# Final Exam Soln
# CM3110
# Fall 2020
# 16 Dec 2020

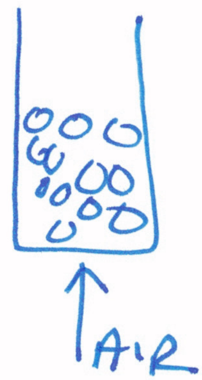
(1) (a) Evaporators. Some design considerations include the viscosity of the fluid (may wish to add a pump rather than rely on natural convection. Also residence time in the unit (food will change taste) and the ability to clean the evaporator (scale, or residue that burns on.) Evaporators w/ single passes have low residence times.

(b) packed beds: Ergun eqn is the dimensionless ΔP vs Q relationship.
(ΔP vs Q: eng'g quantities)

$$\frac{100/3}{Re_{D_H}} + \frac{1.75}{3} = f_{D_H}$$

(see exam handout for defns)

(c) fluidized beds.



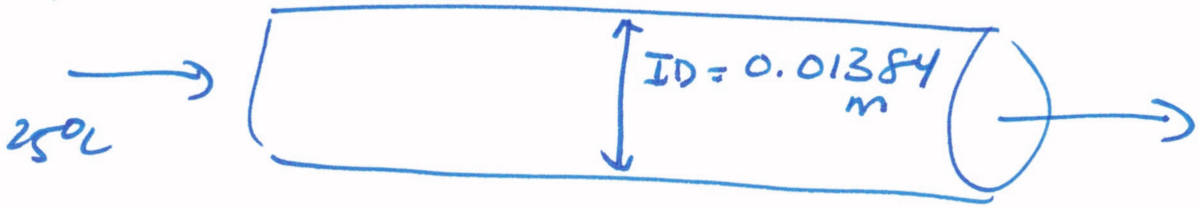

The velocity for incipient fluidization is the lowest velocity that will just lift the bed into a fluidized state, ie Δp of flow just balances the weight of the bed.

$$v_0 = \frac{(\rho_p - \rho) g \, \varepsilon^3 D_p^2}{150 \mu (1 - \varepsilon)}$$

(lecture 13)

This is the minimum $v$ for operation.

2.) $H_2O$




a) Laminar maximum speed

$$Re = 2100 = \frac{\rho \langle V \rangle D}{\mu} \Rightarrow \text{calc } \langle V \rangle$$

$$\langle V \rangle = \frac{(2100)\ 8.937\times10^{-4}\ \frac{kg}{m\,s}}{\left(997.08\ \frac{kg}{m^3}\right)(0.01384\ m)}$$

$$\boxed{\langle V \rangle = 0.1360019\ \frac{m}{s}}$$

$$Q = \langle V \rangle \frac{\pi D^2}{4}$$

$$= \left(0.1360019\ \frac{m}{s}\right)\left(\frac{\pi}{4}\right)(0.01384\ m)^2 \ \frac{15{,}850.2\ gpm}{m^3/s}$$

$$= 0.324\ gpm = \boxed{0.32\ gpm}$$

1

2b) $Q = 0.25$ gpm = Laminar

(part a says laminar up to 0.32 gpm)

LAMINAR FLOW
(Hagen Poiseuille eqn)

