002	0.0007
0.06	270	182.19	0.269	0.0007	278.12	1.005	0.0007	278.12	1.005	0.0007
0.06	280	189.56	0.275	0.0007	279.09	1.008	0.0007	279.09	1.008	0.0007
0.06	290	197.05	0.281	0.0007	280.06	1.011	0.0007	280.06	1.011	0.0007
0.06	300	204.66	0.287	0.0007	281.03	1.014	0.0007	281.03	1.014	0.0007
0.06	310	212.39	0.293	0.0007	282.00	1.017	0.0007	282.00	1.017	0.0007
0.06	320	220.24	0.299	0.0007	282.97	1.020	0.0007	282.97	1.020	0.0007
0.06	330	228.21	0.305	0.0007	283.94	1.023	0.0007	283.94	1.023	0.0007
0.06	340	236.30	0.311	0.0007	284.91	1.026	0.0007	284.91	1.026	0.0007
0.06	350	244.51	0.317	0.0007	285.88	1.029	0.0007	285.88	1.029	0.0007
0.06	360	252.84	0.323	0.0007	286.85	1.032	0.0007	286.85	1.032	0.0007
0.06	370	261.29	0.329	0.0007	287.82	1.035	0.0007	287.82	1.035	0.0007
0.06	380	269.86	0.335	0.0007	288.79	1.038	0.0007	288.79	1.038	0.0007
0.06	390	278.55	0.341	0.0007	289.76	1.041	0.0007	289.76	1.041	0.0007
0.06	400	287.36	0.347	0.0007	290.73	1.044	0.0007	290.73	1.044	0.0007
0.06	410	296.29	0.353	0.0007	291.70	1.047	0.0007	291.70	1.047	0.0007
0.06	420	305.34	0.359	0.0007	292.67	1.050	0.0007	292.67	1.050	0.0007
0.06	430	314.51	0.365	0.0007	293.64	1.053	0.0007	293.64	1.053	0.0007
0.06	440	323.80	0.371	0.0007	294.61	1.056	0.0007	294.61	1.056	0.0007
0.06	450	333.21	0.377	0.0007	295.58	1.059	0.0007	295.58	1.059	0.0007
0.06	460	342.74	0.383	0.0007	296.55	1.062	0.0007	296.55	1.062	0.0007
0.06	470	352.39	0.389	0.0007	297.52	1.065	0.0007	297.52	1.065	0.0007
0.06	480	362.16	0.395	0.0007	298.49	1.068	0.0007	298.49	1.068	0.0007
0.06	490	372.05	0.401	0.0007	299.46	1.071	0.0007	299.46	1.071	0.0007
0.06	500	382.06	0.407	0.0007	300.43	1.074	0.0007	300.43	1.074	0.0007
0.06	510	392.19	0.413	0.0007	301.40	1.077	0.0007	301.40	1.077	0.0007
0.06	520	402.44	0.419	0.0007	302.37	1.080	0.0007	302.37	1.080	0.0007
0.06	530	412.81	0.425	0.0007	303.34	1.083	0.0007	303.34	1.083	0.0007
0.06	540	423.30	0.431	0.0007	304.31	1.086	0.0007	304.31	1.086	0.0007
0.06	550	433.91	0.437	0.0007	305.28	1.089	0.0007	305.28	1.089	0.0007
0.06	560	444.64	0.443	0.0007	306.25	1.092	0.0007	306.25	1.092	0.0007
0.06	570	455.49	0.449	0.0007	307.22	1.095	0.0007	307.22	1.095	0.0007
0.06	580	466.46	0.455	0.0007	308.19	1.098	0.0007	308.19	1.098	0.0007
0.06	590	477.55	0.461	0.0007	309.16	1.101	0.0007	309.16	1.101	0.0007
0.06	600	488.76	0.467	0.0007	310.13	1.104	0.0007	310.13	1.104	0.0007
0.06	610	500.09	0.473	0.0007	311.10	1.107	0.0007	311.10	1.107	0.0007
0.06	620	511.54	0.479	0.0007	312.07	1.110	0.0007	312.07	1.110	0.0007
0.06	630	523.11	0.485	0.0007	313.04	1.113	0.0007	313.04	1.113	0.0007
