31.18 $900psia$, $1000°F$ **steam enters a turbine, expands, and exits as saturated vapor at** $5psia$**. What is the thermal efficiency of the turbine?**

A. 67%

B. 72%

C. 77%

D. 82%

Consider the entering steam as State 1. The steam at State 1 is superheated. Look up the enthalpy and entropy in the Properties of Superheated Steam table.

$$T_1 = 1000°F$$

$$P_1 = 900psia$$

$$h_1 = 1509.2\frac{Btu}{lb}$$

$$s_1 = 1.667\frac{Btu}{lb°R}$$

Consider the leaving steam as State 2. The steam at State 2 is a saturated vapor. Look up the enthalpy in the Properties of Saturated Water and Steam table. This is the *actual* enthalpy at State 2.

$$P_2 = 5psia\,(saturated)$$

$$h_2 = 1130.7\frac{Btu}{lb}$$

Consider the ideal leaving condition for the turbine if the expansion was isentropic i.e. 100% efficient. In such a case, the entropy at the *ideal* State 2 would be equal to the entropy at State 1. Determine the quality of the leaving steam in this case, which would be a saturated mixture. Use the quality to determine the enthalpy at the *ideal* State 2.

$$P_2 = 5psia$$

$$s_{2,ideal} = s_1 = 1.667\frac{Btu}{lb°R}$$

$$s_f = 0.2348\frac{Btu}{lb°R}$$

$$s_{fg} = 1.6092\frac{Btu}{lb°R}$$

$$\chi = \frac{s_{2,ideal} - s_f}{s_{fg}} = \frac{1.667 \frac{Btu}{lb^\circ R} - 0.2348 \frac{Btu}{lb^\circ R}}{1.6092 \frac{Btu}{lb^\circ R}} = 0.89$$

$$h_f = 130.13 \frac{Btu}{lb}$$

$$h_{fg} = 1000.57 \frac{Btu}{lb}$$

$$h_{2,ideal} = h_f + \chi h_{fg} = 130.13 \frac{Btu}{lb} + 0.89 \left(1000.57 \frac{Btu}{lb} \right) = 1020.6 \frac{Btu}{lb}$$

Calculate the efficiency based on the actual and ideal enthalpies at State 2, the turbine exit condion.

$$\eta = \frac{h_1 - h_{2,actual}}{h_1 - h_{2,ideal}} = \frac{1509.2 \frac{Btu}{lb} - 1130.7 \frac{Btu}{lb}}{1509.2 \frac{Btu}{lb} - 1020.6 \frac{Btu}{lb}} = 0.77$$

Answer C