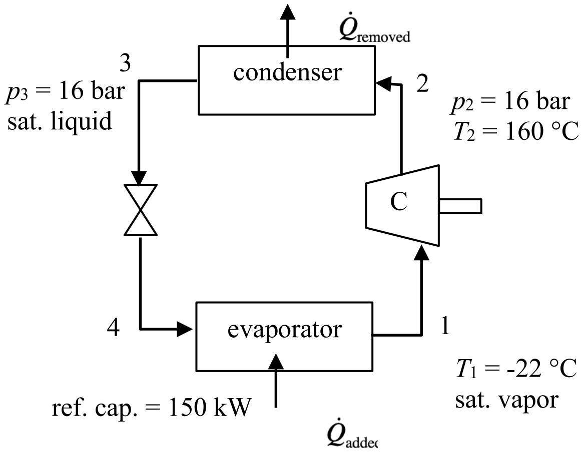
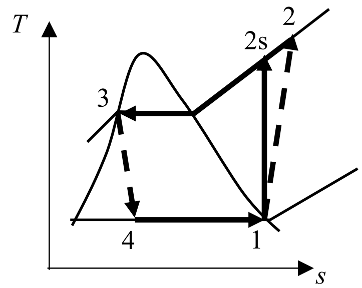
In a vapor-compression refrigeration cycle, ammonia exits the evaporator as saturated vapor at -22 °C. The refrigerant enters the condenser at 16 bar (abs) and 160 °C, and saturated liquid exits at 16 bar (abs). There is no significant heat transfer between the compressor and its surroundings, and the refrigerant passes through the evaporator with a negligible change in pressure. If the refrigerating capacity is 150 kW, determine:

a. the mass flow rate of refrigerant,
b. the power input to the compressor,
c. the coefficient of performance, and
d. the isentropic compressor efficiency.

SOLUTION:





First determine the properties at the various states using Tables from Moran et al., 7th ed.

State 1: T_1 = -22 °C, saturated vapor (Table A-13)
$\Rightarrow$ p_1 = 1.7390 bar, h_1 = 1415.08 kJ/kg, s_1 = 5.6457 kJ/(kg.K)

State 2: p_2 = 16 bar, T_2 = 160 °C $\Rightarrow$ superheated vapor (Table A-15)
$\Rightarrow$ h_2 = 1798.45 kJ/kg, s_2 = 5.7475 kJ/(kg.K)

State 3: p_3 = 16 bar, saturated liquid (Table A-14)
$\Rightarrow$ T_3 = 41.03 °C, h_3 = 376.46 kJ/kg, s_3 = 1.3729 kJ/(kg.K)

State 4: throttling process from 3 to 4, constant pressure from 4 to 1
$\Rightarrow$ $h_4 = h_3$ = 376.46 kJ/kg, $p_4 = p_1$ = 1.7390 bar

The mass flow rate may be determined by applying the 1st Law to the evaporator and making use of the refrigeration capacity (= $\dot{Q}_{\text{added}}$ = 150 kW),

$$\dot{Q}_{\text{added}} = \dot{m}\left(h_1 - h_4\right) \Rightarrow \dot{m} = \frac{\dot{Q}_{\text{added}}}{\left(h_1 - h_4\right)}, \tag{1}$$

$\Rightarrow$ $\boxed{\dot{m} = 0.144 \text{ kg/s}}$.

The power input into the compressor is found by applying the 1st Law to the compressor,

$$\dot{W}_{\text{on comp}} = \dot{m}\left(h_2 - h_1\right), \tag{2}$$

$\Rightarrow$ $\boxed{\dot{W}_{\text{on comp}} = 55.4 \text{ kW}}$.

The coefficient of performance for the refrigeration cycle is defined as,

$$\text{COP}_{\text{ref}} \equiv \frac{\dot{Q}_{\text{added}}}{\dot{W}_{\text{on}}}, \tag{3}$$

$\Rightarrow$ $\boxed{\text{COP}_{\text{ref}} = 2.71}$.

The isentropic efficiency of the compressor is defined as,

$$\eta_{\text{comp}} \equiv \frac{\dot{W}_{\text{on comp},s}}{\dot{W}_{\text{on comp}}} = \frac{\dot{W}_{\text{on comp},s}/\dot{m}}{\dot{W}_{\text{on comp}}/\dot{m}} = \frac{h_{2s} - h_1}{h_2 - h_1}, \tag{4}$$

where

$p_{2s} = p_2 = 16$ bar and $s_{2s} = s_1 = 5.6457$ kJ/(kg.K) $\Rightarrow$ $h_{2s} = 1755.38$ kJ/kg, $T_{2s} = 143$ °C (interpolating from Table A-15),

$\Rightarrow$ $\boxed{\eta_{comp} = 0.888}$.