$$Q = \frac{\pi \, \Delta p \, R^4}{8 \mu L}$$

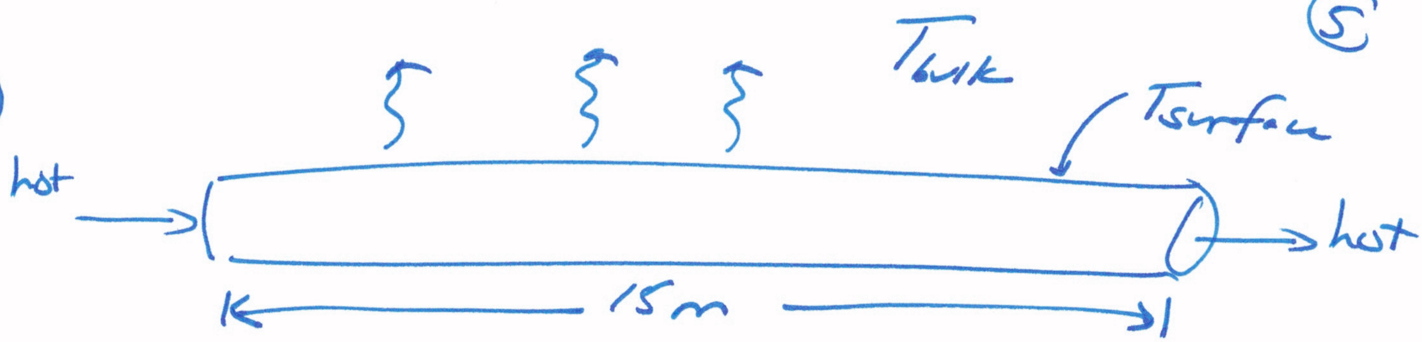
$$\frac{\Delta P}{L} = \frac{8\mu \, Q}{\pi R^4}$$

$$= \frac{8\left(8.937\times10^{-4}\,\frac{kg}{ms}\right)(0.25\text{ gpm})\frac{m^3/s}{15850.2\text{ gpm}}}{\pi\left(\frac{0.01384\,m}{2}\right)^4}$$

$$= 15.6535 \quad \frac{kg\,m^3}{m\,s^2}\,\frac{1}{m^4}\,\frac{N\,s^2}{kg\,m}\,\frac{Pa\,m^2}{N}$$

$$\boxed{\frac{\Delta P}{L} = 16\,\frac{Pa}{m}}$$

3)




Natural convection — no fan
no pump
hot surfaces

AND

radiation — often present w/ natural convection
— high temps

Nat'l convection
need to measure $T_{bulk,air}$, $T_{surface}$

$$T_{film} = \frac{T_b + T_s}{2} \qquad \Delta T = T_s - T_b$$

$$Pr = \frac{C_p \mu}{k} \leftarrow \text{look up at } T_{film}$$

Gr = calculate from eqn 13 of exam handout

$$= \frac{L^3 \rho^2 g \beta \Delta T}{\mu^2}$$

($\rho^2$, $g$, $\beta$, $\mu^2$) look up at $T_{film}$

Calculate $h_{nat'l\ conv}$ from Table 4.7-2 from handout for exam.

RADIATION

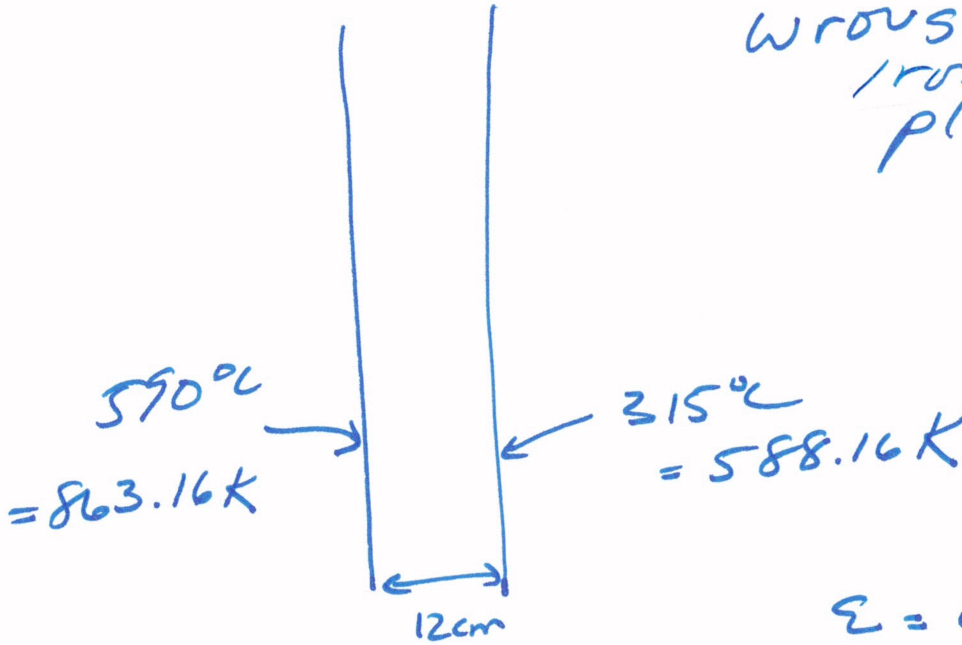
$$h_{rad} = \frac{\varepsilon \sigma \left(T_s^4 - T_L^4\right)}{T_s - T_L}$$

