University of Calgary
Department of Chemical & Petroleum Engineering

ENCH 501: Transport Processes

Mid-Term Examination, Fall 2004

Instructions: Time: 2:00 to 3:30 pm Oct 19, 2004
Attempt All Questions. Open Notes & Book.
Use of calculators permitted

Problem #1 (10 points)

Cooking fires are the leading causes of household fires, accounting for 30% of all fires in the city. Oil is the principal culprit in 60% of fires related to cooking. Water which is used most often to combat fires, however, lead to catastrophic explosions when the water mixes with hot oil. The phenomenon of what happens when drops of water falls into hot oil is being studied.

Water droplets, 3mm in diameter and initially at 20°C, are introduced into large pools of oil at 200°C and 220°C. The droplet in the oil at 200°C was vaporized explosively after 2100 ms. The droplet in oil at 220°C required only 1168 ms to explode. In both cases, it may be assumed that the water in the droplets was well mixed by rapid circulation currents and the temperature within the droplets were uniform at any instant. The heat transfer coefficients around the water droplets in the oil are also assumed to be the same, irrespective of the temperature of the pool of oil. The oil and water are immiscible.

(a) If the water droplet in 200°C oil exploded when superheated to a temperature of 166°C, what is the convective heat transfer coefficient?

(b) Estimate the temperature of the water droplet in the 220°C oil at the instant of explosion.

(c) Estimate how long it will take for a similar droplet of water to explode in oil at 190°C, the recommended cooking oil temperature for frying. Clearly state your assumptions. Can you comment on these results?

Data:

Properties of water: $\rho = 999.8$ kg/m^3; $C_p = 4.22$ kJ/kg K

Problem #2 (15 points)

The Canadian submarine, HMS Chicoutimi, recently had difficulties at sea. The hull of the Victoria class submarine is 70.26m long and the "diameter" is 7.6m. The vessel was designed to operate as "stealth" vehicle, hence its outer surface is covered with 22,000 acoustic tiles. These tiles are assumed square and 25 cm on the side.

For the purposes of the problem, the submarine is approximated as a horizontal cylinder which is partially submerged on its side in sea water at 5°C. The perimeter of the sector of the submarine submerged is measured to be 18.5 m. The tiles are arranged on the surface in a regular array along the vessel length, with a small gap between adjacent tiles. Two edges of each tile are normal to the direction of sea water flow over the hull. The sum total of the width of the gaps along the submarine length is 0.26 m, but each gap is wide enough to break the boundary layer development on the tile upstream of it. There are no gaps between the tiles in the peripheral direction. Thus to the eye, it appears as if the submarine is covered with bands of the tiles.

To rescue the vessel which had lost its power, a steel cable was attached to the front of the submarine and it is to be dragged at a constant speed of 3 knots through the water to port.

(a) Estimate the tension in the 2 cm diameter cable due to the drag force of the sea water on the hull. Show all your steps and state all assumptions. Neglect the force on the front surface of the cylinder, i.e. consider only the drag on the side.

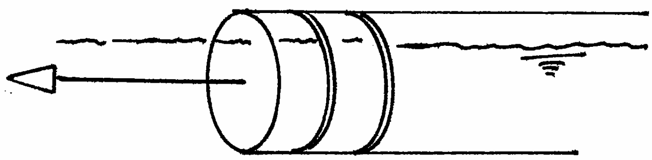
(b) If the cable is assumed elastic and would suffer catastrophic failure at a maximum strain of 0.02, do you expect the cable to snap at the intended towing speed?

(c) Estimate the displacement thickness δ_1 at the rear edge of each tile at a towing speed of 1.5 knots.

Data:
1 knot (kn) is equal 1.852km/hr.

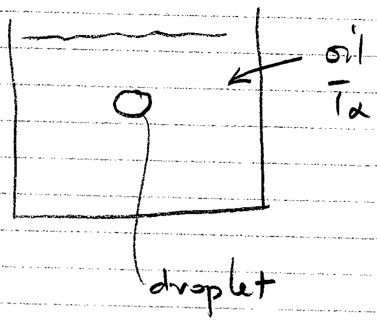
Properties of sea water at 5°C: ρ = 1029 kg/m^3, μ = 1.61 mPa.s

The Young's modulus of the cable material is 265 GPa.



ENCH 501 MID-TERM EXAMINATION Oct. 19, 2

Problem #1



This is a lumped heat capacit[y] problem.

The water droplets gain heat [from] the oil and become superheat[ed] until at a temperature, they ...

This problem is similar to that in the Lecture ...

By eq. 4.14 (Notes)

$$\frac{T - T_\alpha}{T_0 - T_\alpha} = \exp\left[- \frac{hA}{\rho C_p \forall} \cdot t \right]$$

where oil temp $= T_\alpha$; initial droplet temp ...

