FT I Resolução Exercícios

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Conteúdo

I – Resolução

Questão 1 – 1

Indicar as dimensões em M, L, T, θ das unidades de força, energia, pressão, potência e viscosidade (que são unidades derivadas) e definir estas unidades nos sistemas SI, CGS e Britânico.

(i) Força

$$[F] = [m][a] = \mathrm{g\,m/s^2} = \mathrm{M\,L\,T^{-2}}$$

SI: $\mathrm{kg\,m\,s^{-2}}$ **CGS:** $\mathrm{g\,cm\,s^{-2}}$ **Brit:** $\mathrm{lb\,ft\,s^{-2}}$

(ii) Energia

$$[E] = [F][d] = \mathrm{M\,L\,T^{-2}\,m} = \mathrm{M\,L\,T^{-2}\,L} = \mathrm{M\,L^2\,T^{-2}}$$

SI: $\mathrm{kg\,m^2\,s^{-2}}$ **CGS:** $\mathrm{g\,cm^2\,s^{-2}}$ **Brit:** $\mathrm{lb\,ft^2\,s^{-2}}$

(iii) Pressão

$$[P] = [F]/[A] = \mathrm{M\,L\,T^{-2}/m^2} = \mathrm{M\,L\,T^{-2}\,L^{-2}} = \mathrm{M\,T^{-2}\,L^{-1}}$$

SI: $\mathrm{kg\,s^{-2}\,m^{-1}}$ **CGS:** $\mathrm{g\,s^{-2}\,cm^{-1}}$ **Brit:** $\mathrm{lb\,s^{-2}\,ft^{-1}}$

(iv) Potência

$$[P] = [E]/[s] = \mathrm{M\,L^2\,T^{-2}\,T^{-1}} = \mathrm{M\,L^2\,T^{-3}}$$

SI: $\mathrm{kg\,m^2\,s^{-3}}$ **CGS:** $\mathrm{g\,cm^2\,s^{-3}}$ **Brit:** $\mathrm{lb\,ft^2\,s^{-3}}$

(v) Viscosidade

$$\left[-\mu\frac{\mathbf{d}v}{\mathbf{d}x}\right] = [\mu](\mathrm{L/T})/\mathrm{L} = [F/A] = \mathrm{M\,L\,T^{-2}/L^2} =$$
$$= \mathrm{M\,L^{-1}\,T^{-2}} \implies [\mu] = \frac{\mathrm{M\,L^{-1}\,T^{-2}}}{\mathrm{T^{-1}}} = \mathrm{M\,L^{-1}\,T^{-1}}$$

SI: $\mathrm{kg\,m^{-1}\,s^{-1}}$ **CGS:** $\mathrm{g\,cm^{-1}\,s^{-1}}$ **Brit:** $\mathrm{lb\,ft^{-1}\,s^{-1}}$

Questão 1 – 2

Calcular, para cada grandeza derivada indicada em 1-1, os factores de conversão entre os três sistemas.

(i) Força

$$\mathrm{M\,L\,T^{-2}} = 1\,\mathrm{kg\,m\,s^{-2}} = 10^{3+2}\,\mathrm{g\,cm\,s^{-2}} = 10^{5}\,\mathrm{g\,cm\,s^{-2}} =$$
$$= 10^{5}\,\mathrm{g\,cm\,s^{-2}}\frac{\mathrm{lb}}{453.59\,\mathrm{g}}\frac{\mathrm{ft}}{0.3048\,\mathrm{m}} = \frac{10^{5-2}}{453.59 * 0.3048}\,\mathrm{lb\,ft\,s^{-2}} \cong 7.233\,\mathrm{lb\,ft\,s^{-2}}$$

(ii) Energia

$$\mathrm{M\,L^{2}\,T^{-2}} = \mathrm{kg\,m^{2}\,s^{-2}} = 10^{3+2^{2}}\,\mathrm{g\,cm^{2}\,s^{-2}} = 10^{7}\,\mathrm{g\,cm^{2}\,s^{-2}} =$$
$$= 10^{7}\,\mathrm{g\,cm^{2}\,s^{-2}}\frac{\mathrm{lb}}{453.59\,\mathrm{g}}\left(\frac{\mathrm{ft}}{0.3048\,\mathrm{m}}\right)^{2} = \frac{10^{7-2^{2}}}{453.59 * 0.3048^{2}}\,\mathrm{lb\,ft^{2}\,s^{-2}} \cong$$
$$\cong 23.730\,\mathrm{lb\,ft^{2}\,s^{-2}}$$

(iii) Pressão

$$\mathrm{M\,T^{-2}\,L^{-1}} = 1\,\mathrm{kg\,s^{-2}\,m^{-1}} = 10^{3-2}\,\mathrm{g\,s^{-2}\,cm^{-1}} = 10\,\mathrm{g\,s^{-2}\,cm^{-1}} =$$
$$= 10\,\mathrm{g\,s^{-2}\,cm^{-1}}\frac{\mathrm{lb}}{453.59\,\mathrm{g}}\frac{0.3048\,\mathrm{m}}{\mathrm{ft}} = \frac{10^{1+2} * 0.3048}{453.59}\,\mathrm{lb\,s^{-2}\,ft^{-1}} \cong$$
$$\cong 0.672\,\mathrm{lb\,s^{-2}\,ft^{-1}}$$

Questão 1 – 3

Agrupe as variáveis dos problemas que se seguem na forma de grupos adimensionais, aplicando o teorema π de Buckingham:

Q1 – 3 a)

Diferença de pressão entre as duas extremidades dum tubo pelo qual esteja a passar um fluído:

$$\Delta P = f(\rho, \mu, v, D, L)$$

$$[\Delta P] = \mathrm{M\,L^{-1}\,T^{-2}}$$

$$[\rho] = \mathrm{M\,L^{-3}} \qquad [\mu] = \mathrm{M\,L^{-1}\,T^{-1}} \qquad [v] = \mathrm{L\,T^{-1}}$$
$$[D] = \mathrm{L} \qquad [L] = \mathrm{L}$$

(i) π_1

$$\pi_1 = \frac{\Delta P}{D^a\, v^b\, \rho^c} \wedge \frac{[\Delta P]}{[D]^a\,[v]^b\,[\rho]^c} = \frac{\mathrm{M\,L^{-1}\,T^{-2}}}{(\mathrm{L})^a\,(\mathrm{L\,T^{-2}})^b\,(\mathrm{M\,L^{-3}})^c} =$$
$$= \mathrm{M}^{1-c}\,\mathrm{L}^{-1-a-b+3\,c}\,\mathrm{T}^{-2+2\,b} = 1 \implies$$
$$\implies \left\{\begin{aligned} c =& 1 \\ b =& 2 \\ a =& -1 - b + 3\,c = 0 \end{aligned}\right\} \wedge \pi_1 = \frac{\Delta P}{v^2\,\rho}$$

(ii) π_2

$$\pi_2 = \frac{\mu}{D^a\, v^b\, \rho^d} \wedge = \frac{[\mu]}{[D]^a\,[v]^b\,[\rho]^c} = \frac{\mathrm{M\,L^{-1}\,T^{-1}}}{(\mathrm{L})^a\,(\mathrm{L\,T^{-1}})^b\,(\mathrm{M\,L^{-3}})^c} =$$
$$= \mathrm{M}^{1-c}\,\mathrm{L}^{-1-a-b+3\,c}\,\mathrm{T}^{-1+b} \implies \left\{\begin{aligned} c =& 1 \\ b =& 1 \\ a =& -1 - b + 3\,c = 1 \end{aligned}\right\} \wedge \pi_2 = \frac{\mu}{D\,v\,\rho}$$

Nota: Para ter a formula em função de uma variável espeçifica não ha incluímos no grupo das variáveis de recurso

(iii) pi_3

$$\pi_3 = \frac{L}{D^a\, v^b\, \rho^d} = \frac{L}{D}$$

Q1 – 3 b)

