绪论部分

[0-1] 解：令 CO_2 为A，H_2O 为B，依题意知：

$n_A = 0.05\ kmol = 50\ mol$

$m_B = 1000\ kg \quad M_B = 18\ kg/kmol$

$\therefore n_B = \frac{m_B}{M_B} = \frac{1000}{18} = 55.55\ kmol = 55.55\times10^3\ mol$

故溶液中 CO_2 的摩尔分数为：

$$x_A = \frac{n_A}{n_A+n_B} = \frac{50}{50+55.55\times10^3} = 0.0009$$

[0-2] 解：由附录可查得甲醇的安托因常数为：

$A = 7.19736 \quad B = 1574.99 \quad C = 238.86$

据 $\lg P^\circ = A - \frac{B}{t+C}$

已知 $t = 25^\circ C$

$\therefore \lg P^\circ = 7.19736 - \frac{1574.99}{25+238.86} = 1.2283$

故甲醇的饱和蒸气压为：

$P^S = P^\circ = 16.92\ kPa$

$\because y_A = \frac{n_A}{n} = \frac{P_A}{P}$

已知 $P_A = 16.92\times10^3\ Pa$　　$P = 101325\ Pa$

$\therefore y_A = \dfrac{16.92\times10^3}{101325} = 0.167$

据 $W_A = \dfrac{y_A M_A}{y_A M_A + y_B M_B}$

已知 $M_A = 32$　$M_B = 29$　$y_B = 1-0.167 = 0.833$

$\therefore W_A = \dfrac{0.167\times32}{0.167\times32+0.833\times29} = 0.181$

由 $P_A V = n_A RT$

故 $C_A = \dfrac{n_A}{V} = \dfrac{P_A}{RT}$

已知 $P_A = 16.92\times10^3\ Pa$　$T = 273+25 = 298\ K$

$\therefore C_A = \dfrac{16.92\times10^3}{8.314\times298} = 6.83\ (mol/m^3) = 6.83\times10^{-3}\ (kmol/m^3)$

据 $P_A = C_A M_A$

$\therefore P_A = 6.83\times10^{-3}\times32 = 0.22\ (Kg/m^3)$

[0-3]解：令 NaOH为组分1，NaCl为组分2，H_2O为组分3。

画一个草图将过程示意出来，如图所示。

绪论

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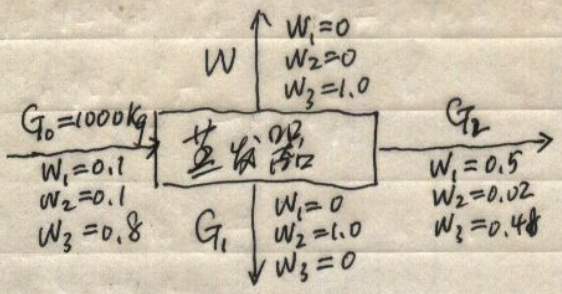


列出各种物料衡算式如下：

总物料：$1000 = W + G_1 + G_2$ ……(1)

NaCl：$1000\times0.1 = 1\times G_1 + 0.02G_2$ ……(2)

NaOH：$1000\times0.1 = 0.5G_2$（关键组分）……(3)

由(3)式可解得食盐分离后的溶液量为：

$G_2 = 200\ Kg$

将G_2代入(2)式可解得分离的食盐量：

$G_1 = 96\ Kg$

将G_1，G_2代入(1)式可解得水分蒸发量：

$W = 704\ Kg$

1-5附件：如附图所示，在U型压差计两测孔所处的截面之间进行能量衡算，运用柏努利方程，得到：

$Z_1 = Z_2 = 0$（取测压的轴线为基准面）

$H_e = 0$（无外加能量）

据 $q_v = \frac{\pi}{4} d^2 u$

已知 $d_1 = 0.04m$ $d_2 = 0.08m$ $q_V = 2.78 \times 10^{-3} m^3/s$

故 $u_1 = \frac{4q_v}{\pi d_1^2} = \frac{4 \times 2.78 \times 10^{-3}}{3.14 \times 0.04^2} = 2.2 m/s$

$$u_2 = \frac{4q_v}{\pi d_2^2} = \frac{4 \times 2.78 \times 10^{-3}}{3.14 \times 0.08^2} = 0.55 m/s$$

