With h and h_o known, the velocity follows from the adiabatic energy equation:

$$h + V^2/2 = h_o, \quad \text{or} \quad 3.074E6 + V^2/2 = 3.264E6\ \frac{J}{kg}\left(\text{or } \frac{m^2}{s^2}\right),$$

$$\text{Solve} \quad V \approx \mathbf{618\ \frac{m}{s}} \quad \textit{Ans.}\text{ (b)}$$

The speed of sound is not in *my* Steam Tables, however, the "isentropic exponent" is:

$$\gamma_{isen} \approx 1.298 \text{ at } p = 500 \text{ kPa and } T = 304°C. \text{ Then} \quad a \approx \sqrt{\frac{\gamma p}{\rho}} = \sqrt{\frac{1.298(5E5)}{1.896}} \approx 585\ \frac{m}{s}$$

$$\text{Then} \quad Ma = V/a = \frac{618}{585} \approx \mathbf{1.06} \quad \textit{Ans.}\text{ (c)} \quad \text{(slightly supersonic)}$$

We could have done nearly as well (±2%) by simply assuming an ideal gas with $k \approx 1.33$.

9.30 Oxygen flows in a duct of diameter 5 cm. At one section, T_o = 300°C, p = 120 kPa, and the mass flow is 0.4 kg/s. Estimate, at this section, (a) V; (b) Ma; and (c) ρ_o.

Solution: For oxygen, from Table A.4, take k = 1.40 and R = 260 J/kg·K. Compute the specific heat: $c_p = kR/(k-1) = 1.4(260)/(1.4-1) = 910$ J/kg·K. Use energy and mass together:

$$T + \frac{V^2}{2c_p} = T_o, \quad \text{or:} \quad T + \frac{V^2}{2(910\ m^2/s^2K)} = 573\ K$$

$$\dot{m} = \rho AV = \frac{p}{RT}AV = \left[\frac{120000\ Pa}{(260\ m^2/s^2K)T}\right]\left(\frac{\pi}{4}\right)(0.05\ m)^2 V = 0.4\ kg/s$$

$$\text{Solve for} \quad T = 542\ K \quad \text{and} \quad \mathbf{V = 239\ m/s} \quad \textit{Ans.}\text{ (a)}$$

With T and V known, we can easily find the Mach number and stagnation density:

$$Ma = \frac{V}{\sqrt{kRT}} = \frac{239}{\sqrt{1.4(260)(542)}} = \frac{239\ m/s}{444\ m/s} = \mathbf{0.538} \quad \textit{Ans.}\text{ (b)}$$

$$\rho = \frac{p}{RT} = \frac{120000}{260(542)} = 0.852\ \frac{kg}{m^3}$$

$$\rho_o = \rho\left(1 + \frac{k-1}{2}Ma^2\right)^{1/(k-1)} = 0.852\left[1 + \frac{0.4}{2}(0.538)^2\right]^{1/0.4} = \mathbf{0.98\ \frac{kg}{m^3}} \quad \textit{Ans.}\text{ (c)}$$