Força actuante sobre uma esfera no seio dum fluído em movimento relativamente a ela:

$$F = f(\rho, \mu, v_r, D)$$

$$\left\{\begin{array}{ll} [F] = \mathrm{M\,L\,T^{-2}} & \\ & \\ [\rho] = \mathrm{M/L^3} & [\mu] = \mathrm{M\,L^{-1}\,T^{-1}} \\ [v_r] = \mathrm{L/T} & [D] = \mathrm{L} \end{array}\right\} \implies$$

$$\implies \{D, v_r, \rho\}$$

- 5 Numero de variáveis
- 3 Numero de grandezas fund presentes
- $5 - 3 = 2$ grupos adimensionais

$$|F| = F[\rho]^a\,[v_r]^b\,[D]^c = |F|(\mathrm{M\,L\,T^{-2}})\,(\mathrm{M/L^3})^a\,(\mathrm{L/T})^b\,(\mathrm{L})^c = |F|\mathrm{M}^{1+a}\,\mathrm{L}^{1-3\,a+b+c}\,\mathrm{T}^{-2-b} =$$

$$\implies \left\{\begin{array}{r} 1 + a = 0 \implies a = -1 \\ -2 - b = 0 \implies b = -2 \\ 1 - 3\,a + b + c = 1 - 3\,(-1) + (-2) + c = 0 \implies c = -2 \end{array}\right\} \implies$$

$$\implies |F| = F/\rho\,v_r^2\,D^2$$

Q1 – 3 c)

Potência necessária para accionar um ventilador:

$$P = f(\rho, \mu, N, D, Q)$$

$$\left\{\begin{array}{ll} [P] = \mathrm{J\,s^{-1}} = \mathrm{kgm^2/s^3} = \mathrm{M\,L^2/T^3} & \\ [\rho] = \mathrm{M/L^3} & [\mu] = \mathrm{M/L\,T} \\ [N] = \mathrm{T^{-1}} & [D] = \mathrm{L} \\ [Q] = \mathrm{M\,L^2/T^2} & \end{array}\right\}$$

- 6 Variávies
- 3 Fundamentais
- $6 - 3 = 3$ Adimensionais

(i)

$$|P| = P[\rho]^a\,[N]^b\,[D]^c = |P|\,\mathrm{M\,L^2/T^3}\,(\mathrm{M/L^3})^a\,(\mathrm{T^{-1}})^b\,(\mathrm{L})^c =$$
$$= |P|\,(\mathrm{M}^{1+a}\,\mathrm{L}^{2-3\,a+c}\,\mathrm{T}^{-3-b}) \implies$$
$$\implies \left\{\begin{array}{r} 1 + a = 0 \implies a = -1 \\ -3 - b = 0 \implies b = -3 \\ 2 - 3\,a + c = 2 - 3\,(-1) + c = 0 \implies c = -5 \end{array}\right\} \implies$$
$$\implies |P| = P/\rho\,N^3\,D^5$$

Q1 – 3 d)

Força actuante sobre um corpo flutuante num líquido em movimento:

$$F = f(\rho, \mu, g, L, V_r)$$

$$[F] = \mathrm{M\,L\,T^{-2}}$$

$$[\rho] = \mathrm{M\,L^{-3}} \qquad [\mu] = \mathrm{M\,L^{-1}\,T^{-2}} \qquad [g] = \mathrm{L\,T^{-2}}$$

$$[L] = \mathrm{L} \qquad [v_r] = \mathrm{L\,T^{-1}}$$

$$\{\rho, L, v_r\}$$

(i) π_1

$$\pi_1 = \frac{\mu}{\rho^a\,L^b\,v_r^c} \wedge \frac{[\mu]}{[\rho]^a\,[L]^b\,[v_r]^c} = \frac{\mathrm{M^1\,L^{-1}\,T^{-2}}}{(\mathrm{M\,L^{-3}})^a\,(\mathrm{L})^b\,(\mathrm{L\,T^{-1}})^c} =$$

$$= \mathrm{M}^{1-a}\,\mathrm{L}^{-1+3\,a-b-c}\,\mathrm{T}^{-2+c} = 1 \implies \left\{\begin{aligned} a =& 1 \\ c =& 2 \\ b =& -1 + 3\,a - c = 0 \end{aligned}\right\} \wedge \pi_1 = \frac{\mu}{\rho\,v_r^2}$$

(ii) π_2

$$\pi_2 = \frac{g}{\rho^a\,L^b\,v_r^c} \wedge \frac{[g]}{[\rho]^a\,[L]^b\,[v_r]^c} = \frac{\mathrm{L^1\,T^{-2}}}{(\mathrm{M\,L^{-3}})^a\,(\mathrm{L})^b\,(\mathrm{L\,T^{-1}})^c} =$$

$$= \mathrm{m}^{0-3\,a}\mathrm{L}^{1+3\,a-b-c}\,\mathrm{T}^{-2+c} = 1 \implies \left\{\begin{aligned} a =& 0 \\ c =& 2 \\ b =& 1 + 3\,a - c = -1 \end{aligned}\right\} \wedge \pi_2 = \frac{g}{L^{-1}\,v_r^2}$$

II – Resolução

III – Exercicios

Questão 3 – 1

Calcular a queda de pressão devido ao atrito de um óleo que flui a uma velocidade média de $2.4\,\mathrm{m\,s^{-1}}$ através de um tubo liso com $30\,\mathrm{m}$ de comprimento e $7.6\,\mathrm{cm}$ de diâmetro (comparar com comprimento $20\,\mathrm{m}$, $30\,\mathrm{m}$ e $50\,\mathrm{m}$).

- $\mu = 5\,\mathrm{cP}$
  (comparar com $4\,\mathrm{cP}$ e $8\,\mathrm{cP}$)
- $\rho = 960\,\mathrm{kg\,m^{-3}}$

E qual a queda de pressão devido ao atrito se rugosidade do tubo = $0.08\,\mathrm{mm}$? (comparar com $0.2\,\mathrm{mm}$ e $0.8\,\mathrm{mm}$). E qual a queda de pressão devido ao atrito se tubo liso com 2 joelhos em ângulo recto?

Resposta – 3
(i)

$$-\mathit{\Delta}P_{at} = 4\,\phi\,L\,\rho\,v^2/D;$$
$$\phi\,(Re,0) = \phi\left(\frac{\rho\,v\,D}{\mu},0\right) = \phi\left(\frac{960*2.4*7.6\ \mathrm{E}-2}{5\ \mathrm{E}-2*10^{-3}/10^{-2}},0\right) =$$
$$= \phi\left(\frac{9.6*2.4*7.6}{5}\,10^2,0\right) \cong \phi\,(35\,020.800,0) \cong 0.00275$$
$$\therefore -\mathit{\Delta}P_{at} \cong 4*0.00275*30*960*(2.4)^2/7.6\ \mathrm{E}-2 =$$
$$= \frac{4*2.75*3.0*9.60*(2.4)^2}{7.6}\ \mathrm{E}\,2 \cong 2.401\,\mathrm{E}4$$

Resposta – 3
(ii)

L/m :	20	30	50
$-\mathit{\Delta}P_{at}$:	$160.067\,\mathrm{E}2$	$2.401\,\mathrm{E}4$	$400.168\,\mathrm{E}2$

Resposta – 3
(iii)

$$-\mathit{\Delta}P_{at} = 4\,\phi\,L\,\rho\,v^2/D;$$
$$\phi\,(Re,\varepsilon/D) = \phi\,(35\,020.800, 0.08\ \mathrm{E}-3/7.6\ \mathrm{E}-2) =$$
$$= \phi\,(35\,020.800, 8\ \mathrm{E}-3/7.6) \cong \phi\,(35\,020.800, 1.053\,\mathrm{E}{-}3) \cong 0.0052$$
$$\therefore -\mathit{\Delta}P_{at} \cong 2.401\,\mathrm{E}4\,\frac{0.0052}{0.00275} \cong 4.540\,\mathrm{E}4$$

