Cankaya University
Faculty of Engineering
Mechanical Engineering Department

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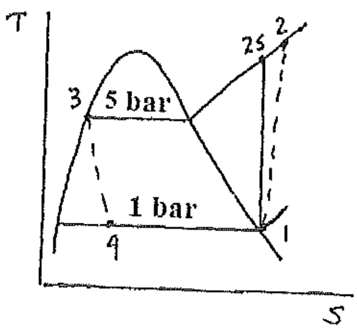
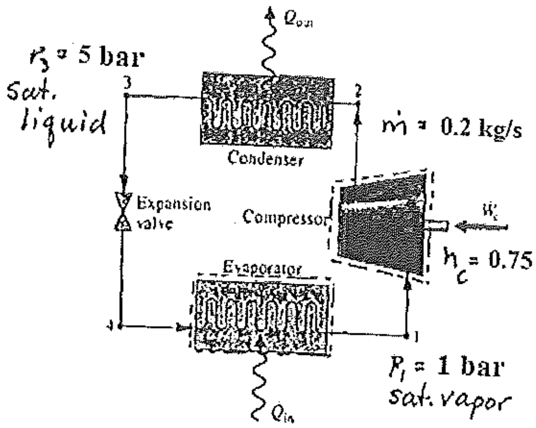
Examples

1) In a vapor-compression refrigeration cycle, Refrigerant 22 is used as the working fluid. The cycle operates at steady state. Saturated vapor enters the compressor at 1 bar, and saturated liquid exits the condenser at 5 bar. The isentropic compressor efficiency is 75%. The mass flow rate of the refrigerant is 0.2 kg/s. Determine
(a) the refrigeration capacity, in kW.
(b) the compressor power in kW.
(c) the coefficient of performance.

Solution:

Schematic and given data:





Determine the properties at different states.

State 1: Refer the following values for saturated vapors at $p_1 = 1$ bar from table A-8:

$$s_1 = s_g = 1.0031\ \text{kJ/kg}\cdot\text{K}$$

$$h_1 = h_g = 232.77\ \text{kJ/kg}$$

State 2: When the compression process through compressor is isentropic that is $s_1 = s_{2s} = 1.0031\ \text{kJ/kg}\cdot\text{K}$.

Use data in table A-9 to determine the value of specific enthalpy at state 2s corresponding to to $p_2 = 5$ bar and $s_{2s} = 1.0031\ \text{kJ/kg}\cdot\text{K}$.

$$h_{2s} = 271.92\ \text{kJ/kg}$$

Use the following expression of compressor isentropic efficiency to determine the value of specific entropy at state 2:

$$\eta_C = \frac{h_{2s} - h_1}{h_2 - h_1}$$

$$h_2 = h_1 + \frac{h_{2s} - h_1}{\eta_C}$$

$$= 232.77\ \text{kJ/kg} + \frac{271.92\ \text{kJ/kg} - 232.77\ \text{kJ/kg}}{0.75}$$

$$= 284.97\ \text{kJ/kg}$$

State 3: Refer the following value for saturated liquid at $p_3 = 5$ bar from table A-8:

$$h_3 = h_f = 45.25\ \text{kJ/kg}$$

State 4: Throttling occurs as the refrigerant flows through the expansion valve. Therefore,

$$h_4 = h_3 = 45.25\ \text{kJ/kg}$$

(a) Use the following expression to determine the refrigeration capacity:

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

$$= (0.2\ \text{kg/s})(232.77 - 45.25)\ \text{kJ/kg}\left|\frac{1\ \text{kW}}{1\ \text{kJ/s}}\right|$$

$$= 37.5\ \text{kW}$$

Thus, the refrigeration capacity is $\boxed{37.5\ \text{kW}}$.

(b) Use the following expression to determine the compressor power:

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

$$= (0.2\ \text{kg/s})(284.97 - 232.77)\ \text{kJ/kg}\left|\frac{1\ \text{kW}}{1\ \text{kJ/s}}\right|$$

$$= 10.44\ \text{kW}$$

Thus, the compressor power is $\boxed{10.44\ \text{kW}}$.