据：$\Delta p = p_1 - p_2 = (\rho_A - \rho_B) g R$

已知：$\rho_A = 1600 kg/m^3$ $\rho_B = 1000 kg/m^3$ $R = -0.165 m$

$\therefore p_1 - p_2 = (1600 - 1000) \times 9.81 \times (-0.165)$

$= -971.2 Pa$

据 $Z_1 + \frac{u_1^2}{2g} + \frac{p_1}{\rho g} + H_e = Z_2 + \frac{u_2^2}{2g} + \frac{p_2}{\rho g} + H_f$

$\therefore H_f = \frac{u_1^2 - u_2^2}{2g} + \frac{p_1 - p_2}{\rho g}$

$= \frac{2.2^2 - 0.55^2}{2 \times 9.81} - \frac{971.2}{1000 \times 9.81} = 0.132 (m)$

据 $H_f = \zeta \frac{u^2}{2g}$

由此可求得局部阻力系数为：

$$\zeta = \frac{2gH_f}{u^2} = \frac{2\times 9.81\times 0.132}{2.2^2} = 0.536$$

1-6 解：由于两截面间连接U-倒置U型压差计，故：

$$\Delta P = (\rho_A - \rho_B)gR$$

依题意知，$\rho_A = 1000\ Kg/m^3$，$\rho_B = 1.25\ Kg/m^3$（空气）

$$R = 0.1\ m$$

故两截面间的压强差为：

$$\Delta P = (1000-1.25)\times 9.81\times 0.1 = 9810\ Pa$$

在两截面间选用柏努利方程，以管轴线为基准面，依题意知，$Z_1 = Z_2 = 0$　$q_m = 3\ Kg/s$

$d_1 = 0.036m$　$d_2 = 0.053\ m$　$\rho = 1000\ Kg/m^3$

$$\therefore q_V = \frac{q_m}{\rho} = \frac{3}{1000} = 3\times 10^{-3}\ (m^3/s)$$

$$\therefore u_1 = \frac{4q_V}{\pi d_1^2} = \frac{4\times 3\times 10^{-3}}{3.14\times 0.036^2} = 2.95\ (m/s)$$

$$u_2 = \frac{4q_V}{\pi d_2^2} = \frac{4\times 3\times 10^{-3}}{3.14\times 0.053^2} = 1.36\ (m/s)$$

$$\text{据，} Z_1 + \frac{u_1^2}{2g} + \frac{P_1}{\rho g} + H_e = Z_2 + \frac{u_2^2}{2g} + \frac{P_2}{\rho g} + H_f$$

$\therefore H_f = \frac{p_1 - p_2}{\rho g} + \frac{u_1^2 - u_2^2}{2g}$

$= \frac{981}{1000 \times 9.81} + \frac{2.95^2 - 1.36^2}{2 \times 9.81} = 0.45$

据 $H_f = \frac{\Delta p_f}{\rho g}$

故知两截面间的压强降为:

$\Delta p_f = \rho g H_f = 1000 \times 9.81 \times 0.455 = 4.46 \times 10^3 (Pa)$

1-7 解:(1) 设贮水槽水面距离水管轴线之高度为 Z,依题意有: $Z + h = \frac{\rho_{Hg}}{\rho} R$

已知 $h = 1.51m$ $R = 0.62m$ $\rho = 1000 kg/m^3$

可解得: $Z = 6.922 m$

当闸阀部分开启时,在贮水槽水面与U型压差计所对应的测压口截面之间通列柏努利方程,并以水管轴线为基准面,依题意有:

$Z_1 = 6.922 m$ $Z_2 = 0$ $u_1 \approx 0$ $u_2 = u$ $p_1 = P_a$ $He = 0$

$p_2 + \rho g h' = \rho_{Hg} g R' + P_a$

已知 $h' = 1.41m$ $R' = 0.42 m$

$\therefore p_2 = P_a + 13600 \times 9.81 \times 0.42 - 1000 \times 9.81 \times 1.41 = P_a + 42202.62$

$$H_f=(\lambda\frac{l}{d}+\zeta)\frac{u^2}{2g}$$

已知：$\lambda=0.02$ $l=15\,m$ $d=0.1\,m$ $\zeta=0.5$

$$\therefore H_f=(0.02\times\frac{15}{0.1}+0.5)\frac{u^2}{2g}=0.1784u^2$$

据 $$Z_1+\frac{u_1^2}{2g}+\frac{p_1}{\rho g}+H_e=Z_2+\frac{u_2^2}{2g}+\frac{p_2}{\rho g}+H_f$$

$$\therefore 6.922+\frac{p_a}{\rho g}=\frac{u^2}{2g}+\frac{p_a+42202.62}{\rho g}+0.1784u^2$$