Resposta – 3
(iv)

$$\varepsilon > \varepsilon_0 \implies \phi > \phi_0 \implies -\mathit{\Delta}P_{at} > -\mathit{\Delta}P_{at,0}$$

Resposta – 3
(v)

$$-\mathit{\Delta}P_{at} = 4\,\phi\,L_{eq}\,\rho\,v^2/D \cong 2.401\,\mathrm{E}4\frac{L_{eq}}{L} =$$
$$= 2.401\,\mathrm{E}4\frac{(L+2*40*D)}{L} = 2.401\,\mathrm{E}4(1+2*40*7.6\ \mathrm{E}-2/30) \cong$$
$$\cong 2.888\,\mathrm{E}4$$

Questão 3 – 2

Corre água a $2.5\,\mathrm{dm}^3\,\mathrm{s}^{-1}$ através dum alargamento súbito de um tubo de $3.6\,\mathrm{cm}$ de diâmetro para um de $4.8\,\mathrm{cm}$. Qual é a perda de carga em m?

$$-\Delta P_{al\;arg}^{at} = \rho\,(v_1 - v_2)^2/2$$

Resposta

$$\frac{-\Delta P_{at}}{\rho\,g} = \frac{\rho\,(\Delta v)^2/2}{\rho\,g} = \frac{\left(\Delta\frac{G_v}{\pi\,r^2}\right)^2}{2\,g} = \left(\frac{G_v}{\pi\;\Delta r^2}\right)^2 (2\,g)^{-1} \cong$$

$$\cong \left(\frac{2.5\ \mathrm{E}{-3}}{\pi\,((3.6\ \mathrm{E}{-2}/2)^2 - (4.8\ \mathrm{E}{-2}/2)^2)}\right)^2 (2 * 9.780) =$$

$$= 8\,\left(\frac{2.5}{\pi\,((3.6)^2 - (4.8)^2)}\right)^2 9.780^{-1} * 10^2 \cong 5.903\,\mathrm{E}{-2}$$

Questão 3 – 3

Qual é a queda de pressão, e a potência necessária para bombear 0.04 $\mathrm{m^3\,s^{-1}}$ de água, através dum condensador com 400 tubos de 4.5 m de comprimento e diâmetro interno de 1 cm sabendo que o coeficiente de contracção à entrada dos tubos (C_c) é 0.6 e rugosidade aço comercial = 0.046 mm $\mu = 10^{-3}\,\mathrm{kg\,m^{-1}\,s^{-1}}$.

$$-\Delta P_{cont} = \frac{\rho\, v^2}{2}(C_c^{-1} - 1)^2$$

Resposta – (i)

$$-\Delta P_{tot} = -\Delta P_{at\ 1} * n - \Delta P_{at\ 2} = n\,\frac{4\,\phi\,\rho\,v^2\,L_1}{D} + \frac{\rho\,v^2}{2}(C_c^{-1} - 1)^2 =$$
$$= \rho\,v^2\,\left(\frac{4\,\phi\,L_1\,n}{D} + \frac{(C_c^{-1} - 1)^2}{2}\right)$$

$$\phi\,(Re, \varepsilon/D) = \phi\left(\frac{D\,\rho\,\bar{v}}{\mu}, \varepsilon/D\right) = \phi\left(\frac{10^{-2} * 10^3 * 1.27}{10^{-3}}, \frac{0.046\ \mathrm{E}{-3}}{10^{-2}}\right) =$$
$$= \phi\,(1.27 * 10^4, 0.046\ \mathrm{E}{-1}) \cong 0.0052$$

$$\therefore -\Delta P_{tot} \cong 10^3\,(1.27)^2\,\left(\frac{4 * 0.0052 * 4.5 * 400}{1\ \mathrm{E}{-2}} + \frac{(0.6^{-1} - 1)^2}{2}\right) \cong 6039.056\,\mathrm{E3}$$

Resposta – (ii)

$$W_{bomba} = -\Delta P_{at\ bomba} * \frac{G_v}{n} \cong 6039.056\,\mathrm{E3} * \frac{0.04}{400} \cong 6.039\,\mathrm{E2}$$

Questão 3 – 4

Quer-se bombear água dum tanque para um depósito 12 m acima do nível daquele, a um caudal de 1.25 $\mathrm{dm}^3\,\mathrm{s}^{-1}$, através dum tubo de ferro de 25 mm de diâmetro e 30 m de comprimento. O tanque e o reservatório encontram-se à pressão atmosférica. Qual é a potência da bomba necessária?

- $\mu = 1.30 * 10^{-3}\,\mathrm{kg\,m^{-1}\,s^{-1}}$
- $\rho = 1000\,\mathrm{kg\,m^{-3}}$
- Rugosidade do ferro $= 0.046\,\mathrm{mm}$

Resposta

$$
\begin{aligned}
W_b &= -\mathit{\Delta} P_b\, G_v = h_b\, \rho\, g\, G_v = \\
&= \left(Z_2 + \frac{v^2}{2\,g} + h_{at}\right)\, \rho\, g\, G_v = \\
&= \left(Z_2 + \frac{v^2}{2\,g} + \frac{-\mathit{\Delta} P_{at}}{\rho\, g}\right)\, \rho\, g\, G_v = \\
&= Z_2\, \rho\, g\, G_v + \left(\frac{v^2}{2} + \frac{4\,\phi\,\rho\, v^2\, L/D}{\rho}\right)\, \rho\, G_v = \\
&= Z_2\, \rho\, g\, G_v + \left(\frac{1}{2} + \frac{4\,\phi\, L}{D}\right)\, v^2\, \rho\, G_v = \\
&= Z_2\, \rho\, g\, G_v + \left(\frac{1}{2} + \frac{4\,\phi\, L}{D}\right)\, \left(\frac{G_v}{\pi\,(D/2)^2}\right)^2\, \rho\, G_v = \\
&= Z_2\, \rho\, g\, G_v + \left(2^3 + \frac{4^3\,\phi\, L}{D}\right)\, \frac{G_v^3 \rho}{\pi^2\, D^4};
\end{aligned}
$$

$$
\begin{aligned}
\phi\,(Re, \varepsilon/D) &= \phi\left(\frac{\rho\, D\, \bar{v}}{\mu}, \varepsilon/D\right) = \phi\left(\frac{10^3 * 25 * 10^{-3} 2.55}{1.30 * 10^{-3}}, \frac{0.046\ \mathrm{E}{-3}}{25\ \mathrm{E}{-3}}\right) = \\
&= \phi\left(\frac{25 * 2.55}{1.30}\, 10^3, 0.046/25\right) \cong \phi\,(49.038\,\mathrm{E}3, 1.840\,\mathrm{E}{-3}) \cong 0.00255
\end{aligned}
$$

$$
\begin{aligned}
\therefore W_b &= 12 * 10^3 * 9.780 * 1.25 * 10^{-3} + \\
&+ \left(2^3 + \frac{4^3 * 0.00255 * 30}{25 * 10^{-3}}\right)\, \frac{(1.25 * 10^{-3})^3 * 10^3}{\pi^2\, (25 * 10^{-3})^4} = \\
&= 12 * 9.780 * 1.25 + \left(2^3 + \frac{4^3 * 2.55 * 30}{25}\right)\, \frac{(1.25)^3}{\pi^2\, (25)^4} * 10^6 \cong 249.971
\end{aligned}
$$

Questão 3 – 5

Pretende-se bombear $4\,\mathrm{dm^3\,s^{-1}}$ de uma solução de ácido sulfúrico através dum tubo de $2.5\,\mathrm{cm}$ de diâmetro, em chumbo, e a uma altura de $25\,\mathrm{m}$. O tubo tem $30\,\mathrm{m}$ de comprimento e contém dois joelhos em ângulo recto. Calcular a potência da bomba teoricamente necessária.

