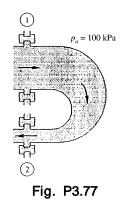**P3.77** Water at 20°C flows steadily through a reducing pipe bend, as in Fig. P3.77. Known conditions are $p_1 = 350$ kPa, $D_1 = 25$ cm, $V_1 = 2.2$ m/s, $p_2 = 120$ kPa, and $D_2 = 8$ cm. Neglecting bend and water weight, estimate the total force which must be resisted by the flange bolts.

$p_a = 100$ kPa

Fig. P3.77

Solution: First establish the mass flow and exit velocity:

$$\dot{m} = \rho_1 A_1 V_1 = 998\left(\frac{\pi}{4}\right)(0.25)^2(2.2) = 108 \ \frac{kg}{s} = 998\left(\frac{\pi}{4}\right)(0.08)^2 V_2, \quad \text{or} \quad V_2 = 21.5 \ \frac{m}{s}$$

The CV surrounds the bend and cuts through the flanges. The force balance is

$$\sum F_x = -F_{bolts} + p_{1,gage} A_1 + p_{2,gage} A_2 = \dot{m}_2 u_2 - \dot{m}_1 u_1, \quad \text{where} \quad u_2 = -V_2 \quad \text{and} \quad u_1 = V_1$$

$$\text{or} \quad F_{bolts} = (350000 - 100000)\frac{\pi}{4}(0.25)^2 + (120000 - 100000)\frac{\pi}{4}(0.08)^2 + 108(21.5 + 2.2)$$

$$= 12271 + 101 + 2553 \approx \mathbf{14900 \, N} \quad \textit{Ans.}$$