得 $u=3.38\,m/s$

故水的流量为：

$$q_v=\frac{\pi}{4}d^2u=\frac{\pi}{4}\times0.1^2\times3.38$$

$$=0.02653\,m^3/s=95.15\,m^3/h$$

(2) 当阀门全开时，取贮水槽水面与放水管出口之间连同柏努利方程，以放水管轴线为基准面，依题意有：

$Z_1=6.922\,m$ $Z_2=0$ $u_1=0$ $u_2=u$

$P_1=P_2=P_a$ $H_e=0$

$$H_f=[\lambda(\frac{l}{d}+\frac{l_e}{d})+\zeta]\frac{u^2}{2g}$$

已知 $\lambda=0.018$ $l=35\,m$ $\frac{l_e}{d}=15$ $\zeta=0.5$

$\therefore H_f = [0.018 \times (\frac{35}{0.1} + 15) + 0.5] \frac{u^2}{2g} = 0.36u^2$

据 $Z_1 + \frac{u_1^2}{2g} + \frac{P_1}{\rho g} + He = Z_2 + \frac{u_2^2}{2g} + \frac{P_2}{\rho g} + H_f$

$\therefore 6.922 = \frac{u^2}{2g} + 0.36u^2$

解得: $u = 4.1\ m/s$

再在贮水槽水面与出口所对应的截面之间应用柏努利方程，以此管轴线为基准面。依题意有：

$Z_1 = 6.922\ m \quad Z_2 = 0 \quad u_1 \approx 0 \quad u_2 = 4.1\ m/s \quad P_1 = P_a \quad P_2 = P_2$

$He = 0$

$H_f = (\lambda \frac{L}{d} + \zeta) \frac{u_2^2}{2g}$

且已知 $\lambda = 0.018 \quad \zeta = 0.5$

$\therefore H_f = (0.018 \times \frac{15}{0.1} + 0.5) \times \frac{4.1^2}{2 \times 9.81} = 2.742\ (m)$

据 $Z_1 + \frac{u_1^2}{2g} + \frac{P_1}{\rho g} + He = Z_2 + \frac{u_2^2}{2g} + \frac{P_2}{\rho g} + H_f$

$\therefore 6.922 + \frac{P_a}{\rho g} = \frac{4.1^2}{2 \times 9.81} + \frac{P_2}{\rho g} + 2.742$

解得: $P_2 = P_a + 32603.82$

由(1)知U型压差计内R=0时，其水柱高度：

$$h(\text{水}) = 1.5 + \frac{0.62}{2} = 1.2\ (m)$$

设U型压差计读数为R，则水柱高度为

$$h = 1.2 + \frac{R}{2}$$

依题意得：

$$P_a + 32603.82 + (1.2 + \frac{R}{2}) \times 1000 \times 9.81 = P_a + 13600 \times 9.81 R$$

由此可解得U型压差读数：

$$R = 0.345\ m$$

1-8 解(1) 已知 q_v、l 不变

据 $\Delta P_f = \lambda \frac{l}{d} \frac{\rho u^2}{2}$

当流体在管内为层流时：$\lambda = \frac{64}{Re}$

则 $\lambda = \frac{64}{Re} = \frac{64}{\frac{du\rho}{\mu}} = \frac{64}{\frac{4dq_v\rho}{\mu\pi d^2}} = \frac{64\pi\mu d}{4q_v\rho} \propto d$

$$u = \frac{4q_v}{\pi d^2} \propto \frac{1}{d^2}$$

$$\therefore \Delta P_f = \lambda \frac{l}{d} \frac{\rho u^2}{2} \propto \frac{1}{d^4}$$

当 $d'=1.3d$ 时

$$\frac{\Delta p_f'}{\Delta p_f}=\frac{d^4}{d'^4}=\frac{d^4}{(1.3d)^4}=\left(\frac{1}{1.3}\right)^4=0.35$$