- $\rho_{sol\ ac} = 1531\,\mathrm{kg\,m^{-3}}$
- $\mu_{sol\ ac} = 0.065\,\mathrm{kg\,m^{-1}\,s^{-1}}$
- rugosidade chumbo $= 0.05\,\mathrm{mm}$

Resposta

$$
\begin{aligned}
W_b &= -\Delta P_b\, G_v = h_b\, \rho\, g\, G_v = \\
&= (Z_2 + h_{at})\ \rho\, g\, G_v = \\
&= Z_2\, \rho\, g\, G_v + \left(\frac{-\Delta P_{at}}{\rho\, g}\right)\ \rho\, g\, G_v = \\
&= Z_2\, \rho\, g\, G_v + \left(4\, \phi\, \rho\, v^2\, L_{eq}/D\right)\ G_v = \\
&= Z_2\, \rho\, g\, G_v + \left(\frac{G_v}{\pi\, r^2}\right)^2\ (L + 2*40*D)\ \frac{4\,\phi\,\rho\, G_v}{D} = \\
&= Z_2\, \rho\, g\, G_v + \frac{4^3\,\phi\,\rho\,(L+2*40*D)\,G_v^2}{\pi^2\, D^5} = \\
&= Z_2\, \rho\, g\, G_v + \frac{4^3\,\phi\,\rho\,(L+2*40*D)\,G_v^2}{\pi^2\, D^5};
\end{aligned}
$$

$$
\begin{aligned}
\phi\,(Re, \varepsilon/D) &= \phi\left(\frac{\rho\, D\, \bar{v}}{\mu}, \varepsilon/D\right) = \phi\left(\frac{\rho\, D}{\mu}\frac{G_v}{\pi\,(D/2)^2}, \varepsilon/D\right) = \\
&= \phi\left(\frac{\rho\, G_v\, 4}{\mu\, \pi\, D}, \varepsilon/D\right) = \phi\left(\frac{1531*4*10^{-3}*4}{0.065*\pi*2.5*10^{-2}}, \frac{0.05*10^{-3}}{2.5*10^{-3}}\right) = \\
&= \phi\left(\frac{1.531*4^2}{6.5*\pi*2.5}*10^4, 2*10^{-2}\right) \cong \phi\,(4.798\,\mathrm{E}3, 2*10^{-2}) \cong 0.0069
\end{aligned}
$$

$$
\begin{aligned}
W_b &\cong 25*1531*9.780*4*10^{-3} + \\
&+ \frac{4^3*0.0069*1531*(30+2*40*2.5*10^{-2})*(4*10^{-3})^2}{\pi^2*(2.5*10^{-2})^5} = \\
&= 2.5*1.531*9.780*40 + \frac{4^5*6.9*1.531*(3+2*4*2.5*10^{-2})}{\pi^2*2.5^5}10^5 \cong \\
&\cong 3.593\,\mathrm{E}6
\end{aligned}
$$

IV – Exercicios

Questão 4 – 1

Bombeia-se um produto petrolífero a um certo caudal por um tubo horizontal com um comprimento de $100\,\mathrm{m}$ e um diametro (D) de $0.15\,\mathrm{m}$. A queda de pressão por atrito no tubo é $70\,\mathrm{kN\,m^{-2}}$ Durante uma reparação no tubo usou-se tubagem alternativa ($70\,\mathrm{m}$ de $0.2\,\mathrm{m}$ de diâmetro, seguidos de $50\,\mathrm{m}$ de $0.1\,\mathrm{m}$ de diâmetro). A bomba existente tem uma pressão de descarga de $350\,\mathrm{kN\,m^{-2}}$. Trabalhando com o mesmo caudal pode-se continuar a usar a mesma bomba durante as reparações? Despreze a variação de energia cinética.

- $L_1 = 100\,\mathrm{m}$
- $D_1 = 0.15\,\mathrm{m}$
- $-\Delta P_{at} = 70\,\mathrm{kN\,m^{-2}}$
- $-\Delta P_{desc} = 350\,\mathrm{kN\,m^{-2}}$
- $\varepsilon = 0.005\,\mathrm{mm}$
- $\mu = 0.5 * 10^{-3}\,\mathrm{kg\,m^{-1}\,s^{-1}}$
- $\rho = 700\,\mathrm{kg\,m^{-3}}$
- tubagem alternativa:
  - $L_{2.1} = 70\,\mathrm{m}$
  - $D_{2.1} = 0.2\,\mathrm{m}$
  - $L_{2.2} = 50\,\mathrm{m}$
  - $D_{2.2} = 0.1\,\mathrm{m}$

Resposta

$$W_{b.1} \geq W_{b.2} \vee W_{b.1} \leq W_{b.2}$$

$$w_{b.2} = -\Delta P_{b.2}\, G_v = h_{b.2}\,\rho\, g\, G_v = (h_{at.2.1} + h_{at.2.2})\,\rho g G_v =$$

$$= \begin{pmatrix} \dfrac{-\Delta P_{at.2.1}}{\rho g} + \\ + \dfrac{-\Delta P_{at.2.2}}{\rho g} \end{pmatrix} \rho\, g\, G_v =$$

$$= \begin{pmatrix} 4\,\phi_{2.1}\,\rho\, L_{eq.2.1}\, v_{2.1}^2/D_{2.1} + \\ + 4\,\phi_{2.2}\,\rho\, L_{eq.2.2}\, v_{2.2}^2/D_{2.2} \end{pmatrix} G_v =$$

$$= \begin{pmatrix} \dfrac{\phi_{2.1}\, L_{eq.2.1}}{D_{2.1}} \left(\dfrac{G_v}{\pi\,(D_{2.1}/2)^2}\right)^2 + \\ + \dfrac{\phi_{2.2}\, L_{eq.2.2}}{D_{2.2}} \left(\dfrac{G_v}{\pi\,(D_{2.2}/2)^2}\right)^2 \end{pmatrix} \rho\, G_v\, 4 =$$

$$= \begin{pmatrix} \dfrac{\phi_{2.1}\, L_{eq.2.1}}{D_{2.1}^5} + \\ + \dfrac{\phi_{2.2}\, L_{eq.2.2}}{D_{2.2}^5} \end{pmatrix} \frac{\rho\, G_v^3\, 4^3}{\pi^2} =$$

$$= \begin{pmatrix} \dfrac{\phi_{2.1}\, L_{eq.2.1}}{D_{2.1}^5} + \\ + \dfrac{\phi_{2.2}\, L_{eq.2.2}}{D_{2.2}^5} \end{pmatrix} \left(\bar{v}\,\pi\,(D_1/2)^2\right)^3\, \frac{\rho\, 4^3}{\pi^2} =$$

$$= \begin{pmatrix} \dfrac{\phi_{2.1}\, L_{eq.2.1}}{D_{2.1}^5} + \\ + \dfrac{\phi_{2.2}\, L_{eq.2.2}}{D_{2.2}^5} \end{pmatrix} \left(\frac{Re_1\,\mu}{\rho\, D_1}\, 4\,(D_1/2)^2\right)^3 \rho\,\pi =$$

$$= \begin{pmatrix} \dfrac{\phi_{2.1}\, L_{eq.2.1}}{D_{2.1}^5} + \\ + \dfrac{\phi_{2.2}\, L_{eq.2.2}}{D_{2.2}^5} \end{pmatrix} (Re_1\,\mu\, D_1)^3\, \frac{\pi}{\rho^2}$$

$$Re_1\,(\phi_1\, Re_1^2, \varepsilon/D_1) = Re_1\left(\left(\frac{-\Delta P_{at}\, D_1}{4\,\rho\, v^2\, L_1}\right)\left(\frac{\bar{v}\, D_1\,\rho}{\mu}\right)^2, \frac{\varepsilon}{D_1}\right) =$$

$$= Re_1\left(\frac{-\Delta P_{at}\, D_1^3\,\rho}{4\,\mu^2\, L_1}, \frac{\varepsilon}{D_1}\right) = Re_1\left(\frac{-\Delta P_{at}\, D_1^3\,\rho}{4\,\mu^2\, L_1}, \frac{\varepsilon}{D_1}\right) =$$

