

**8-88** Water is heated by hot oil in a heat exchanger. The outlet temperature of the oil and the rate of exergy destruction within the heat exchanger are to be determined.

**Assumptions** 1 Steady operating conditions exist. 2 The heat exchanger is well-insulated so that heat loss to the surroundings is negligible and thus heat transfer from the hot fluid is equal to the heat transfer to the cold fluid. 3 Changes in the kinetic and potential energies of fluid streams are negligible. 4 Fluid properties are constant.

**Properties** The specific heats of water and oil are given to be 4.18 and 2.3 kJ/kg·°C, respectively.

**Analysis** We take the cold water tubes as the system, which is a control volume.

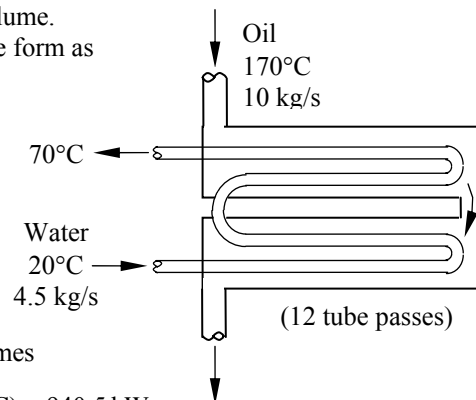
The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\text{Rate of net energy transfer by heat, work, and mass}} = \underbrace{\Delta \dot{E}_{\text{system}}}_{\text{Rate of change in internal, kinetic, potential, etc. energies}} \stackrel{\text{no (steady)}}{=} 0$$

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{Q}_{\text{in}} + \dot{m}h_1 = \dot{m}h_2 \quad (\text{since } \Delta \text{ke} \cong \Delta \text{pe} \cong 0)$$

$$\dot{Q}_{\text{in}} = \dot{m}c_p(T_2 - T_1)$$



Then the rate of heat transfer to the cold water in this heat exchanger becomes

$$\dot{Q} = [\dot{m}c_p(T_{\text{out}} - T_{\text{in}})]_{\text{water}} = (4.5 \text{ kg/s})(4.18 \text{ kJ/kg} \cdot ^\circ\text{C})(70^\circ\text{C} - 20^\circ\text{C}) = 940.5 \text{ kW}$$

Noting that heat gain by the water is equal to the heat loss by the oil, the outlet temperature of the hot water is determined from

$$\dot{Q} = [\dot{m}c_p(T_{\text{in}} - T_{\text{out}})]_{\text{oil}} \rightarrow T_{\text{out}} = T_{\text{in}} - \frac{\dot{Q}}{\dot{m}c_p} = 170^\circ\text{C} - \frac{940.5 \text{ kW}}{(10 \text{ kg/s})(2.3 \text{ kJ/kg} \cdot ^\circ\text{C})} = 129.1^\circ\text{C}$$

(b) The rate of entropy generation within the heat exchanger is determined by applying the rate form of the entropy balance on the entire heat exchanger:

$$\underbrace{\dot{S}_{\text{in}} - \dot{S}_{\text{out}}}_{\text{Rate of net entropy transfer by heat and mass}} + \underbrace{\dot{S}_{\text{gen}}}_{\text{Rate of entropy generation}} = \underbrace{\Delta \dot{S}_{\text{system}}}_{\text{Rate of change of entropy}} \stackrel{\text{no (steady)}}{=} 0$$

$$\dot{m}_1 s_1 + \dot{m}_3 s_3 - \dot{m}_2 s_2 - \dot{m}_4 s_4 + \dot{S}_{\text{gen}} = 0 \quad (\text{since } \dot{Q} = 0)$$

$$\dot{m}_{\text{water}} s_1 + \dot{m}_{\text{oil}} s_3 - \dot{m}_{\text{water}} s_2 - \dot{m}_{\text{oil}} s_4 + \dot{S}_{\text{gen}} = 0$$

$$\dot{S}_{\text{gen}} = \dot{m}_{\text{water}}(s_2 - s_1) + \dot{m}_{\text{oil}}(s_4 - s_3)$$

Noting that both fluid streams are liquids (incompressible substances), the rate of entropy generation is determined to be

$$\dot{S}_{\text{gen}} = \dot{m}_{\text{water}} c_p \ln \frac{T_2}{T_1} + \dot{m}_{\text{oil}} c_p \ln \frac{T_4}{T_3}$$

$$= (4.5 \text{ kg/s})(4.18 \text{ kJ/kg} \cdot \text{K}) \ln \frac{70 + 273}{20 + 273} + (10 \text{ kg/s})(2.3 \text{ kJ/kg} \cdot \text{K}) \ln \frac{129.1 + 273}{170 + 273} = 0.736 \text{ kW/K}$$

The exergy destroyed during a process can be determined from an exergy balance or directly from its definition  $\dot{X}_{\text{destroyed}} = T_0 \dot{S}_{\text{gen}}$ ,

$$\dot{X}_{\text{destroyed}} = T_0 \dot{S}_{\text{gen}} = (298 \text{ K})(0.736 \text{ kW/K}) = 219 \text{ kW}$$