0.06	640	534.80	0.491	0.0007	314.01	1.116	0.0007	314.01	1.116	0.0007
0.06	650	546.61	0.497	0.0007	314.98	1.119	0.0007	314.98	1.119	0.0007
0.06	660	558.54	0.503	0.0007	315.95	1.122	0.0007	315.95	1.122	0.0007
0.06	670	570.59	0.509	0.0007	316.92	1.125	0.0007	316.92	1.125	0.0007
0.06	680	582.76	0.515	0.0007	317.89	1.128	0.0007	317.89	1.128	0.0007
0.06	690	595.05	0.521	0.0007	318.86	1.131	0.0007	318.86	1.131	0.0007
0.06	700	607.46	0.527	0.0007	319.83	1.134	0.0007	319.83	1.134	0.0007
0.06	710	620.00	0.533	0.0007	320.80	1.137	0.0007	320.80	1.137	0.0007
0.06	720	632.66	0.539	0.0007	321.77	1.140	0.0007	321.77	1.140	0.0007
0.06	730	645.45	0.545	0.0007	322.74	1.143	0.0007	322.74	1.143	0.0007
0.06	740	658.37	0.551	0.0007	323.71	1.146	0.0007	323.71	1.146	0.0007
0.06	750	671.42	0.557	0.0007	324.68	1.149	0.0007	324.68	1.149	0.0007
0.06	760	684.60	0.563	0.0007	325.65	1.152	0.0007	325.65	1.152	0.0007
0.06	770	697.91	0.569	0.0007	326.62	1.155	0.0007	326.62	1.155	0.0007
0.06	780	711.35	0.575	0.0007	327.59	1.158	0.0007	327.59	1.158	0.0007
0.06	790	724.92	0.581	0.0007	328.56	1.161	0.0007	328.56	1.161	0.0007
0.06	800	738.62	0.587	0.0007	329.53	1.164	0.0007	329.53	1.164	0.0007
0.06	810	752.45	0.593	0.0007	330.50	1.167	0.0007	330.50	1.167	0.0007
0.06	820	766.41	0.599	0.0007	331.47	1.170	0.0007	331.47	1.170	0.0007
0.06	830	780.50	0.605	0.0007	332.44	1.173	0.0007	332.44	1.173	0.0007
0.06	840	794.72	0.611	0.0007	333.41	1.176	0.0007	333.41	1.176	0.0007
0.06	850	809.07	0.617	0.0007	334.38	1.179	0.0007	334.38	1.179	0.0007
0.06	860	823.55	0.623	0.0007	335.35	1.182	0.0007	335.35	1.182	0.0007
0.06	870	838.16	0.629	0.0007	336.32	1.185	0.0007	336.32	1.185	0.0007
0.06	880	852.90	0.635	0.0007	337.29	1.188	0.0007	337.29	1.188	0.0007
0.06	890	867.77	0.641	0.0007	338.26	1.191	0.0007	338.26	1.191	0.0007
0.06	900	882.78	0.647	0.0007	339.23	1.194	0.0007	339.23	1.194	0.0007
0.06	910	897.92	0.653	0.0007	340.20	1.197	0.0007	340.20	1.197	0.0007
0.06	920	913.19	0.659	0.0007	341.17	1.200	0.0007	341.17	1.200	0.0007
0.06	930	928.59	0.665	0.0007	342.14	1.203	0.0007	342.14	1.203	0.0007
0.06	940	944.12	0.671	0.0007	343.11	1.206	0.0007	343.11	1.206	0.0007
0.06	950	959.78	0.677	0.0007	344.08	1.209	0.0007	344.08	1.209	0.0007
0.06	960	975.57	0.683	0.0007	345.05	1.212	0.0007	345.05	1.212	0.0007
0.06	970	991.49	0.689	0.0007	346.02	1.215	0.0007	346.02	1.215	0.0007
0.06	980	1007.54	0.695	0.0007	346.99	1.218	0.0007	346.99	1.218	0.0007
0.06	990	1023.72	0.701	0.0007	347.96	1.221	0.0007	347.96	1.221	0.0007
0.06	1000	1040.03	0.707	0.0007	348.93	1.224	0.0007	348.93	1.224	0.0