(2) 当流体在光滑管内为湍流，且 $Re=10^5$ 时，

$$\lambda=\frac{0.3164}{Re^{0.25}}$$

又 $\lambda \propto d^{0.25}$

故 $\Delta p_f \propto d^{0.25}\times\frac{1}{d}\times\frac{1}{d^4}=\frac{1}{d^{4.75}}$

当 $d'=1.3d$ 时

$$\frac{\Delta p_f'}{\Delta p_f}=\left(\frac{1}{1.3}\right)^{4.75}=0.288$$

(3) 当流动处于阻力平方区，$\lambda=0.11\left(\frac{\varepsilon}{d}\right)^{0.25}$ 时，

$$\lambda \propto \left(\frac{1}{d}\right)^{0.25}$$

故 $\Delta p_f \propto \left(\frac{1}{d}\right)^{0.25}\times\frac{1}{d}\times\frac{1}{d^4}=\frac{1}{d^{5.25}}$

当 $d'=1.3d$ 时

$$\frac{\Delta p_f'}{\Delta p_f}=\left(\frac{1}{1.3}\right)^{5.25}=0.252$$

1-9解：依题意知操作条件下空气的体积流量为：

$$q_V = \frac{\pi}{4} d^2 u n$$

已知 $d = 0.02\,m$ $u = 9\,m/s$ $n = 13$

$$\therefore q_V = \frac{\pi}{4} \times 0.02^2 \times 9 \times 13 = 0.0368\ m^3/s$$

$$\because q_m = \rho_m q_v$$

而 $$\rho_m = \rho_0 \cdot \frac{P}{P_0} \frac{T_0}{T}$$

已知 $\rho_0 = 1.293\,Kg/m^3$ $T = 323\,K$ $P = 1.96\times10^5 + 9.87\times10^4 = 2.947\times10^5\,Pa$

$$\therefore \rho_m = 1.293 \times \frac{2.947\times10^5}{101325} \times \frac{273}{323} = 3.18\,Kg/m^3$$

故空气的质量流量为：

$$q_m = 3.18 \times 0.0368 = 0.117\,Kg/s$$

$$\because q_V = q_{V0} \frac{P_0}{P} \frac{T}{T_0}$$

故标准状况下的体积流量为：

$$q_{V0} = q_V \frac{P}{P_0} \cdot \frac{T_0}{T} = 0.0368 \times \frac{2.947\times10^5}{101325} \times \frac{273}{323}$$

$$= 0.0905\ (m^3/s)$$

1—10解：已知 $d=0.015\ m$ $u=0.6\ m/s$ $\rho=830\ Kg/m^3$

$\mu=5\times10^{-3}\ Pa.s$

∴ (1) $Re=\frac{du\rho}{\mu}=\frac{0.015\times0.6\times830}{5\times10^{-3}}=1494$

(2) 由 $Re=1494$ 可知管内流动为层流，据：

$$u=u_{max}\left(1-\frac{r^2}{R^2}\right)$$

且 $u=\bar{u}$

而 $\bar{u}=\frac{1}{2}u_{max}$

∴ $1-\frac{r^2}{R^2}=\frac{1}{2}$

已知 $R=\frac{d}{2}=\frac{0.015}{2}$

可解得：$r=0.0053\ m=5.3\ mm$

(3) 层流流动时：

$$\lambda=\frac{64}{Re}=\frac{64}{1494}=0.043$$

据 $\Delta P_f=\lambda\frac{l}{d}\frac{\rho u^2}{2}$

已知 $l=15\ m$

∴ $\Delta P_f=0.043\times\frac{15}{0.015}\times\frac{830\times0.6^2}{2}=6400\ (Pa)$

1-11 解：在A、B两截面之间列柏努利方程，已知：

$Z_1 \approx Z_2$，$u_1 = u_2$　$H_e = 0$　$\Delta h = 0.45\ m$　$d = 0.05\ m$

依题意知：

$$P_1 - P_2 = \rho g \Delta h$$

据 $Z_1 + \frac{u_1^2}{2g} + \frac{P_1}{\rho g} + H_e = Z_2 + \frac{u_2^2}{2g} + \frac{P_2}{\rho g} + H_f$

