Problem: 3-4

Given: Air at 15 °C is to be heated to 40 °C by mixing it in a steady flow with a quantity of air at 90 °C.

Find: Calculate
i) the ratio of mass flow of air at 90 °C and at 15 °C.
ii) the effectiveness of the heating process if the atmospheric temperature is 15 °C.

Assume: the mixing process is adiabatic and neglect changes in kinetic and potential energy

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Let the ratio of mass flows required be y; let the air at 15 °C be stream 1, the air at 90 °C be stream 2, and the mixed airstream at 40 °C be stream 3.
Then

$$c_pT_1 + yc_pT_2 = (1+y)c_pT_3$$

or

$$\begin{aligned} yc_p(T_2 - T_3) &= c_p(T_3 - T_1) \\ y(90-40) &= 40-15 \end{aligned}$$

therefore

$$y = \frac{25}{50} = 0.5$$

Let the system considered be a stream of air of unit mass, heated from 15 to 40 °C.
The increase of exergy of the system per unit mass of air initially at 15 °C is

$$\begin{aligned} \psi_3 - \psi_1 &= (h_3 - h_1) - T_0(s_3 - s_1) \\ &= 1.005(40-15) - 288(s_3 - s_1) \end{aligned}$$

Therefore

$$s_3 - s_1 = c_p \ln\left(\frac{T_3}{T_1}\right) = 1.005 \ln\left(\frac{313}{288}\right) = 0.0831\ kJ/kg \cdot K$$

The increase of exergy of the system per unit mass of air initially at 15 °C is:

$$\begin{aligned} \psi_3 - \psi_1 &= (1.005 \times 25) - (288 \times 0.0831) \\ &= 1.195\ kJ/kg \end{aligned}$$

The system, which is the air being heated, is "surrounded" by the airstream being cooled. Therefore, the loss of exergy of the surroundings is given by $y(\psi_2 - \psi_3)$ per unit mass of air initially at 15 $°C$.
The loss of exergy of surroundings be unit mass of air initially at 15 $°C$ is:

$$\begin{aligned}\psi_2 - \psi_3 &= 0.5\{(h_2 - h_3) - T_0(s_2 - s_3)\} \\ &= 0.5\left(1.005(90 - 40) - 288 \times 1.005 \ln \frac{363}{313}\right) \\ &= 3.65\ kJ/kg\end{aligned}$$

Therefore the effectiveness is

$$\begin{aligned}\epsilon &= \frac{1.195}{3.65} = 0.327 \\ &= 32.7\%\end{aligned}$$

The low figure of the effectiveness is an indication of the highly irreversible nature of the mixing process.