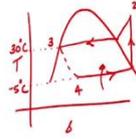
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In a vapour compression refrigeration cycle working with refrigerant R-134a, the evaporator and condenser temperatures are -5 °C and 30 °C respectively.

Determine

- a) compression work
- b) refrigerating effect
- c) heat rejected in the condenser
- d) COP
- e) cycle efficiency



$$\begin{aligned}
 w_c &= h_2 - h_1 = 241.8 \text{ kJ/kg} \\
 q_L &= h_1 - h_4 = 154.1 \text{ kJ/kg} \\
 q_H &= h_3 - h_2 = -179 \text{ kJ/kg} \\
 \text{COP} &= \frac{q_L}{w_c} = 6.2 \\
 \eta &= \frac{\text{COP}_{\text{VCR}}}{\text{COP}_{\text{Carnot}}} = \frac{6.2}{24/7}
 \end{aligned}$$

$$\begin{aligned}
 h_1 &= 395.9 \frac{\text{kJ}}{\text{kg}} \\
 s_1 &= 1.7308 \frac{\text{kJ}}{\text{kg}\cdot\text{K}} \\
 h_2 &= h_3 = 771 \text{ kJ/kg} \\
 T_2 &\approx 35^\circ\text{C} \\
 h_2 &\approx 420.8 \text{ kJ/kg}
 \end{aligned}$$

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TABLE 2 (Continued)  
HFC-134a Superheated Vapor—Constant Pressure Tables

V = Volume in m<sup>3</sup>/kg    h = Enthalpy in kJ/kg    s = Entropy in kJ/kgK    v<sub>g</sub> = Velocity of Sound in m/sec  
Cp = Heat Capacity at Constant Pressure in kJ/kgC