求A、B段总阻力损失为：

$$H_f = \frac{P_1 - P_2}{\rho g} = \Delta h = 0.45\ (m)$$

其中直管阻力损失为 H_{f1}，已知 $q_V = 0.0023\ m^3/s$，流体的流速：

$$u = \frac{4q_V}{\pi d^2} = \frac{4 \times 0.0023}{3.14 \times 0.05^2} = 1.17\ (m/s)$$

据 $H_{f1} = \lambda \frac{l}{d} \frac{u^2}{2g}$

已知 $\lambda = 0.03$　$l = 10\ m$

则 $H_{f1} = 0.03 \times \frac{10}{0.05} \times \frac{1.17^2}{2 \times 9.81} = 0.42\ (m)$

由此可知局部阻力 H_{f2} 为：

$$H_{f2} = H_f - H_{f1} = 0.45 - 0.42 = 0.03\ (m)$$

据 $H_{f2} = \zeta \frac{u^2}{2g}$

$\therefore \frac{p_2 - p_1}{\rho g} = 2.98 (m)$

或 $p_2 = p_1 + 2.98\rho g = p_1 + 29236.8$

对于U型管内 p_A 与 p_B，应有：

$p_A = p_2$

$p_B = p_1 + \rho g h = p_1 + 1000 \times 9.81 \times 1.5 = p_1 + 14715$

$\therefore p_A - p_B = p_2 - p_1 - \rho g h$

$= p_1 + 29236.8 - p_1 - 14715 = 14521.8 (Pa) > 0$

故知左侧压强大于右侧，从而右侧的水银面高。

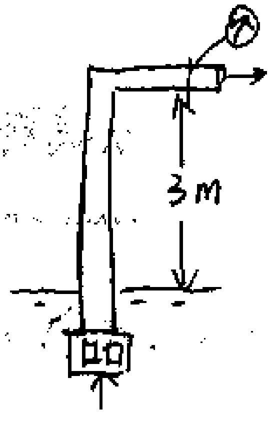
设压差计的读数为R，据：

$\Delta p = p_A - p_B = (\rho_0 - \rho) g R$

$\therefore R = \frac{p_A - p_B}{(\rho_0 - \rho) g} = \frac{14521.8}{(13600-1000) \times 9.81} = 0.117 (m)$

1-13 解：如图所示

已知 $q_v = 0.005 m^3/s$，$d = 0.05 m$



$\therefore u = \frac{4 q_v}{\pi d^2} = \frac{4 \times 0.005}{3.14 \times 0.05^2} = 2.55 (m/s)$

$\because Re = \frac{d u \rho}{\mu} = \frac{0.05 \times 2.55 \times 998}{1.005 \times 10^{-3}}$

$= 1.27 \times 10^5$

因 $\varepsilon/d = \frac{0.2}{150} = 0.004$

由摩擦系数图可查得：$\lambda = 0.0295$

吸入管路总阻力损失为：

$$H_f = (\lambda \frac{l}{d} + \zeta_1 + \zeta_2)\frac{u^2}{2g}$$

$$= (0.0295 \times \frac{8}{0.05} + 10 + 0.75) \times \frac{2.55^2}{2 \times 9.81} = 5.127(m)$$

在吸入液面与真空表所处截面间列伯努利方程，以吸入液面为基准面，依题意知：

$Z_1 = 0$ $Z_2 = 3\ m$ $u_1 \approx 0$ $u_2 = 2.55\ m/s$ $P_1 = P_a$

$P_2 = P$ $H_e = 0$ $H_f = 5.127\ m$

据：$Z_1 + \frac{u_1^2}{2g} + \frac{P_1}{\rho g} + H_e = Z_2 + \frac{u_2^2}{2g} + \frac{P_2}{\rho g} + H_f$

$\therefore \frac{P_a}{\rho g} = 3 + \frac{2.55^2}{2 \times 9.81} + \frac{P}{\rho g} + 5.127$

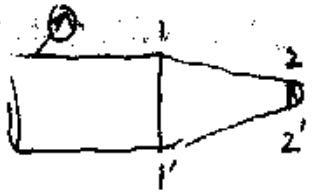
解得 $P = P_a - 82812$

由此可知泵入口处以表压表计真空表的读数为：

$$h = \frac{P}{\rho_{Hg} g} = \frac{82812}{13600 \times 9.81} = 0.62\ mHg = 620\ (mm)$$