(c) Calculate the coefficient of performance from the following relation:

$$\beta = \frac{\dot{Q}_{in}}{\dot{W}_C} = \frac{37.5\ \text{kW}}{10.44\ \text{kW}} = 3.59$$

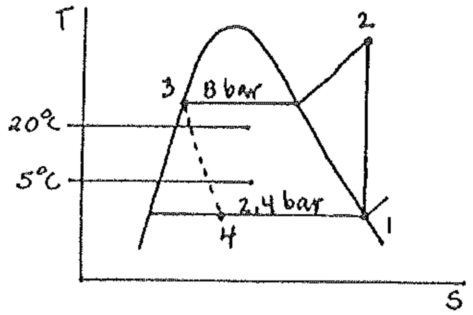
Thus, the coefficient of performance is $\boxed{3.59}$.

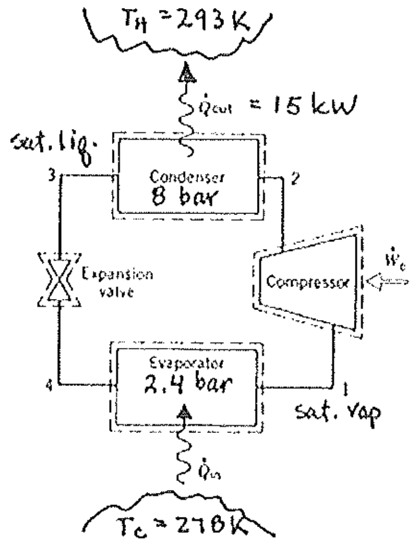
2) An ideal vapor-compression heat pump cycle with Refrigerant 134a as the working fluid provides heating at a rate of 15 kW to maintain a building at 20°C when the outside temperature is 5°C. Saturated vapor at 2.4 bar leaves the evaporator, and saturated liquid at 8 bar leaves the condenser. Calculate (a) the power input to the compressor, in kW. (b) the coefficient of performance. (c) the coefficient of performance of a Carnot heat pump cycle operating between thermal reservoirs at 20 and 5°C.

KNOWN: An ideal vapor-compression heat pump cycle uses Refrigerant 134a as the working fluid and provides a known energy output to heat a building. Data are known at various locations.

FIND: Determine (a) the compressor power, (b) the coefficient of performance, and (c) the maximum theoretical coefficient of performance for a heat pump operating between reservoirs at 20°C and 5°C.

SCHEMATIC & GIVEN DATA:





ENGINEERING MODEL: See Example 10.1.

ANALYSIS: First, fix each of the principal states.

State 1 $p_1 = 2.4$ bar, sat. vapor $\Rightarrow h_1 = 244.09$ kJ/kg, $s_1 = 0.9222$ kJ/kg·K

State 2 $p_2 = 8$ bar, $s_2 = s_1 \Rightarrow h_2 = 268.97$ kJ/kg

State 3 $p_3 = 8$ bar, sat. liquid $\Rightarrow h_3 = 93.42$ kJ/kg

State 4 Throttling process $\Rightarrow h_4 = h_3 = 93.42$ kJ/kg

(a) To determine the compressor, first find the mass flow rate from

$$\dot{Q}_{out} = \dot{m}(h_2 - h_3)$$

or

$$\dot{m} = \frac{\dot{Q}_{out}}{h_2 - h_3} = \frac{(15\ \text{kW})}{(268.97 - 93.42)\ \frac{\text{kJ}}{\text{kg}}} \left|\frac{1\ \text{kJ/s}}{1\ \text{kW}}\right| = 0.08544\ \text{kg/s}$$

thus,

$$\dot{W}_c = \dot{m}(h_2 - h_1) = \left(.08544\ \frac{\text{kg}}{\text{s}}\right)(268.97 - 244.09)\frac{\text{kJ}}{\text{kg}} \left|\frac{1\ \text{kW}}{1\ \text{kJ/s}}\right|$$

$$= 2.126\ \text{kW} \quad \longleftarrow \quad \dot{W}_c$$

(b) The coefficient of performance is

$$\gamma = \frac{\dot{Q}_{out}}{\dot{W}_c} = \frac{15}{2.126} = 7.055 \quad \longleftarrow \quad \gamma$$

(c) For a reversible heat pump operating between reservoirs at $T_H = 293$ K and $T_C = 278$ K

$$\gamma_{max} = \frac{T_H}{T_H - T_C} = 19.53 \quad \longleftarrow \quad \gamma_{max}$$