CH3030 TUTORIAL - 11 (OPTIONAL) BY: S. VISHAL
CH18B020

① Finding the flow properties :

- μ, K, C_p were obtained from Perry's handbook. They were obtained at the "average flow Temperature" = $\frac{T_{exit} + T_{entry}}{2}$

- ρ was obtained at the same Temperature from Engineering toolbox.com, a site suggested in CH2014 (Heat & Mass Transfer)

Thermophysical properties

Benzene → MW = 78 g mol^{-1} ; T_{avg} = 313 K

i) C_p : C_1 = 129440 C_2 = −169.5 C_3 = 0.6471

$C_p = C_1 + C_2 T + C_3 T^2$

= 139872.41 J/mol K

= 1.792 kJ/kg K (MW = 92)

ii) μ : C_1 = 7.5117 C_2 = 294.68 C_3 = −2.794

$\mu = \exp\left(C_1 + \frac{C_2}{T} + C_3 \ln T + C_4 T^{C_5}\right)$

= 4.996×10^{-4} Pa·s.

iii) k : C_1 = 0.23444 −0.000305 ??

$k = C_1 + C_2 T$ = 0.139 W/m K

iv) ρ = 857.7 kg/m³ (engineering toolbox.

References: table 2-138, table 2-147,

Perry's handbook

Toluene: MW = 92 g mol^{-1} t_{avg} = 333 K

Using the same references & eqns we get.

i) C_p = 1.8096 kJ/kg K

ii) μ = 3.869 × 10^{-4} Pa-s

iii) K = 0.124 W/mK

iv) ρ = 824.7 kg/m^3

Flow Properties

~~Benzene~~ i) **Pipes**:

Inner pipe 40NP 1-1/4'' : { ID = 1.38 in. = 0.035 m ; OD = 1.66 in. = 0.0422 m

Outer pipe 40NP 2'' : { ID = 2.067 = 0.0525 m ; OD = 2.375 = 0.0603 m

ii) **Benzene**: (flows in inner pipe)

$$Re = \frac{\rho v d}{\mu} = \frac{\dot{m}}{A} \times \frac{4A}{P} \times \frac{1}{\mu}$$

$$= \frac{1.3 \times 4}{\pi (d_{inner}) \times \mu} = 94518.8048$$

$$Pr = \frac{\mu c_p}{k} = 6.4506$$

From JP holman table - 6.8

$0.6 < Pr < 100$ Re is turbulent regime

$\Rightarrow$ Dittus Boelter corelation (with no wall effects)

$$Nu = 0.023\, Re^{0.8}\, Pr^{0.4} \quad 0.4 \text{ for heating}$$

$$= \cancel{HB} \; 463.43$$

$$\Rightarrow h = \frac{Nu\, k}{d} \quad \cancel{0.2644}$$

$$\Rightarrow h_{Benzene} = 1833.725 \; W/m^2K$$

Energy Balance :

$$\dot{m}_{Benzene}\, C_{p,B}\, \Delta T_{,B} = \dot{m}_T\, C_{p,T}\, \Delta T_{toluene}$$

$$\Rightarrow \dot{m}_{toluene} = 0.644 \, kg/s$$

$$Re_{toluene} = \frac{0.644 \times 4}{\pi\,(0.0422 + 0.0525) \times 3.89 \times 10^{-4}}$$

$$= 22258.526$$

$$Pr = \frac{3.889 \times 10^{-4} \times 1.8096 \times 10^3}{0.124}$$

$$= 5.6462$$

Similar conditions

$$\therefore Nu = 0.023\, Re^{0.8}\, Pr^{0.3} \quad 0.3 \text{ since cooling}$$

$$= 116.211$$

$$d_{for\ Heat\ transfer} = \frac{(0.055)^2 - (0.0422)^2}{0.0422}$$

$\hookrightarrow$ area, perimeter of inner pipe only

$$= 0.0 23m$$

$\Rightarrow h = 626.528 \ W/m^2 K$

Heat Transfer Calculation

$U_{real} A \ LMTD = Q$

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

Benzene : $30 \rightarrow 50\,^\circ C$ (counter current)

$\updownarrow \Delta T_2$ $\quad \updownarrow \Delta T_1$

Toluene : $40\,^\circ C \leftarrow 80\,^\circ C$

$$\Rightarrow LMTD = \frac{30 - 10}{\ln 3} = 18.21\,^\circ C$$

$Q = \dot{m}_{Benzene} \, C_{p,Benzene} \, \Delta T_{1,Benzene}$

$= 46.605 \ kJ/s$

$$\therefore \frac{1}{U_{real} A} = 3.9062 \times 10^{-4} \ ~~K~~ \ ~~W/K~~ \ W/K \quad ~~K~~/W$$

~~But U_{real} =~~

$\Rightarrow R_{real} = 3.9062 \times 10^{-4}$ ~~at~~ ~~K~~ W/K $\quad K/W$ —— (1)

$$\text{But } R_{real} = \frac{1}{h_i \pi d_i l} + \frac{1}{h_o \pi d_o l} + \frac{R_{foul}}{l}$$

$d_i \downarrow$ ID of inner pipe

$d_o \downarrow$ Outer Dia of inner pipe

R_{foul} fouling factor

$$= \frac{4.9595 \times 10^{-3} + 0.012 + 2 \times 10^{-4}}{l} \quad \text{—— (2)}$$

Equating ① & ② we get,

$l = 47.28$ m.

Assumptions :

① ~~Wall~~ pipe ~~or~~ resistance has been neglected
(material of wall not given & ~~wall is this~~ pipe is thin)

② Properties ~~as~~ (thermophysical) calculated at
$T = \frac{T_{enit} + T_{entry}}{2}$ are assumed to be representative
of the whole length of fluid.

③ wall effects ignored. (T_{fluid} is not uniform radially too, but this is ignored)

④ Heat losses are assumed to be negligible