若增大输水量，则入口处的动压头增大，管路阻力增大，故真空表的读数亦增大。

1-14解：如图所示，在1，2截面之间列伯努利方程，以管路轴线为基准面，依题意



知：$Z_1=Z_2$　$H_e=0$

$H_f\approx 0$　$P_1=P_a+0.8\times10^6$

$q_V=0.025\ m^3/s$　$d_1=0.08m$　$d_2=0.04m$　$P_2=P$

则：$u_1=\frac{4\times0.025}{3.14\times0.08^2}=4.98\ m/s$

$u_2=\frac{4\times0.025}{3.14\times0.04^2}=19.9\ m/s$

据 $Z_1+\frac{u_1^2}{2g}+\frac{P_1}{\rho g}+H_e=Z_2+\frac{u_2^2}{2g}+\frac{P_2}{\rho g}+H_f$

$\therefore\ \frac{4.98^2}{2\times9.81}+\frac{P_a+0.8\times10^6}{1000\times9.81}=\frac{19.9^2}{2\times9.81}+\frac{P}{1000\times9.81}$

解得：$P=P_a+614400$

水进入喷嘴时压力（与流体流动方向相同）为：

$F_1=P_1A_1=(101325+0.8\times10^6)\times\frac{\pi}{4}\times0.08^2=4528.2\ (N)$

水离开喷嘴时的压力（与流动方向相反）为：

$F_2=P_2A_2=(101325+614400)\times\frac{\pi}{4}\times0.04^2=898.95\ (N)$

由此可知水流对喷嘴的作用力为：

$F=F_1-F_2=4528.2-898.95$

$=3629\ (N)$

1-15 解：(1) 按照截面A处的盐水通过循环系统管路又重新回到截面A处，则盐水经过管路的能量损失即为泵所提供的能量，即：

$$W_e = \Sigma h_{f1} + \Sigma h_{f2}$$

已知 $\Sigma h_{f1} = 98.1\ J/Kg$ $\Sigma h_{f2} = 49\ J/Kg$

$\therefore W_e = 98.1 + 49 = 147.1\ J/Kg$

据 $N_e = q_v \rho W_e$

已知 $q_v = 0.0125\ m^3/s$ $\rho = 1100\ Kg/m^3$ $\eta = 70\%$

$\therefore N_e = 0.0125 \times 1100 \times 147.1 = 2023 (W)$

故泵的轴功率为：

$$N = \frac{N_e}{\eta} = \frac{2023}{0.7} = 2889 (W) = 2.89 (KW)$$

(2) 在换热器一侧 A、B 两压强表所测压口所在截面之间列柏努利方程，并以A处为基准面，依题意有：

$Z_1 = 0$ $Z_2 = 7m$ $u_1 = u_2$ $P_1 = P_a + 2.5\times10^5$ $P_2 = P_B$

$W_e = 0$ $\Sigma h_f = 98.1\ J/Kg$

据：$$Z_1 g + \frac{u_1^2}{2} + \frac{P_1}{\rho} + W_e = Z_2 g + \frac{u_2^2}{2} + \frac{P_2}{\rho} + \Sigma h_f$$

$$\therefore \frac{P_a + 2.5\times10^5}{1100} = 7\times9.81 + \frac{P_B}{1100} + 98.1$$

解得：$P_B = P_a + 66553 = 66553\ P_a$（表压）

1-16 解：首先在吸入端液面与吸入路泵入口处真空表所在截面之间列柏努利方程，以吸入端液面为基准面，依题意知：

$Z_1=0$ $Z_2=1.5\,m$ $P_1=P_a$ $P_2=P_a-2.47\times10^4$

$u_1\approx0$ $u_2=u$ $W_e=0$ $\sum h_f=2u^2$

据 $Z_1g+\frac{u_1^2}{2}+\frac{P_1}{\rho}+W_e=Z_2g+\frac{u_2^2}{2}+\frac{P_2}{\rho}+\sum h_f$

$\therefore \frac{P_a}{1000}=1.5\times9.81+\frac{u^2}{2}+\frac{P_a-2.47\times10^4}{1000}+2u^2$