$\varepsilon$ = 0.79 (look up) (see handout)

$$h = h_{nat'l\ conv} + h_{rad}$$

4.)

wrought iron plates




$\varepsilon = 0.94$

$\frac{q_{net}}{A} = ?$

$$\frac{q}{A} = \frac{\sigma\,(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

$$\frac{(5.676 \times 10^{-8}\ \frac{W}{m^2 K^4})(863.16\,K^4 - 588.16\,K^4)}{\left(\frac{2}{0.94} - 1\right)}$$

$$= 21{,}917\ \frac{W}{m^2}$$

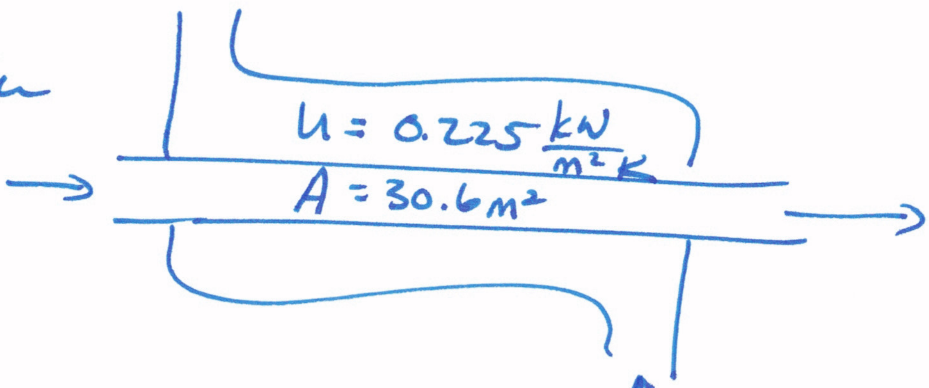
$$= \boxed{22\ \frac{kW}{m^2}}$$

//

5.) water

1.4 kg/s →

25°C




75°C

heat xfr fluid

k = 0.180 W/mK

$C_p$ = 1.97 kJ/kgK

1.85 kg/s

We only know inlet temps

⟹ use heat exchanger effectiveness

$$(\dot{m} C_p)_{water} = \left(1.4 \frac{kg}{s}\right)\left(4.182 \frac{kJ}{kg\,K}\right)$$

$$= 5.8548 \frac{kJ}{s\,K}$$

$$(\dot{m} C_p)_{heat\ xfr\ fluid} = \left(1.85 \frac{kg}{s}\right)\left(1.97 \frac{kJ}{kg\,K}\right)$$

$$= 3.6445 \frac{kJ}{s\,K}$$ ⟸ minimum fluid

$$\frac{C_{min}}{C_{max}} = \frac{3.6445}{5.8548} = 0.62$$

$$NTU = \frac{UA}{C_{min}} = \frac{\left(0.225\ \frac{kW}{m^2 K}\right)(30.6\ m^2)}{3.6445\ \frac{kW}{K}}$$

$$= 1.9$$

From Figure 4.9-3

$$\boxed{\varepsilon = 0.73}$$

(see next page)