$A = 4\pi R^2$, $\forall = \frac{4}{3}\pi R^3$

(a) When $T_\alpha = 200^\circ C$, and $T_e = 166^\circ C$ + ...

$$\frac{166 - 200}{20 - 200} = \exp\left[- \frac{h \cdot 4\pi R^2}{\rho C_p \frac{4}{3}\pi R^3} \cdot t \right]$$

$$= \exp\left[- \frac{6h}{\rho C_p D} \cdot t \right]$$

$$\frac{-34}{-180} = \exp\left[- \frac{6 \times h \times 2.1}{\ldots} \right.$$

$\therefore \quad h = 1674.2 \quad W/m^2K.$ $\longrightarrow$

(b) Now $T_\alpha = 220°C$ and h is as above.

$$\frac{T_e - 220}{20 - 220} = \exp\left[-\frac{6h \times 1.168}{999.8(4220)(3)(10^{-3})}\right]$$

$$= \exp\left[-5.5367(10^{-4})h\right]$$

$$= 0.39576$$

The droplet explodes at

$\therefore \quad T_e = 140.85\,°C$ $\longrightarrow$

(c) When $T_\alpha = 190°C$, there are 2 unknown the T_e (explosion temp.) and time, t.

However, estimate T_e by linear extrapolation from the 2 previous problems.

T_α, °C	T_e °C	
190	?	$\longrightarrow$ 178.58°C
200	166	
220	140.85	

Substitute into equation

$$\frac{178.58 - 190}{20 - 190} = \exp\left[-\frac{(1674.2)(6)(t)}{999.8(4220)(3)(10^{-3})}\right.$$

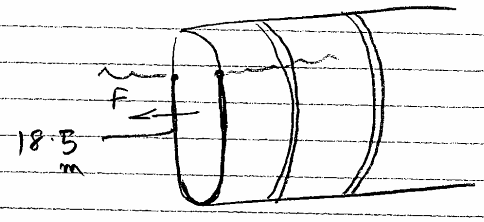
The most obvious observations are that:

1) As the oil temperature decreases, the temperature at which the explosion occ rises.

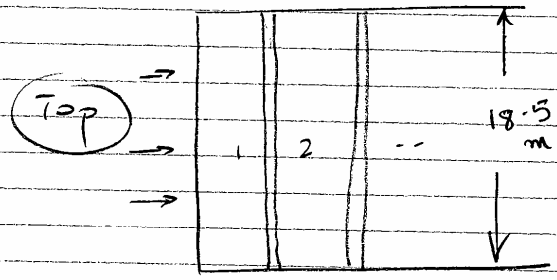
2. It requires more time for a dropl to explode as the oil temperature decreases.

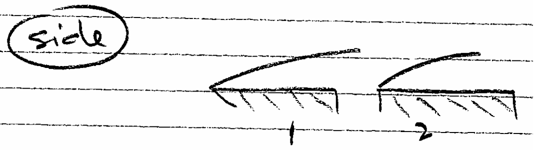
The theoretical limit for water superheat fo water is $T_e \sim 279 - 302\ ^\circ C$. Since the droplets are exploding below this range of temperature, one can suspect that nuclei such as dust particles are present

Problem #2.

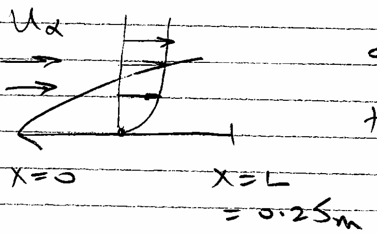


The submerged part of wall will be approximat[ed] as a flat plate, widt[h] 18.5 m, and a total of panels - each 0.25 m lo[ng]





Thus if one solves for t[he] drag on one panel, × 280 to get total skin drag.



First, show that the b.l. is

$$U_\alpha = 3 \text{ knots} = \frac{3(1.852)(1000)}{3600} = 1.543$$

$$Re_L = \frac{L U_\alpha \rho}{\mu} = \frac{0.25(1.543)(1029)}{1.61(10^{-3})} = 2.4$$

This is $< 5(10^5)$ ∴ b.l. is lamin[ar]

From Notes, eq. 5.24

$$\tau_w\Big|_x = \frac{3}{2}\frac{\mu U_\alpha}{4.64}\left(\frac{U_\alpha}{\nu x}\right)^{\frac{1}{2}} = \beta x^{-\frac{1}{2}}$$

On one panel

Drag, $D = \int^L \beta W x^{-1/2}\,dx$. where $W = 1[8.5]$

$$\beta = \frac{3}{2}\,\frac{1}{4.64}\left(\mu \rho U_\alpha^3\right)^{\frac{1}{2}} = 0.3233\left(\mu \rho U_\alpha^3\right)$$

$$= 0.3233\left(1.61\,(10^{-3}) \times 1029 \times 1.543^3\right)^{\frac{1}{2}} = 0.79758$$

$$\therefore \quad D = 2\,(0.79758)(18.5)(0.25)^{\frac{1}{2}} = 14.\!:$$

Total drag on the hull, $F = D \times 280 = 4131$

This equals the force in the cable.

The tension = Force / Area of cable

X-Area of cable $= \pi R^2 = \pi\,(10^{-4})\ m^2$

$$\therefore \text{ The normal stress, } \sigma = \frac{4131.47}{\pi(10^{-4})}$$

$$= 1.3158\,(10^6)\ Pa$$

(b) By Hooke's Law

$\sigma = E\,\varepsilon$, σ = normal stress

ε = strain , E = You[ng's] mod[ulus]

The max. stress that the cable can handle is

$$\sigma = 265\,(10^9)(0.02) = 5.3\,(10^9)\ P$$

This is greater than $1.3158\,(10^6)$ Pa. $\therefore$ cable will NOT snap.

(c) From Notes, $\delta_1 = 3/8\ \delta = 1.74\sqrt{\frac{\nu x}{U_\alpha}}$

At the rear edge of each tile, $x = L = 0.25\,m$