TEMP °C	SATURATED VAPOR				SUPERHEATED VAPOR				TEMP °C
	v	h	s	Qp	v	h	s	Qp	
10	0.0008	201.1	0.925	1.000	0.0008	201.1	0.925	1.000	10
15	0.0008	201.2	0.926	1.000	0.0008	201.2	0.926	1.000	15
20	0.0008	201.3	0.927	1.000	0.0008	201.3	0.927	1.000	20
25	0.0008	201.4	0.928	1.000	0.0008	201.4	0.928	1.000	25
30	0.0008	201.5	0.929	1.000	0.0008	201.5	0.929	1.000	30
35	0.0008	201.6	0.930	1.000	0.0008	201.6	0.930	1.000	35
40	0.0008	201.7	0.931	1.000	0.0008	201.7	0.931	1.000	40
45	0.0008	201.8	0.932	1.000	0.0008	201.8	0.932	1.000	45
50	0.0008	201.9	0.933	1.000	0.0008	201.9	0.933	1.000	50
55	0.0008	202.0	0.934	1.000	0.0008	202.0	0.934	1.000	55
60	0.0008	202.1	0.935	1.000	0.0008	202.1	0.935	1.000	60
65	0.0008	202.2	0.936	1.000	0.0008	202.2	0.936	1.000	65
70	0.0008	202.3	0.937	1.000	0.0008	202.3	0.937	1.000	70
75	0.0008	202.4	0.938	1.000	0.0008	202.4	0.938	1.000	75
80	0.0008	202.5	0.939	1.000	0.0008	202.5	0.939	1.000	80
85	0.0008	202.6	0.940	1.000	0.0008	202.6	0.940	1.000	85
90	0.0008	202.7	0.941	1.000	0.0008	202.7	0.941	1.000	90
95	0.0008	202.8	0.942	1.000	0.0008	202.8	0.942	1.000	95
100	0.0008	202.9	0.943	1.000	0.0008	202.9	0.943	1.000	100
105	0.0008	203.0	0.944	1.000	0.0008	203.0	0.944	1.000	105
110	0.0008	203.1	0.945	1.000	0.0008	203.1	0.945	1.000	110
115	0.0008	203.2	0.946	1.000	0.0008	203.2	0.946	1.000	115
120	0.0008	203.3	0.947	1.000	0.0008	203.3	0.947	1.000	120
125	0.0008	203.4	0.948	1.000	0.0008	203.4	0.948	1.000	125
130	0.0008	203.5	0.949	1.000	0.0008	203.5	0.949	1.000	130
135	0.0008	203.6	0.950	1.000	0.0008	203.6	0.950	1.000	135
140	0.0008	203.7	0.951	1.000	0.0008	203.7	0.951	1.000	140
145	0.0008	203.8	0.952	1.000	0.0008	203.8	0.952	1.000	145
150	0.0008	203.9	0.953	1.000	0.0008	203.9	0.953	1.000	150
155	0.0008	204.0	0.954	1.000	0.0008	204.0	0.954	1.000	155
160	0.0008	204.1	0.955	1.000	0.0008	204.1	0.955	1.000	160
165	0.0008	204.2	0.956	1.000	0.0008	204.2	0.956	1.000	165
170	0.0008	204.3	0.957	1.000	0.0008	204.3	0.957	1.000	170
175	0.0008	204.4	0.958	1.000	0.0008	204.4	0.958	1.000	175
180	0.0008	204.5	0.959	1.000	0.0008	204.5	0.959	1.000	180
185	0.0008	204.6	0.960	1.000	0.0008	204.6	0.960	1.000	185
190	0.0008	204.7	0.961	1.000	0.0008	204.7	0.961	1.000	190
195	0.0008	204.8	0.962	1.000	0.0008	204.8	0.962	1.000	195
200	0.0008	204.9	0.963	1.000	0.0008	204.9	0.963	1.000	200
205	0.0008	205.0	0.964	1.000	0.0008	205.0	0.964	1.000	205
210	0.0008	205.1	0.965	1.000	0.0008	205.1	0.965	1.000	210
215	0.0008	205.2	0.966	1.000	0.0008	205.2	0.966	1.000	215
220	0.0008	205.3	0.967	1.000	0.0008	205.3	0.967	1.000	220
225	0.0008	205.4	0.968	1.000	0.0008	205.4	0.968	1.000	225
230	0.0008	205.5	0.969	1.000	0.0008	205.5	0.969	1.000	230
235	0.0008	205.6	0.970	1.000	0.0008	205.6	0.970	1.000	235
240	0.0008	205.7	0.971	1.000	0.0008	205.7	0.971	1.000	240
245	0.0008	205.8	0.972	1.000	0.0008	205.8	0.972	1.000	245
250	0.0008	205.9	0.973	1.000	0.0008	205.9	0.973	1.000	250