$$= Re_1\left(\frac{70 * 10^3 * 0.15^3 * 700}{4 * (0.5 * 10^{-3})^2 * 100}, \frac{0.005 * 10^{-3}}{0.15}\right) \cong$$

$$\cong Re_1\left(\frac{70^2 * 1.5^3}{4 * (0.5)^2} * 10^5, 33.333\,\mathrm{E}{-6}\right) \cong$$

$$\cong Re_1\,(1.654\,\mathrm{E}9, 3.333\,\mathrm{E}{-5}) \cong 1.00 * 10^6$$

$$\phi_{2.1}\,(Re_{2.1}, \varepsilon/D_{2.1}) = \phi_{2.1}\left(\frac{\rho\, v_{2.1}\, D_{2.1}}{\mu}, \frac{\varepsilon}{D_{2.1}}\right) =$$

$$= \phi_{2.1}\left(\frac{\rho\, D_{2.1}}{\mu}\left(\frac{G_v}{\pi\,(D_{2.1}/2)^2}\right), \frac{\varepsilon}{D_{2.1}}\right) =$$

$$= \phi_{2.1}\left(\frac{\rho\, 4}{\mu\,\pi\, D_{2.1}}\left(\bar{v}\,\pi (D_1/2)^2\right), \frac{\varepsilon}{D_{2.1}}\right) =$$

$$= \phi_{2.1}\left(\frac{\rho\, 4}{\mu\,\pi\, D_{2.1}}\left(\left(\frac{Re_1\,\mu}{\rho\, D_1}\right)\frac{\pi\, D_1^2}{4}\right), \frac{\varepsilon}{D_{2.1}}\right) =$$

$$= \phi_{2.1}\left(\frac{Re_1\, D_1}{D_{2.1}}, \frac{\varepsilon}{D_{2.1}}\right) \cong \phi_{2.1}\left(\frac{10^6 * 0.15}{0.2}, \frac{0.005 * 10^{-3}}{0.2}\right) \cong$$

$$\cong \phi_{2.1}\,(7.5\ \mathrm{E}5, 2.5\ \mathrm{E}{-5}) \cong 0.00149$$

$$\phi_{2.2}\left(\frac{Re_1\, D_1}{D_{2.2}}, \frac{\varepsilon}{D_{2.2}}\right) \cong \phi_{2.2}\left(\frac{10^6 * 0.15}{0.1}, \frac{0.005 * 10^{-3}}{0.1}\right) =$$

$$= \phi_{2.2}\,(1.5 * 10^5, 5 * 10^{-5}) \cong 0.0020$$

$$\therefore W_{b.2} \cong$$

$$\cong \left(\frac{0.00149 * 70}{0.2^5} + \frac{0.0020 * 50}{0.1^5}\right)\left(10^6 * 0.5 * 10^{-3} * 0.15\right)^3\, \frac{\pi}{700^2} =$$

$$= \left(\frac{1.49 * 70}{2^5} * 10^2 + 10^4\right)(5 * 15)^3\, \frac{\pi}{700^2} \cong 2.793\,\mathrm{E}4 >$$

$$> W_{b.1} = -\Delta P_{b.1}\, G_v = -\Delta P_{b.1} \frac{Re_1\,\mu\,\pi\, D_1}{\rho\, 4} \cong$$

$$\cong 350 * 10^3 \frac{10^6 * 0.005 * 10^{-3} * \pi * 0.15}{700 * 4} \cong 294.524$$

$\therefore$ É necessário uma bomba mais forte

Questão 4 – 2

Uma bomba desenvolve uma pressão de $800\,\mathrm{kN\,m^{-2}}$ e bombeia água por um tubo de $300\,\mathrm{m}$ (diâmetro $= 1.5\,\mathrm{dm}$) de um reservatório à pressão atmosférica para um reservatório $60\,\mathrm{m}$ acima, também à pressão atmosférica. Com as válvulas completamente abertas o caudal é $0.05\,\mathrm{m^3\,s^{-1}}$. Devido à corrosão e às incrustações, a rugosidade efectiva do tubo aumenta 10 vezes. De que percentagem diminui o caudal? Despreze a variação de energia cinética.

- $\Delta P_b = 800\,\mathrm{kN\,m^{-2}}$
- $L = 300\,\mathrm{m}$
- $D = 1.5\,\mathrm{dm}$
- $Z_2 = 60\,\mathrm{m}$
- $G_{v.0} = 0.05\,\mathrm{m^3\,s^{-1}}$
- $\varepsilon = 10\,\varepsilon_0$
- $\mu = 1\ \mathrm{E{-}3}\,\mathrm{kg\,m^{-1}\,s^{-1}}$
- $\rho = 1000\,\mathrm{kg\,m^{-3}}$

Resposta

$$\frac{G_{v.1}}{G_{v.0}} = G_{v.0}^{-1}\,\bar{v}_1\,\pi\,(D/2)^2 = \frac{\pi\,D^2}{G_{v.0}\,4}\left(\frac{Re_1\,\mu}{D\,\rho}\right);$$

$$\begin{aligned}
\varepsilon_0\,(\phi, Re) &= \varepsilon_0\left(\frac{-\Delta P_{at}\,D}{4\,L\,v^2\,\rho}, \frac{\bar{v}\,D\,\rho}{\mu}\right) = \\
&= \varepsilon_0\left(\frac{h_{at}\,\rho\,g\,D}{4\,L\,\rho}\left(\frac{G_v}{\pi\,(D/2)^2}\right)^{-2}, \frac{D\,\rho}{\mu}\frac{G_v}{\pi\,(D/2)^2}\right) = \\
&= \varepsilon_0\left(\frac{(h_b - Z_2)\,g\,\pi^2\,D^5}{L\,G_v^2\,64}, \frac{\rho\,G_v\,4}{\mu\,\pi\,D}\right) = \\
&= \varepsilon_0\left(\frac{\left(\frac{-\Delta P_b}{\rho\,g} - Z_2\right)\,g\,\pi^2\,D^5}{L\,G_v^2\,64}, \frac{\rho\,G_v\,4}{\mu\,\pi\,D}\right) = \\
&= \varepsilon_0\left(\frac{(-\Delta P_b - Z_2\,\rho\,g)\,\pi^2\,D^5}{L\,G_v^2\,64\,\rho}, \frac{\rho\,G_v\,4}{\mu\,\pi\,D}\right) = \\
&= \varepsilon_0\left(\frac{(800*10^3 + 60*10^3*9.780)\,\pi^2*0.15^5}{300*10^3*0.005^2*64*10^3}, \frac{10^3*0.05*4}{10^{-3}*\pi*0.15}\right) = \\
&= \varepsilon_0\left(\frac{(80 + 6*9.780)\,\pi^2*0.15^5}{3*5^2*64}*10^2, \frac{10^6*4}{\pi*3}\right) = \\
&= \varepsilon_0\,(2.165\,\mathrm{E{-}3}, 4.244\,\mathrm{E5}) \cong 0.00059*0.15 = 8.85*10^{-5}
\end{aligned}$$

$$\begin{aligned}
Re_1\,(\phi_1\,Re_1^2, \varepsilon_1/D) &= Re_1\left(\left(\frac{-\Delta P_{at}\,D}{4\,L_{eq}\,v_1^2\,\rho}\right)\left(\frac{\bar{v}_1\,D\,\rho}{\mu}\right)^2, \frac{10\,\varepsilon_0}{D}\right) = \\
&= Re\left(\frac{-\Delta P_{at}\,D^3\,\rho}{4\,L_{eq}\,\mu^2}, \frac{10\,\varepsilon_0}{D}\right) = Re\left(h_{at}\,\rho\,g\frac{D^3\,\rho}{4\,L_{eq}\,\mu^2}, \frac{\varepsilon}{D}\right) = \\
&= Re\left((h_b - Z_2)\frac{D^3\,\rho^2\,g}{4\,L_{eq}\,\mu^2}, \frac{\varepsilon}{D}\right) = Re\left(\left(\frac{-\Delta P_b}{\rho\,g} - Z_2\right)\frac{D^3\,\rho^2\,g}{4\,L_{eq}\,\mu^2}, \frac{\varepsilon}{D}\right) = \\
&= Re\left((-\Delta P_b - Z_2\,\rho\,g)\,\frac{D^3\,\rho}{4\,L_{eq}\,\mu^2}, \frac{\varepsilon}{D}\right) = \\
&= Re\left((800*10^3 - 60*10^3*9.780)\,\frac{(0.15)^3\,10^3}{4*300*(10^{-3})^2}, \frac{10\varepsilon_0}{0.15}\right) = \\
&= Re\left((800 - 60*9.780)\,\frac{(0.15)^3}{4*300}*10^{12}, \frac{10\varepsilon_0}{0.15}\right)
\end{aligned}$$

