CH3030 TUTORIAL - II (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" = $\frac{T_{out} + T_{entry}}{2}$
- 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

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

$$= 139872.41 \text{ J/mol/K}$$

$$= 1.792 \text{ kJ/kg K} \quad (MW = 92)$$

ii) μ : C_1 = 7.8117 C_2 = 294.68 C_3 = −2.294.

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

$$= 4.996 \times 10^{-4} \text{ Pa.s.}$$

iii) k : C_1 = 0.23444 $\rightarrow$ 0.000305 $\nearrow$

$$k = C_1 + C_2 T = 0.139 \text{ W/m/K}$$

iv) ρ = 858.2 kg/m^3 (engineering toolbox.)

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

Perry's handbook

$t_{avg} = 333K$

Toluene:

$MW = 92\ g\ mol^{-1}$

Using the same references & empns we get.

i) $C_p = 1.8026\ kJ/kg\,K$

ii) $\mu = 3.869 \times 10^{-4}\ Pa\cdot S$

iii) $K = 0.124\ W/m/K$

iv) $\rho = 824.7\ kg/m^3$

Flow Properties

Assumption: i) Pipes:

Inner pipe NOMP 1-1/4": $\begin{cases} ID = 1.38in. = 0.035m \\ OD = 1.66in. = 0.0422m \end{cases}$

Outer pipe NOMP 2": $\begin{cases} ID = 2.067 = 0.0525m \\ OD = 2.375 = 0.0603m \end{cases}$

ii) Reynolds: (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 in turbulent region

⇒ Dittus Boelter correlation (with no wall effects)

$$Nu = 0.023 Re^{0.8} Pr^{0.4}$$ 0.4 for heating

$$= \text{Hall } 463.43$$

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

$$\Rightarrow h_{Benzene} = 853.72 \text{ W/m}^2\text{K}$$

Energy Balance:

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

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

$$Re_{toluene} = \frac{0.644 \times 4}{\pi (0.0422 + 0.025) \times 3.89 \times 10^{-4}}$$

$$= 22258.5$$

$$Pr = \frac{3.89 \times 10^{-4} \times 1.8096 \times 10^3}{0.124}$$

$$= 5.6762$$

Similar conditions

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

$$= 116.21$$

$$d = \frac{(0.055)^2 - (0.0422)^2}{0.0422}$$ ← inner perimeter of annular type only

$$= 0.0225 \text{ m}$$ for Heat transfer

$\Rightarrow h = 626.528$ W/m²K

Heat Transfer Calculation

Overall & LMTD = Q

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

(counter current)

Benzene : 30 → 50 °C
ΔT_2 ↕ ΔT_1
Toluene : 40 °C ← 80 °C

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

$$Q = \dot{m}_{Benzene} C_{p,Benzene} \Delta T_{1,Benzene}$$
$$= 46.605 \text{ kJ/s}$$

$$\therefore \frac{1}{U_{overall}} = 3.9062 \times 10^{-4} \text{ W/K}$$

But U_{real} =

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

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

(d_i: ID of inner pipe; d_o: Outer dia of inner pipe; 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 resistance has been neglected (material of wall not given so wall is thin)

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

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

④ Heat losses are assumed to be negligible

References

1. Specific heats: https://www.accessengineeringlibrary.com/content/book/9780071834087/toc-chapter/chapter2/section/section15#/c9780071834087ch02lev2sec04
2. https://www.pennusa.com/products/schedule_40.php
3. Table 2-138 Vapor Viscosity of Inorganic and Organic Substances (Pa·s) (https://www.accessengineeringlibrary.com/content/book/9780071834087/toc-chapter/chapter2/section/section26#/c9780071834087ch02lev2sec11)
4. Table 2-147 Thermal Conductivity of Inorganic and Organic Liquids [W/(m·K)]
5. https://www.engineeringtoolbox.com/toluene-methylbenzene-density-specific-weight-temperature-pressure-d_2097.html
6. https://www.engineeringtoolbox.com/benzene-benzol-density-specific-weight-temperaure-pressure-d_2057.html?vA=40&degree=C#
7. Heat Transfer by JP Holman(table 6-8), 1989, SI Metric Edition