34.13 A Rankine cycle operates between $14.7psia$ and $900psia$. The temperature of the steam entering the turbine is $1200°F$. What is the maximum thermal efficiency of the cycle?

A. 14%

B. 21%

C. 34%

D. 39%

Use the Rankine Cycle schematic, T-s diagram, and efficiency formula. Work around the cycle starting with State 3, the superheated steam entering the turbine. Use the properties of Superheated Steam table to obtain the enthalpy and entropy at State 3.

$$P_3 = 900psia$$

$$T_3 = 1200°F$$

$$h_3 = 1621.8\frac{Btu}{lb}$$

$$s_3 = 1.739\frac{Btu}{lb°R}$$

For State 4, assume the turbine is isentropic i.e. has 100% efficiency. Use the properties of Saturated Water and Steam table to look up enthalpy and entropy values. Determine the quality at State 4. Use the quality to determine the enthalpy at State 4.

$$P_4 = 14.7psia$$

$$s_4 = s_3 = 1.739\frac{Btu}{lb°R}$$

$$s_f = 0.3122\frac{Btu}{lb°R}$$

$$s_{fg} = 1.4443\frac{Btu}{lb°R}$$

$$\chi_4 = \frac{s_4 - s_f}{s_{fg}} = \frac{1.739\frac{Btu}{lb°R} - 0.3122\frac{Btu}{lb°R}}{1.4443\frac{Btu}{lb°R}} = 0.988$$

$$h_f = 180.18\frac{Btu}{lb}$$

$$h_{fg} = 970.07\frac{Btu}{lb}$$

$$h_4 = h_f + \chi_4 h_{fg} = 180.18\frac{Btu}{lb} + (0.988)\left(970.07\frac{Btu}{lb}\right) = 1138.5\frac{Btu}{lb}$$

For State 1, assume the steam exits the condenser as a saturated liquid. Obtain the enthalpy for State 1.

$$h_1 = h_{f@14.7psia} = 180.18\frac{Btu}{lb}$$

For State 2, assume $\dot{w}_{pump} \approx 0$, therefore $h_2 \approx h_1$.

$$h_2 = 180.18\frac{Btu}{lb}$$

Calculate the efficiency of the cycle, which is maximized by favorable assumptions used in determining the enthalpies for State 4 and State 2.

$$\eta = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{\dot{m}\left(h_3 - h_4\right) - \dot{m}\left(h_2 - h_1\right)}{\dot{m}\left(h_3 - h_2\right)} = \frac{h_3 - h_4}{h_3 - h_2}$$

$$\eta = \frac{1621.8\frac{Btu}{lb} - 1138.5\frac{Btu}{lb}}{1621.8\frac{Btu}{lb} - 180.18\frac{Btu}{lb}} = 0.335$$

Answer C