Questão 4 – 3

Pretende-se construir um permutador de calor com um certo número de tubos, todos com $25\,\mathrm{mm}$ de diâmetro e $5\,\mathrm{m}$ de comprimento, dispostos em paralelo. O permutador será utilizado como arrefecedor, com uma capacidade de $5\,\mathrm{MW}$ e o aumento de temperatura na água de alimentação deve ser de $20\,\mathrm{K}$. Sabendo que a queda de pressão nos tubos não deve exceder $2\,\mathrm{kN\,m^{-2}}$, calcular o número mínimo de tubos a instalar. Supor que os tubos são lisos.

Dados

$\mu = 1\,\mathrm{mN\,s\,m^{-2}}$

$\rho = 1000\,\mathrm{kg\,m^{-1}}$

$C_p(\mathrm{H_2O}) = 4.18\ \mathrm{E}\,3\,\mathrm{J\,kg^{-1}\,K^{-1}}$

Questão 4 – 4

Calcular o diâmetro hidráulico médio (d_{hm}) do espaço anelar entre um tubo de $4\,\mathrm{cm}$ e outro de $5\,\mathrm{cm}$.

$$d_{hm} = 4\,\frac{\text{sessão reta}}{\text{perímetro molhado}}$$

Questão 4 – 5

Um permutador de calor de caixa e tubos tem uma secção recta conforme se representa na figura seguinte. O permutador consiste em 9 tubos com diâmetro de 2.5 cm inseridos dentro de uma conduta circular com um diâmetro de 12.5 cm. O permutador tem um comprimento de 1.5 m. No lado da caixa circula água, e no interior dos tubos circula um termofluído.

água $\rho = 1000\,\mathrm{kg\,m^{-3}}$ $\mu = 1\ \mathrm{E{-}3}\,\mathrm{kg\,m^{-1}\,s^{-1}}$

termofluído $\rho = 8000\,\mathrm{kg\,m^{-3}}$ $\mu = 5\ \mathrm{E{-}3}\,\mathrm{kg\,m^{-1}\,s^{-1}}$

Q4 – 5 a)

Calcule a queda de pressão $(-\Delta P_{at})$ no lado da caixa quando o caudal de água em circulação nessa zona é $G_v = 0.825\,\mathrm{m^3 min^{-1}}$. Suponha que tanto a parede exterior dos tubos como a parede interna da caixa têm superfícies lisas. Para efeitos de cálculo use o diâmetro hidráulico médio d_{hm}:

$$d_{hm} = 4\,\frac{\text{sessão reta}}{\text{perímetro molhado}}$$

Q4 – 5 b)

Calcule o caudal de termofluído em circulação no interior dos tubos quando a queda de pressão no interior dos tubos é $(-\Delta P_{at} = 6\,\mathrm{kPa})$. A rugosidade da superfície interior dos tubos é $0.2\,\mathrm{mm}$.

VI – Exercicios

Questão 6 – 2

Circula água a $2\,\mathrm{m/s}$ por um tubo de $2.5\,\mathrm{m}$ de comprimento e $25\,\mathrm{mm}$ de diâmetro. Sabendo que o tubo está a $320\,\mathrm{K}$ e que a água entra a $293\,\mathrm{K}$ e sai a $295\,\mathrm{K}$, qual é o valor do coeficiente de transferência de calor.

Agua:

- $C_P = 4181\,\mathrm{J\,g^{-1}\,K^{-1}}$
- $\rho = 1000\,\mathrm{kg\,m^{-3}}$

$$\bar{h} = h_{int} = \frac{Q}{A_{cont,int}\ \mathit{\Delta} T_{\ln}} = \frac{G_{Agua}\, C_{P,agua}\ \mathit{\Delta} T_{agua}}{A_{cont,int}\ \left(\frac{\Delta\, \mathit{\Delta} T}{\Delta \ln \mathit{\Delta} T}\right)} =$$

$$= \frac{(\rho\, v\, A_{int})\ C_{P,agua}\ \mathit{\Delta} T_{agua}}{A_{cont,int}\ (\mathit{\Delta} T_2 - \mathit{\Delta} T_1)} \ln \frac{\mathit{\Delta} T_2}{\mathit{\Delta} T_1} =$$

$$= \frac{\left(1000 * 2 * \pi * (25 * 10^{-3})^2\right) * 4181 * (295 - 293)}{\pi * (25 * 10^{-3}/2)\, 2.5\ ((320 - 295) - (320 - 293))} \ln \frac{320 - 295}{320 - 293} =$$

$$= -2 * 2 * 4181 * 10 \ln \frac{320 - 295}{320 - 293} \cong 1287.096\,\mathrm{E1}$$

VII – Exercicios

Questão 7 – 3

Um permutador de calor de invólucro e tubos (com 10 tubos que realizam 8 passagens pelo invólucro) está dimensionado para aquecer $2.5\,\mathrm{kg\,s^{-1}}$ de água de $15\,°\mathrm{C}$ a $85\,°\mathrm{C}$. O aquecimento é conseguido graças à passagem de um óleo de processo, que se encontra disponível a $160\,°\mathrm{C}$. O coeficiente de filme do lado do óleo assume o valor de $400\,\mathrm{W\,m^{-2}\,K^{-1}}$. A água circula pelo interior dos tubos. Os tubos possuem um diâmetro externo de $25\,\mathrm{mm}$ e um diâmetro interno de $23\,\mathrm{mm}$. Sabendo que o óleo sai do permutador de calor a $100\,°\mathrm{C}$, calcule:

- Fator de Correlação de θ_m : $y = 0.87$
- Condutividade da parede do tubo: $k_W = 45\,\mathrm{W\,m^{-1}\,K^{-1}}$
- $C_{p,oleo} = 2350\,\mathrm{J\,kg^{-1}\,K^{-1}}$
- $C_{p,agua} = 4181\,\mathrm{J\,kg^{-1}\,K^{-1}}$
- $k_{agua} = 0.643\,\mathrm{W\,m^{-1}\,K^{-1}}$
- $\mu_{agua} = 548 * 10^{-6}\,\mathrm{kg\,m^{-1}\,s^{-1}}$
- $\rho_{agua} = 1000\,\mathrm{kg\,m^{-1}}$

Q7 – 3 a)

O caudal mássico de óleo necessário para realizar a operação desejada.

$$G_{m,oleo,1} = \frac{Q_{oleo}}{C_{m,p,oleo}\ \Delta T_{oleo}} = \frac{-Q_{agua}}{C_{m,p,oleo}\ \Delta T_{oleo}} =$$

$$= -\frac{G_{m,agua}\, C_{m,p,agua}\ \Delta T_{agua}}{C_{m,p,oleo}\ \Delta T_{oleo}} = -\frac{2.5 * 4181 * (85 - 15)}{2350 * (100 - 160)} \cong 5.189$$

Q7 – 3 b)

O comprimento que deverá ter cada tubo do permutador.

