39.19 A refrigeration cycle using R-1234yf operates between $0°F$ and $120°F$. Refrigerant leaves the evaporator with $20°F$ of superheat. There is no subcooling. What is the volume flow rate of refrigerant leaving the evaporator per ton of refrigeration?

A. $0.1\frac{ft^3}{min}$

B. $4.4\frac{ft^3}{min}$

C. $8.3\frac{ft^3}{min}$

D. $9.2\frac{ft^3}{min}$

In the reference handbook lookup Pressure Versus Enthalpy Curves for Refrigerant 1234yf and find the enthalpy at states 1 and 3 of the refrigeration cycle.

State 1, the evaporator is known to operate at $0°F$, however the superheat must also be accounted for. Move to the right of the saturation curve into the superheated region to $20°F$ and read the enthalpy and the density. Note that lines of constant density are to the right and slanted slightly up in this region of the chart. Take the inverse of density to determine the specific volume for state 1.

$$T_1 = 20°F$$

$$h_1 = 90\frac{Btu}{lb}$$

$$v = \frac{1}{\rho} = \frac{1}{.6\frac{lb}{ft^3}} = 1.67\frac{ft^3}{lb}$$

Since we are interested in the evaporator, we can skip State 2 and jump to State 3, where the condenser temperature is known and the refrigerant is known to exit the condenser as a saturated liquid (no subcooling). Read the enthalpy:

$$T_3 = 120°F$$

$$\chi_3 = 0$$

$$h_3 = 50\frac{Btu}{lb}$$

To find the volume flow rate of refrigerant at State 1 per ton of cooling, write the expression $\frac{\dot{V}_R}{\dot{Q}_L}$, where $\dot{V}_R$ can be expressed as a product of $\dot{m}$, mass flow rate, and v, specif volume. $\dot{Q}_L$ can be expressed as a product of $\dot{m}$, mass flow rate, and the difference in enthalpy across the evaporator, $h_1 - h_4$. Note the mass flow rate cancels out of the expression.

$$\frac{\dot{V}_R}{\dot{Q}_L} = \frac{(\dot{m})(v_1)}{(\dot{m})(h_1 - h_4)} = \frac{(v_1)}{(h_1 - h_4)} = \frac{1.67\frac{ft^3}{lb}}{90\frac{Btu}{lb} - 50\frac{Btu}{lb}} = .042\frac{ft^3}{Btu}$$

The evaporator capacity must be converted to tons, which introduces time units that are needed in order to specify a volume flow *rate*.

$$.042\frac{ft^3}{Btu}\left(\frac{\left(12,000\frac{Btu}{hr}\right)\left(\frac{1hr}{60min}\right)}{1ton}\right) = 8.4\frac{ft^3}{min \cdot ton}$$

Answer C

39.20 A heat pump with a $3KW$ compressor has a heating capacity of $50,000\frac{Btu}{hr}$ and a cooling capacity of $40,000\frac{Btu}{hr}$. What is the COP when the unit is operated in heating mode?

A. 1.0

B. 3.9

C. 4.9

D. 5.0

Since we are only interested in the Coefficient of Performance when the unit is operated as a Heat Pump, select the formula below and ignore the cooling capacity:

$$COP_{HP} = \frac{Q_H}{W}$$

Substitute and solve, converting all units such that they cancel and the COP is unitless.

$$COP_{HP} = \frac{Q_H}{W} = \frac{50,000\frac{Btu}{hr}}{(3KW)\left(3412\frac{Btu}{hr \cdot KW}\right)} = 4.9$$

Note the COP for a heat pump is always slightly greater than for the same device operating as a refrigerator under the same conditions because the compressor energy provides useful heating, whereas in cooling mode the waste heat must be rejected and therefore reduces the system efficiency.

If the heat pump were in cooling mode, the COP would be:

$$COP_R = \frac{Q_L}{W} = \frac{40,000\frac{Btu}{hr}}{(3KW)\left(3412\frac{Btu}{hr \cdot KW}\right)} = 3.9$$

$$COP_R + 1 = COP_{HP}$$

Answer C