Problem 16 Solution

\[ W_s = 300 \text{W} \]

Flow, \( Q = 100(20 - T), \ \text{T} \text{C} \)

\[ W_{\text{lost}} = W_{\text{actual}} - W_{\text{rev}} \]

\[ W_{\text{rev}} = \sum_{\text{out}} m_j B_j - \sum_{\text{in}} m_i B_i \]

\[ = m_2 B_2 - m_1 B_1 \]

\[ = \dot{m} (B_2 - B_1) \quad \text{(since } m_1 = m_2 = \dot{m}) \]

\[ = \dot{m} \left[ (H_2 - T_0 S_2) - (H_1 - T_0 S_1) \right] \]

\[ = \dot{m} (H_2 - H_1) - \dot{m} T_0 (S_2 - S_1) \]

\[ = \dot{m} \Delta H - \dot{m} T_0 \Delta S \quad \text{(1)} \]

\[ \Delta S \text{ from S+VN, p. 183} \]

\[ dH = C_p dT + \left[ V - T \left( \frac{\partial V}{\partial T} \right)_p \right] dP \quad (6.20) \]

\[ dS = \frac{C_p}{T} dT - \left( \frac{\partial V}{\partial T} \right)_T dP \quad (6.21) \]

But for a liquid, in this situation

\[ H = f(T) \quad \text{since } P \text{ is constant} \]

\[ S = f(T) \quad \text{assuming no } \Delta P \]
Thus,

\[ \Delta H = \langle C_p \rangle \Delta T = \langle C_p \rangle (T_2 - T_1) \]

\[ \Delta S = \langle C_p \rangle \ln \left( \frac{T_2}{T_1} \right) \]

Since \( C_p \) is roughly constant for liquids over small changes of temperature,

\[ \langle C_p \rangle = 4180 \text{ J/kg·K} \]

Hence,

\[ \Delta H = (4180 \text{ J/kg·K}) (30 - 40 \text{ K}) \]

\[ = -41800 \text{ J/kg} \]

\[ \Delta S = (4180 \text{ J/kg·K}) \ln \left( \frac{30 + 273}{40 + 273} \right) \]

\[ = -135.73 \text{ J/kg·K} \]

(Note: You could also get these from the steam tables for saturated liquid at \( T_1 \) & \( T_2 \). You are then assuming (as above) that \( H = f(p) \) and \( S = f(p) \). Results are comparable.)

Going back to 0,

\[ W_{irr} = \left( \frac{1 \text{ kg/min}}{60 \text{ s/min}} \right) \left( -41800 \text{ J/kg} \right) \]

\[ - \left( \frac{1 \text{ kg/min}}{60 \text{ s/min}} \right) \left( \frac{1 \text{ km}}{29.3 \text{ K}} \right) \left( -135.73 \text{ J/kg·K} \right) \]

\[ = -696.67 W - (-662.80 W) \]

\[ W_{irr} = -33.9 W \]

is work obtained from a reversible process.
Derivation:

\[
W_{\text{lost}} = W_{\text{actual}} - W_{\text{net}}
\]

\[
= \frac{W_5}{W_5}
\]

\[
= (+300\, \text{W}) - (-33.9\, \text{W})
\]

\[
= \frac{\text{work done}}{\text{work done}}
\]

\[
W_{\text{lost}} = 333.9\, \text{W}
\]

Thus, if the process described — namely, cooling a stream of water from 40°C to 30°C — were done reversibly, you would obtain 33.9 W of work from it. Our process is very inefficient, however, and requires that we put 300 W of work into it!

Sources of irreversibility:

\((\sim 90\%)\) * Stirrer — mechanical irreversibility, work of stirrer generally dissipated as heat.

\((\sim 10\%)\) * Heat loss to surroundings — heat transfer occurs over finite \(\Delta T\).

\(\text{small since} \ \Delta T \text{ is small} \)