$$L = \frac{A_e}{2\,\pi\,r_e} = \frac{A_i}{2\,\pi\,r_i}; \qquad (\bar{h}_i\,A_i)^{-1} =$$

$$= \frac{y\,\Delta(\Delta T)_{\ln}}{Q_{agua}} = \frac{y\,\left(\frac{\Delta T_1 - \Delta T_0}{\ln(\Delta T_1/\,\Delta T_0)}\right)}{(G_{m,agua}\,C_{p,agua}\;\Delta T_{agua})} =$$

$$= \frac{y(\Delta T_1 - \Delta T_0)}{(G_{m,agua}\,C_{p,agua}\;\Delta T_{agua})\,\ln(\Delta T_1/\,\Delta T_0)} =$$

$$= (h_i\,A_i)^{-1} + (h_e\,A_e)^{-1} + \frac{x_w}{k_w\,A_w} =$$

$$= \left(\begin{array}{l} \left(\left(\frac{k_{agua}\,0.023}{D_i}\left(\frac{\rho\,D_i\,u}{\mu_{agua}}\right)^{0.8}\left(\frac{C_{p,agua}\,\mu_{agua}}{k}\right)^{0.4}\right)(2\,\pi\,(D_i/2)\,L)\right)^{-1} \quad + \\ +\,(h_e\,2\,\pi\,(D_e/2)\,L)^{-1} \quad + \\ +\frac{(D_e - D_i)/2}{k_w}\left(\frac{A_e - A_i}{\ln(A_e/A_i)}\right)^{-1} \end{array}\right) =$$

$$= \left(\begin{array}{l} \frac{\mu_{agua}^{0.4}}{k_{agua}^{0.6}\,0.023\,\rho_{agua}^{0.8}\,u^{0.8}\,C_{p,agua}^{0.4}\,D_i^{0.8}}(\pi\,L)^{-1} \quad + \\ +\,(h_e\,D_e)^{-1}\,(\pi\,L)^{-1} \quad + \\ +\frac{(D_e - D_i)/2}{k_w}\left(\frac{\ln(D_e/D_i)}{D_e - D_i}\right)(\pi\,L)^{-1} \end{array}\right) =$$

$$= \left(\begin{array}{l} \frac{\mu_{agua}^{0.4}}{k_{agua}^{0.6}\,0.023\,\rho_{agua}^{0.8}\,C_{p,agua}^{0.4}\,D_i^{0.8}}\left(\frac{G_{m,agua}}{n_{tubos}\,\rho_{agua}\,(\pi\,(D_i/2)^2)}\right)^{-0.8} \quad + \\ +\,(h_e\,D_e)^{-1} \quad + \\ +\frac{\ln(D_e/D_i)}{(2\,k_w)} \end{array}\right)(\pi\,L)^{-1} =$$

$$= \left(\begin{array}{l} \frac{\mu_{agua}^{0.4}\,n_{tubos}^{0.8}\,\pi^{0.8}\,D_i^{0.8}}{k_{agua}^{0.6}\,0.023\,C_{p,agua}^{0.4}\,G_{m,agua}^{0.8}\,2^{1.6}} \quad + \\ +\,(h_e\,D_e)^{-1} \quad + \\ +\frac{\ln(D_e/D_i)}{(2\,k_w)} \end{array}\right)(\pi\,L)^{-1} \implies$$

$$\implies L = \left(\begin{array}{l} \frac{\mu_{agua}^{0.4}\,n_{tubos}^{0.8}\,\pi^{0.8}\,D_i^{0.8}}{k_{agua}^{0.6}\,0.023\,C_{p,agua}^{0.4}\,G_{m,agua}^{0.8}\,2^{1.6}} \quad + \\ +\,(h_e\,D_e)^{-1} \quad + \\ +\frac{\ln(D_e/D_i)}{(2\,k_w)} \end{array}\right) *$$

$$* \frac{(G_{m,agua}\,C_{p,agua}\;\Delta T_{agua})\,\ln(\Delta T_1/\,\Delta T_0)}{\pi\,y(\Delta T_1 - \Delta T_0)} =$$

$$= \left(\begin{array}{l} \frac{(548*10^{-6})^{0.4}*10^{0.8}*\pi^{0.8}*(23*10^{-3})^{0.8}}{(0.643)^{0.6}*0.023*4181^{0.4}*(2.5)^{0.8}*2^{1.6}} \quad + \\ +\,(400*25*10^{-3})^{-1} \quad + \\ +\frac{\ln(25/23)}{(2*45)} \end{array}\right) *$$

$$* \frac{2.5*4181*(85-15)*\ln\left(\frac{100-15}{160-85}\right)}{\pi*0.87*((100-15)-(160-85))} \cong 379.147$$

Q7 – 3 c)

A área total necessária.

$$A_w = \frac{A_e - A_i}{\ln(A_e/A_i)} = \pi L \frac{D_e - D_i}{\ln(D_e/D_i)} \cong \pi\, 379.147 \frac{(25 - 23) * 10^{-3}}{\ln(25/23)} \cong 28.570$$

Questão 7 – 4

Condensa-se benzeno à temperatura de 353 K no exterior dos tubos dum permutador de calor do tipo caixa/tubos, com tubos verticais de diâmetros interior 22 mm e exterior 25 mm, fazendo passar água pelo interior dos tubos a um caudal de 0.03 $\mathrm{m^3/s}$. Qual será o comprimento total de tubo necessário, sabendo que a água entra a 290 K e sai a 300 K, e que o coeficiente de transferência de calor do lado da água é 850 $\mathrm{W\,m^{-2}\,K^{-1}}$?

- Condutividade térmica do material da parede do tubo: $k_w = 45\,\mathrm{W\,m^{-1}\,K^{-1}}$
- $C_{p,agua} = 4181\,\mathrm{J\,kg^{-1}\,K^{-1}}$
- $\rho_{agua} = 1000\,\mathrm{kg\,m^{-3}}$
- $\mu_{ben} = 0.35 * 10^{-3}\,\mathrm{kg\,m^{-1}\,s^{-1}}$
- $\rho_{ben} = 880\,\mathrm{kg\,m^{-3}}$
- $k_{ben} = 0.15\,\mathrm{W\,m^{-1}\,K^{-1}}$
- $\lambda_{ben} = 394\,\mathrm{kJ\,kg^{-1}}$

$$L = \frac{A_e}{\pi D_e} = \frac{A_i}{\pi D_i}; \quad (\bar{h}\,A)^{-1} = \frac{\Delta(\Delta T)_{\ln}}{Q_{agua}} = \frac{\left(\frac{\Delta T_1 - \Delta T_0}{\ln(\Delta T_1/\Delta T_0)}\right)}{(G_{m,agua}\,C_{p,agua}\,\Delta T_{agua})} =$$

$$= (h_i\,A_i)^{-1} + (h_{ben}\,A_e)^{-1} + \frac{x_w}{k_w\,A_w} =$$

$$= \left(\begin{array}{l} (h_i\,(\pi\,D_i\,L))^{-1} \hfill + \\ + \left(\left(1.47\left(\frac{k_{ben}^3\,\rho_{ben}^2\,g}{4\,M_{ben}\,\mu_{ben}}\right)^{1/3}\right)(\pi\,D_e\,L)\right)^{-1} \hfill + \\ + \frac{(D_e - D_i)/2}{k_w}\left(\frac{\ln(A_e/A_i)}{A_e - A_i}\right) \end{array}\right) =$$

$$= \left(\begin{array}{l} (h_i\,D_i)^{-1}\,(\pi\,L)^{-1} \hfill + \\ + \frac{4^{1/3}\,\mu_{ben}^{1/3}}{1.47\,k_{ben}^{3*1/3}\,\rho_{ben}^{2*1/3}\,g^{1/3}\,D_e}\left(\frac{G_{ben}}{A_e/L}\right)^{1/3}(\pi\,L)^{-1} \hfill + \\ + \frac{(D_e - D_i)/2}{k_w}\left(\frac{\ln(A_e/A_i)}{A_e - A_i}\right) \end{array}\right) =$$

