31.13 $10\frac{lb}{min}$ **of** $10psig$ **steam with a temperature of** $400°F$ **enters a heat exchanger and is cooled to** $120°F$ **at atmospheric pressure. What is the heat transfer assuming no losses?**

A. $530,000\frac{Btu}{hr}$

B. $590,000\frac{Btu}{hr}$

C. $630,000\frac{Btu}{hr}$

D. $690,000\frac{Btu}{hr}$

The heat transfer will be given by the product of the mass flow rate and the change in enthalpy of the steam as it travels through the heat exchanger with pressure and temperature both decreasing during the process. Let State 1 represent the entering steam and State 2 represent the leaving condition. The mass flow rate is given. Both enthalpies need to be determined.

$$\dot{Q} = \dot{m}\Delta h = \dot{m}\left(h_1 - h_2\right)$$

Start by checking the steam table by looking up Properties of Saturated Water and Steam by pressure.

$$P_1 = 10psig \approx 25psia$$

$$T_1 = 400°F$$

Note the saturation temperature at $25psia$.

$$T_{sat@25psia} = 240°F$$

$$T_1 > T_{sat@P_1}$$

Since the temperature at State 1 is greater than the saturation temperature for the given pressure at State 1, the steam must be *superheated*. To confirm this assertion as well as to obtain the enthalpy for State 1, check the table Properties of Superheated Steam.

$$h_1 = 1238.6\frac{Btu}{lb}$$

Return to the Properties of Saturated Water and Steam table and find the saturation temperature for atmospheric pressure. Unsurprisingly, the saturation temperature is $212°F$ aka the boiling point of water.

$$P_2 = 14.7psia$$

$$T_2 = 120°F$$

$$h_{sat@14.7psia} = 180.2\frac{Btu}{lb}$$

$$T_{sat@14.7psia} = 212^{\circ}F$$

$$T_2 < T_{sat@P_2}$$

Since the temperature at State 2 is less than the saturation temperature, the water must be *sub-cooled*. Since there is no sub-cooled water table in the reference handbook, it is necessary to calculate the enthalpy at State 2 using the specific heat relationship.

$$\Delta h = c_p \Delta T$$

$$h_{sat} - h_2 = c_p \left(T_{sat} - T_2 \right)$$

Rearrange, substitute, and solve for h_2.

$$h_2 = h_{sat} - c_p \left(T_{sat} - T_2 \right) = \left(180.2 \frac{Btu}{lb} \right) - \left(1 \frac{Btu}{lb \cdot {}^{\circ}F} \right) \left(212^{\circ}F - 120^{\circ}F \right) = 88.2 \frac{Btu}{lb}$$

Finally, solve for the heat transfer. Convert units as required to produce $\frac{Btu}{hr}$ in the final answer.

$$\dot{Q} = \dot{m} \left(h_1 - h_2 \right) = \left(10 \frac{lb}{min} \right) \left(\frac{60 min}{1 hr} \right) \left(1238.6 \frac{Btu}{lb} - 88.2 \frac{Btu}{lb} \right) = 690,240 \frac{Btu}{hr}$$

Answer D