255	0.0008	206.0	0.974	1.000	0.0008	206.0	0.974	1.000	255
260	0.0008	206.1	0.975	1.000	0.0008	206.1	0.975	1.000	260
265	0.0008	206.2	0.976	1.000	0.0008	206.2	0.976	1.000	265
270	0.0008	206.3	0.977	1.000	0.0008	206.3	0.977	1.000	270
275	0.0008	206.4	0.978	1.000	0.0008	206.4	0.978	1.000	275
280	0.0008	206.5	0.979	1.000	0.0008	206.5	0.979	1.000	280
285	0.0008	206.6	0.980	1.000	0.0008	206.6	0.980	1.000	285
290	0.0008	206.7	0.981	1.000	0.0008	206.7	0.981	1.000	290
295	0.0008	206.8	0.982	1.000	0.0008	206.8	0.982	1.000	295
300	0.0008	206.9	0.983	1.000	0.0008	206.9	0.983	1.000	300
305	0.0008	207.0	0.984	1.000	0.0008	207.0	0.984	1.000	305
310	0.0008	207.1	0.985	1.000	0.0008	207.1	0.985	1.000	310
315	0.0008	207.2	0.986	1.000	0.0008	207.2	0.986	1.000	315
320	0.0008	207.3	0.987	1.000	0.0008	207.3	0.987	1.000	320
325	0.0008	207.4	0.988	1.000	0.0008	207.4	0.988	1.000	325
330	0.0008	207.5	0.989	1.000	0.0008	207.5	0.989	1.000	330
335	0.0008	207.6	0.990	1.000	0.0008	207.6	0.990	1.000	335
340	0.0008	207.7	0.991	1.000	0.0008	207.7	0.991	1.000	340
345	0.0008	207.8	0.992	1.000	0.0008	207.8	0.992	1.000	345
350	0.0008	207.9	0.993	1.000	0.0008	207.9	0.993	1.000	350
355	0.0008	208.0	0.994	1.000	0.0008	208.0	0.994	1.000	355
360	0.0008	208.1	0.995	1.000	0.0008	208.1	0.995	1.000	360
365	0.0008	208.2	0.996	1.000	0.0008	208.2	0.996	1.000	365
370	0.0008	208.3	0.997	1.000	0.0008	208.3	0.997	1.000	370
375	0.0008	208.4	0.998	1.000	0.0008	208.4	0.998	1.000	375
380	0.0008	208.5	0.999	1.000	0.0008	208.5	0.999	1.000	380
385	0.0008	208.6	1.000	1.000	0.0008	208.6	1.000	1.000	385
390	0.0008	208.7	1.000	1.000	0.0008	208.7	1.000	1.000	390
395	0.0008	208.8	1.000	1.000	0.0008	208.8	1.000	1.000	395
400	0.0008	208.9	1.000	1.000	0.0008	208.9	1.000	1.000	400
405	0.0008	209.0	1.000	1.000	0.0008	209.0	1.000	1.000	405
410	0.0008	209.1	1.000	1.000	0.0008	209.1	1.000	1.000	410
415	0.0008	209.2	1.000	1.000	0.0008	209.2	1.000	1.000	415
420	0.0008	209.3	1.000	1.000	0.0008	209.3	1.000	1.000	420
425	0.0008	209.4	1.000	1.000	0.0008	209.4	1.000	1.000	425
430	0.0008	209.5	1.000	1.000	0.0008	209.5	1.000	1.000	430
435	0.0008	209.6	1.000	1.000	0.0008	209.6	1.000	1.000	435
440	0.0008	209.7	1.000	1.000	0.0008	209.7	1.000	1.000	440
445	0.0008	209.8	1.000	1.000	0.0008	209.8	1.000	1.000	445
450	0.0008	209.9	1.000	1.000	0.0008	209.9	1.000	1.000	450
455	0.0008	210.0	1.000	1.000	0.0008	210.0	1.000	1.000	455
460	0.0008	210.1	1.000	1.000	0.0008	210.1	1.000	1.000	460
465	0.0008	210.2	1.000	1.000	0.0008	210.2	1.000	1.000	465
470	0.0008	210.3	1.000	1.000	0.0008	210.3	1.000	1.000	470
475	0.0008	210.4	1.000	1.000	0.0008	210.4	1.000	1.000	475
480	0.0008	210.5	1.000	1.000	0.0008	210.5	1.000	1.000	480
485	0.0008	210.6	1.000	1.000	0.0008	210.6	1.000	1.000	485
490	0.0008	210.7	1.000	1.000	0.0008	210.7	1.000	1.000	490
495	0.0008	210.8	1.000	1.000	0.0008	210.8	1.000	1.000	495
500	0.0008	210.9	1.000	1.000	0.0008	210.9	1.000	1.000	500