$$= \left(\begin{array}{l} (h_i\,D_i)^{-1} \hfill + \\ + \frac{4^{1/3}\,\mu_{ben}^{1/3}}{1.47\,k_{ben}\,\rho_{ben}^{2/3}\,g^{1/3}\,D_e}\left(\frac{(Q_{ben}\,C_{p,ben}^{-1}\,\rho_{ben}^{-1})\,L}{(\pi\,D_e\,L)}\right)^{1/3} \hfill + \\ + \frac{\ln(D_e/D_i)}{2\,k_w} \end{array}\right)(\pi\,L)^{-1} =$$

$$= \left(\begin{array}{l} (h_i\,D_i)^{-1} \hfill + \\ + \frac{4^{1/3}\,\mu_{ben}^{1/3}}{1.47\,k_{ben}\,\rho_{ben}\,g^{1/3}\,D_e^{4/3}\,\pi^{1/3}\,C_{p,ben}^{1/3}}(-Q_{agua})^{1/3} \hfill + \\ + \frac{\ln(D_e/D_i)}{2\,k_w} \end{array}\right)(\pi\,L)^{-1} =$$

$$= \left(\begin{array}{l} (h_i\,D_i)^{-1} \hfill + \\ + \frac{4^{1/3}\,\mu_{ben}^{1/3}\,(-G_{m,agua}\,\rho_{agua}\,\Delta T_{agua})^{1/3}}{1.47\,k_{ben}\,\rho_{ben}\,g^{1/3}\,D_e^{4/3}\,\pi^{1/3}\,C_{p,ben}^{1/3}} \hfill + \\ + \frac{\ln(D_e/D_i)}{2\,k_w} \end{array}\right)(\pi\,L)^{-1} \implies$$

$$\implies L =$$

$$= \left(\begin{array}{l} (h_i\,D_i)^{-1} \hfill + \\ + \frac{4^{1/3}\,\mu_{ben}^{1/3}\,(-G_{m,agua}\,\rho_{agua}\,\Delta T_{agua})^{1/3}}{1.47\,k_{ben}\,\rho_{ben}\,g^{1/3}\,D_e^{4/3}\,\pi^{1/3}\,C_{p,ben}^{1/3}} \hfill + \\ + \frac{\ln(D_e/D_i)}{2\,k_w} \end{array}\right) *$$

$$* \left(\frac{G_{m,agua}\,C_{p,agua}\,\Delta T_{agua}}{\pi(\Delta T_1 - \Delta T_0)}\,\ln\frac{\Delta T_1}{\Delta T_0}\right) =$$

$$= \left(\begin{array}{l} (850 * 22 * 10^{-3})^{-1} \hfill + \\ + \frac{4^{1/3} * (0.35 * 10^{-3})^{1/3} * (-0.03 * 880 * (300 - 290))^{1/3}}{1.47 * 0.15 * 880 * g^{1/3} * D_e^{4/3} * \pi^{1/3} * C_{p,ben}^{1/3}} \hfill + \\ + \frac{\ln(D_e/D_i)}{2\,k_w} \end{array}\right) *$$

$$* \left(\frac{G_{m,agua}\,C_{p,agua}\,\Delta T_{agua}}{\pi(\Delta T_1 - \Delta T_0)}\,\ln\frac{\Delta T_1}{\Delta T_0}\right)$$

VIII – Exercicios

Questão 8 – 1

Numero de Reynald

$$\phi\, Re^2 = \frac{(-\varDelta P)\, D\, \rho^3}{L\, 4\, \mu^2} \cong 3\,298\,978.977$$

$$\frac{D}{e} = \frac{0.115 * 10^{-3}}{26.5 * 10^{-3}} \cong 0.004 \implies$$
$$\implies 2.8 * 10^4$$

$$L = \frac{A_e}{2\,\pi\, r_e} = \frac{A_i}{2\,\pi\, r_i}; \qquad (\bar{h}_i\, A_i)^{-1} =$$

$$= \frac{\varDelta(\varDelta T)_{\ln}}{Q} = \frac{\frac{\varDelta T_1 - \varDelta T_0}{\ln(\varDelta T_1 /\, \varDelta T_0)}}{(G_{rea}\ \varDelta H_{R^\circ})} =$$
$$= \frac{330 - \varDelta T_0}{(G_{m,agua}\, C_{p,agua}\ \varDelta T_{agua})\, \ln(\varDelta T_1 /\, \varDelta T_0)} =$$

$$= (h_i\, A_i)^{-1} + (h_e\, A_e)^{-1} + \frac{x_w}{k_w\, A_w} + \frac{R_{ext,incrust}}{A_{incrust,interna}} + \frac{x_{int}}{K_{int}\, A_{incrust,int}} =$$

$$= \left(\begin{array}{lr}
\left(0.023\, \frac{K}{D_i} \left(\frac{\rho\, D_i\, u}{\mu}\right)^{0.8} \left(\frac{C_p\, \mu}{K}\right)^{0.4} (1 + 3.5\,(D_i/D_s))\right)^{-1} A_i^{-1} & + \\
+\left(\frac{0.87\, K}{d_r} \left(\frac{\mu}{\mu_s}\right)^{0.14} \left(\frac{C_p\, \mu}{K}\right)^{1/3} \left(\frac{L^2\, N\, \rho}{\mu}\right)^{0.62}\right)^{-1} A_e^{-1} & + \\
+\frac{(D_e - D_i)/2}{k_w} \left(\frac{A_e - A_i}{\ln(A_e/A_i)}\right)^{-1} & + \\
+\frac{R_{ext,incrust}}{A_{incrust,interna}} & + \\
+\frac{x_{int}}{K_{int}\, A_{incrust,int}} &
\end{array}\right) =$$

$$= \left(\begin{array}{lr}
\left(1067 \left(1 + 0.00293\, \frac{T_{agua,0} + T_{agua,1}}{2}\right) \frac{u^{0.8}}{d_i^{0.2}}\, (1 + 3.5\, D_i/D_s)\ A_i^{-1}\right)^{-1} & + \\
+\frac{d_r\, \mu_s^{0.14}\, \mu^{0.44/3}}{0.87\, K^{2/3}\, C_p^{1/3}\, N^{0.62}\, \rho^{0.62}\, (\pi\, D_e\, L)}\, L^{-1.24} & + \\
+\frac{(D_e - D_i)/2}{k_w} \left(\frac{\ln(D_e/D_i)}{D_e - D_i}\right) (\pi\, L)^{-1} & + \\
+\frac{R_{ext,incrust}}{A_{incrust,interna}} & + \\
+\frac{x_{int}}{K_{int}\, A_{incrust,int}} &
\end{array}\right) =$$

$$= \left(\begin{array}{lr}
(h_i\, A_i)^{-1} & + \\
+\frac{1.1 * (0.01 * 10^{-1})^{0.14} * (0.0065*)^{0.44/3}}{0.87 * (0.5)^{2/3} * (2.55 * 10^3)^{1/3} * (130)^{0.62} * (1340)^{0.62} * \pi * (28 * 10^{-3})}\, L^{-2.24} & + \\
+\frac{\ln(28/26.5)}{(2 * 15.9)\, \pi}\, L^{-1} & + \\
+\frac{R_{ext,incrust}}{A_{incrust,interna}} & + \\
+\frac{x_{int}}{K_{int}\, A_{incrust,int}} &
\end{array}\right) =$$

$$= \left(\begin{array}{lr}
(h_i\, A_i)^{-1} & + \\
+0.000\, L^{-2.24} & + \\
+\frac{x_w}{k_w\, A_w} & + \\
+\frac{R_{ext,incrust}}{A_{incrust,interna}} & + \\
+\frac{x_{int}}{K_{int}\, A_{incrust,int}} &
\end{array}\right) = 2661.380^{-1}$$