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The University of Calgary
Department of Chemical & Petroleum Engineering

ENCH 501: Transport Phenomena Quiz #5 **November 2, 2010**

Time Allowed: 40 mins. **Name:**

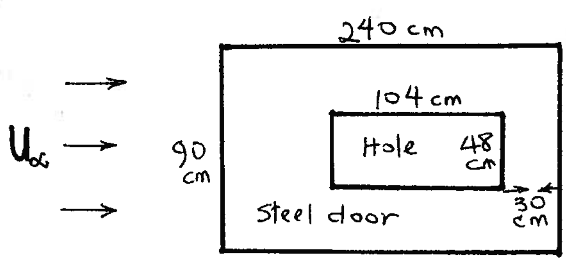
Zinc (m.pt. 419.53°C) is a metal that, although it is only 0.0075% of the earth crust and is the 24th most abundant element, is the 4th most common metal in use, behind iron, aluminum and copper. World-wide, 47 to 50% of it is used to protect steel from corrosion by hot-dip galvanization, painting or electroplating. Metal roofs, chain-link fences, light posts, walls, windows and doors in industrial facilities, heat exchangers and car bodies are examples of objects often coated with zinc to prolong their useful lives. Zinc is also used in batteries, in alloys with copper to make brass, as chemicals in diet supplements, deodorants, luminescent paints and anti-dandruff shampoos. This problem is about galvanization of steel doors by hot-dipping.

A door (top view) with dimensions shown in the sketch is held horizontally by two clamps on its longer sides. The door has a hole measuring 104 by 48 cm for mounting reinforced glass, and the hole is equidistant from the long sides. The door is dragged through a stagnant pool of molten zinc at 459.3°C, at a steady speed of 0.11 m/s. You may assume that both the door and the liquid are at the same temperature. Thus there is no heat exchange between the door and the molten zinc.

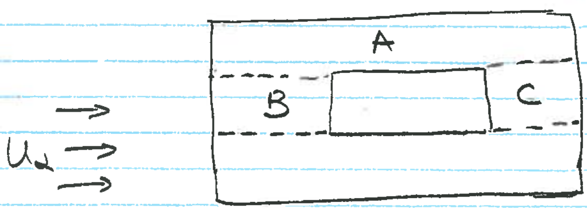
What force must the clamps be able to maintain so that the door does not slide off and fall into the pool? Use the ***integral method***. Show important steps in your analysis but do **not** derive all the equations.

Data: Properties of Zinc (*Hopkins*, M.R. and *Toye*, T.C., ***Proc. Phys. Soc. B***, v63, 773-82, 1950)

At 459.3°C, $\rho = 6{,}860\ kg/m^3$ and $\mu = 3.88$ mPa s

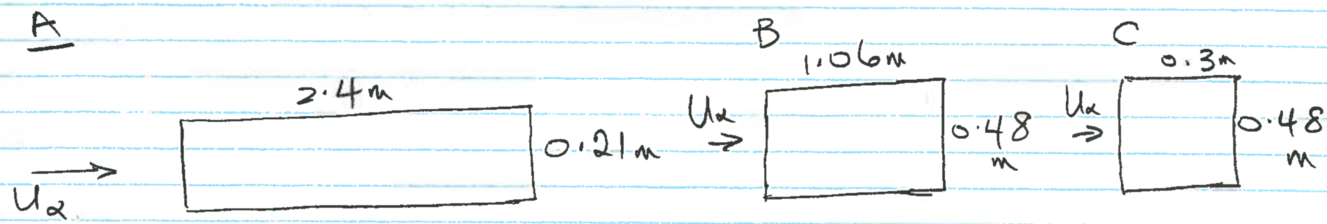


ENCH 501 Quiz #5 solution Nov. 2, 2010



The door essentially has 3 zones of surfaces, each with a leading edge.

There are 4 of surface zone A, and 2 each of zones B and C.

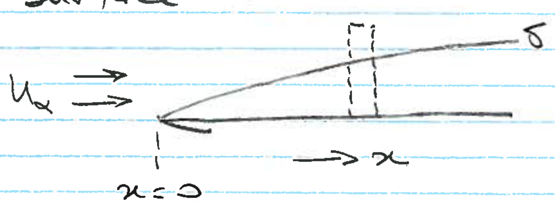


Check: If the flow over zone A is entirely laminar, the other zones will also have laminar b.l.

$$Re_x = \frac{x U_\infty \rho}{\mu} = \frac{(2.4)(0.11)(6860)}{3.88(10^{-3})} = 4.67(10^5) < 5(10^5)$$

$\therefore$ b.l. is laminar.

Flow over flat surface



The momentum integral eq. of the b.l., eq. 5.13 Notes is:

$$\mu \left.\frac{du}{dy}\right|_{y=0} = \frac{d}{dx}\left[\int_0^\delta \rho (U_\infty - u) u \, dy\right]$$

The b.c.s are

$y = 0 \quad u = 0$

$y = \delta \quad u = U_\infty$

$y = \delta \quad \frac{du}{dy} = 0$

$y = 0 \quad \frac{d^2u}{dy^2} = 0$

Assume a velocity profile

$$u = a + by + cy^2 + dy^3$$ and apply b.c.

we get $$\frac{u}{U_\alpha} = \frac{3}{2}\left(\frac{y}{\delta}\right) - \frac{1}{2}\left(\frac{y}{\delta}\right)^3$$ Eq. 5.16 Notes

Substitute this eq. into the integral eq. and solve to get $$\delta = 4.64\sqrt{\frac{\nu x}{U_\alpha}} \quad ; \quad \nu = \mu/\rho$$

Now The local shear stress on the wall at x, per unit width, is:

$$\tau_{y=0} = \mu \left.\frac{du}{dy}\right|_{y=0} = \frac{\mu U_\alpha}{\delta}\left(\frac{3}{2}\right)$$

$$= \frac{3}{2}\frac{\mu U_\alpha}{4.64}\left[\frac{U_\alpha}{\nu x}\right]^{\frac{1}{2}}$$ Eq. 5.24 Notes

or $$\tau_{y=0} = \beta\, x^{-\frac{1}{2}} \quad ; \quad \beta = \frac{3}{2}\frac{\mu U_\alpha}{4.64}\left[\frac{U_\alpha}{\nu}\right]^{\frac{1}{2}}$$

∴ Drag on one surface - A, B or C (Both L + W change)

$$D = \int_0^L \tau_{y=0} W\, dx = W\beta\int_0^L x^{-\frac{1}{2}} dx$$

$$= 2W\beta L^{\frac{1}{2}}$$

β (SI units) $$= \frac{3}{2}\frac{(3.88)(10^{-3})(0.11)}{4.64}\left[\frac{0.11 \times 6860}{3.88(10^{-3})}\right]^{\frac{1}{2}} = 6.0847(10^{-2})$$

Total drag on door =

$$4\left(2 \times 0.21 \times 6.0847(10^{-2}) \times 2.4^{\frac{1}{2}}\right) + 2\left(2 \times 0.48 \times 6.0847 \times (10^{-2}) \times 1.06^{\frac{1}{2}}\right) + 2\left(2 \times 0.48 \times 6.0847(10^{-2}) \times 0.3^{\frac{1}{2}}\right)$$

$$= 0.3426 \text{ N}$$

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