Air flows steadily between two sections in a long straight portion of 10.2 cm diameter pipe. The temperature and pressure at the inlet are 27 °C and 590 kPa (gage), and at the outlet are 10 °C and 26 kPa (gage). Calculate:

a. the change in specific internal energy between the inlet and outlet,
b. the change in the specific enthalpy between the inlet and outlet,
c. the change in density between the inlet and outlet, and
d. the change in specific entropy between the inlet and outlet.
e. Would you expect compressibility effects to be important for this flow?

State any major assumptions you make.

SOLUTION:

Determine the corresponding absolute temperatures and pressures.

T_1 = (27 + 273) K = 300 K
T_2 = (10 + 273) K = 283 K
p_1 = (590 + 101) kPa = 691 kPa
p_2 = (26 + 101) kPa = 127 kPa

Assume that the air behaves as a perfect gas.

$$u_2 - u_1 = c_V (T_2 - T_1) = 717 \text{ J}/(\text{kg}\cdot\text{K})(283\text{ K} - 300\text{ K}) = -12.2 \text{ kJ/kg} \quad (1)$$

$$h_2 - h_1 = c_P (T_2 - T_1) = 1004 \text{ J}/(\text{kg}\cdot\text{K})(283\text{ K} - 300\text{ K}) = -17.1 \text{ kJ/kg} \quad (2)$$

$$\rho_1 = \frac{p_1}{RT_1} = \frac{(127*10^3 \text{ Pa})}{(287 \text{ J}/(\text{kg}\cdot\text{K}))(300\text{ K})} = 8.03 \text{ kg/m}^3 \quad (3)$$

$$\rho_2 = \frac{p_2}{RT_2} = \frac{(691*10^3 \text{ Pa})}{(287 \text{ J}/(\text{kg}\cdot\text{K}))(283\text{ K})} = 1.56 \text{ kg/m}^3 \quad (4)$$

$$\therefore \rho_2 - \rho_1 = -6.46 \text{ kg/m}^3 \quad (5)$$

$$s_2 - s_1 = c_P \ln\frac{T_2}{T_1} - R\ln\frac{p_2}{p_1} = 1004 \text{ J}/(\text{kg}\cdot\text{K})\ln\frac{283\text{ K}}{300\text{ K}} - 287 \text{ J}/(\text{kg}\cdot\text{K})\ln\frac{127\text{ kPa}}{691\text{ kPa}} = 428 \text{ J/kg} \quad (6)$$

Since the change in density is large compared to the flow's initial density,

$$\frac{\rho_2 - \rho_1}{\rho_1} = \frac{-6.46 \text{ kg/m}^3}{8.03 \text{ kg/m}^3} = -0.805 \quad (7)$$

we should expect that compressibility effects are significant.