$$Q = \varepsilon\,(m\,c_p)_{min}\,(T_{hi} - T_{ci})$$

$$= (0.73)\left(3.6445\ \frac{kW}{K}\right)(75 - 25)\,K$$

$$= 133\ kW$$

$$= \boxed{130\ kW}$$ //

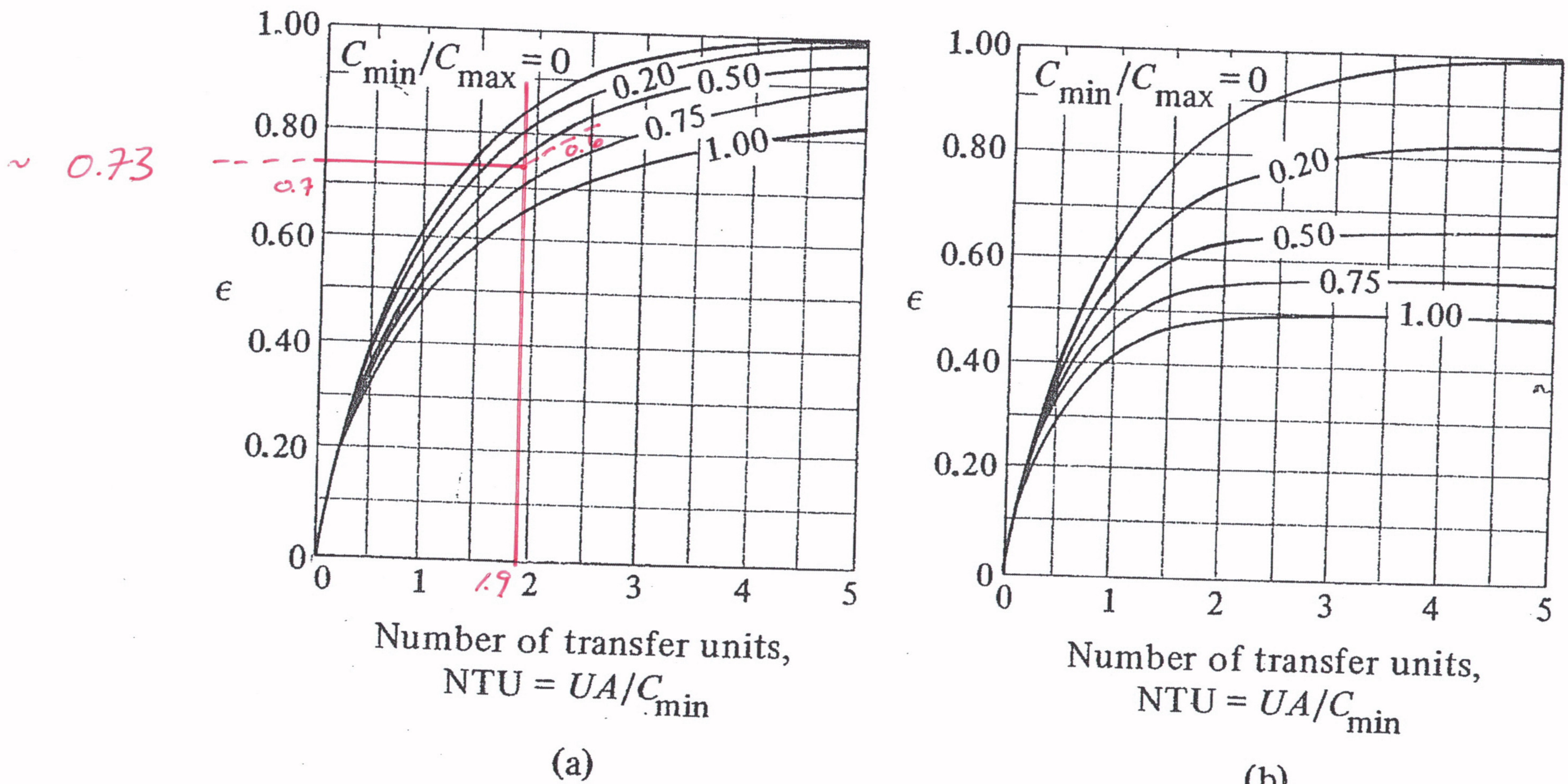



FIGURE 4.9-7. *Heat-exchanger effectiveness ε: (a) counterflow exchanger, (b) parallel flow exchanger.*