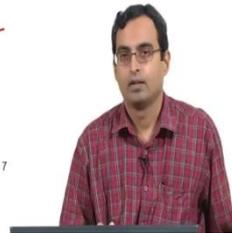
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$$\begin{aligned}
 \text{COP}_{\text{Carnot}} &= \frac{Q_L}{Q_H - Q_L} \\
 &= \frac{Q_L}{Q_L \left( \frac{Q_H}{Q_L} - 1 \right)} \\
 &= \frac{1}{\frac{Q_H}{Q_L} - 1} \\
 &= \frac{T_L}{T_H - T_L} \\
 &= \frac{273 - 5}{273 + 30 - (273 - 5)} = \frac{268}{35} = 7.65
 \end{aligned}$$



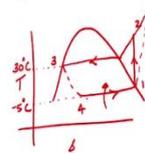
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In a vapour compression refrigeration cycle working with refrigerant R-134a, the evaporator and condenser temperatures are  $-5^\circ\text{C}$  and  $30^\circ\text{C}$  respectively.

Determine

- compression work
- refrigerating effect
- heat rejected in the condenser
- COP
- cycle efficiency



$$\begin{aligned}
 w_c &= h_1 - h_2 = -24.9 \text{ kJ/kg} & h_3 &= 241.8 \\
 q_L &= h_1 - h_4 = 154.1 \text{ kJ/kg} & h_4 &= h_3 = 241.8 \\
 q_H &= h_3 - h_2 = -17.9 \text{ kJ/kg}
 \end{aligned}$$

$$\text{COP} = \frac{q_L}{|w_c|} = 6.2$$

$$\eta = \frac{\text{COP}_{\text{vcr}}}{\text{COP}_{\text{Carnot}}} = \frac{6.2}{7.65} = 0.8 = 80\%$$

$$\begin{aligned}
 h_1 &= 395.9 \frac{\text{kJ}}{\text{kg}} \\
 s_1 &= 1.7308 \frac{\text{kJ}}{\text{kg}\cdot\text{K}} \\
 p_2 &= p_3 = 771 \text{ kPa} \\
 T_c &\approx 35^\circ\text{C} \\
 h_2 &\approx 420.8 \text{ kJ/kg}
 \end{aligned}$$

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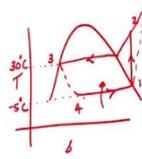
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In a vapour compression refrigeration cycle working with refrigerant R-134a, the evaporator and condenser temperatures are  $-5^{\circ}\text{C}$  and  $30^{\circ}\text{C}$  respectively.

Determine

- compression work
- refrigerating effect
- heat rejected in the condenser
- COP
- cycle efficiency



$$w_c = h_1 - h_2 = -24.9 \text{ kJ/kg} \quad h_3 = 241.8$$

$$q_L = h_1 - h_4 = 154.1 \text{ kJ/kg} \quad h_4 = h_3 = 241.8$$

$$q_H = h_3 - h_2 = -17.9 \text{ kJ/kg}$$

$$\text{COP} = \frac{q_L}{|w_c|} = 6.2$$

$$\eta = \frac{\text{COP}_{\text{vics}}}{\text{COP}_{\text{carnot}}} = \frac{6.2}{7.65} = 0.8 = 80\%$$

$$h_1 = 395.9 \frac{\text{kJ}}{\text{kg}}$$

$$s_1 = 1.3308 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$$

$$p_2 = p_3 = 7.71 \text{ kPa}$$

$$T_2 \approx 35^{\circ}\text{C}$$

$$h_2 \approx 420.8 \text{ kJ/kg}$$

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