解得：$u=2\,m/s$

然后在贮槽液面与排水管与喷头连接处列柏努利方程，以贮槽液面为基准面，依题意知：

$Z_1=0$ $Z_2=14\,m$ $u_1\approx0$ $u_2=2\,m/s$ $P_1=P_a$

$P_2=P_a+9.5\times10^4$ $We=We$ $\sum h_f=\sum h_{f1}+\sum h_{f2}=12u^2$

据 $Z_1g+\frac{u_1^2}{2}+\frac{P_1}{\rho}+We=Z_2g+\frac{u_2^2}{2}+\frac{P_2}{\rho}+\sum h_f$

$\therefore \frac{P_a}{1000}+We=14\times9.81+\frac{2^2}{2}+\frac{P_a+9.5\times10^4}{1000}+12\times2^2$

解得：$We=282.34\,(J/Kg)$

$\therefore Q_V=\frac{\pi}{4}d^2u=\frac{\pi}{4}\times0.107^2\times2=0.0079\,(m^3/s)$

故泵的有效功率为：

$Ne=Q_V\rho We=0.0079\times1000\times282.34=2.23\,(KW)$

1-17解：对于烟囱内和烟道气，已知 $d=2m$，$q_v=22.2m^3/s$

$\therefore u=\frac{4q_v}{\pi d^2}=\frac{4\times22.2}{3.14\times2^2}=7.07(m/s)$

已知 $\rho=0.67kg/m^3$ $\mu=2.6\times10^{-5}Pa\cdot s$

$\therefore Re=\frac{du\rho}{\mu}=\frac{2\times7.07\times0.67}{2.6\times10^{-5}}=3.64\times10^5$

已知 $\varepsilon/d=0.0004$

根据查摩擦系数图可知 $\lambda=0.0177$

故烟囱内的流动阻力损失已经出口损失为：

$H_f=\lambda\frac{H}{d}\frac{u^2}{2g}=0.0177\times\frac{H}{2}+\frac{7.07^2}{2\times9.81}=0.023H$

烟囱外的大气视为静止状态，地面处压强为 P_a，烟囱顶部处压强为 P_2，已知 $\rho_{空}=1.15kg/m^3$，根静力学原理：

$P_a=P_2+\rho_{空}gH$

$=P_2+1.15\times9.81H=P_2+11.28H$

在烟囱内底部至烟囱出口内侧面之间列伯努利方程，以烟囱内底部为基准面，作如下标注：

$Z_1=0$ $Z_2=H$ $u_1=u_2$ $P_1=P_a-196$ $P_2=P_a-11.28H$

$He=0$ $H_f=0.023H$

据 $Z_1+\frac{u_1^2}{2g}+\frac{P_1}{\rho g}+He=Z_2+\frac{u_2^2}{2g}+\frac{P_2}{\rho g}+H_f$

$$\therefore \frac{P_a-196}{0.67\times9.81}=H+\frac{P_a-11.28H}{0.67\times9.81}+0.023H$$

由此可解得烟囱的高度 $H=43\ m$。

1-18解：依题意知 ab 管段 $d=0.01\ m$ $\rho=0.5\ kg/m^3$ $\mu=2\times10^{-5}\ Pa\cdot s$，设气体流速为 u。

则 $Re=\frac{du\rho}{\mu}=\frac{0.01\times u\times0.5}{2\times10^{-5}}=250u$

考虑到气体黏度、最小均很小，故流体在管内的流动型态为层流，则：

$$\lambda=\frac{64}{Re}=\frac{64}{250u}$$

由此可知气体通过 ab 管段的阻力损失为：

$$H_f=\lambda\frac{l_e}{d}\frac{u^2}{2g}$$

已知 $l_e=10\ m$

$$\therefore H_f=\frac{64}{250u}\times\frac{10}{0.01}\times\frac{u^2}{2\times9.81}=13.05u$$

在 a、b 管段之间列柏努利方程，以入口 a 为基准面

依题意知：$Z_1=0$ $Z_2\approx0$（忽略） $u_1=u_2=u$

$P_1=P$ $P_2=P-\rho_{H_2O}gH$ $H=0.042$ $H_e=0$

据 $Z_1+\frac{u_1^2}{2g}+\frac{P_1}{\rho g}+H_e=Z_2+\frac{u_2^2}{2g}+\frac{P_2}{\rho g}+H_f$

$\therefore \frac{P}{0.5\times9.81}=\frac{P-1000\times9.81\times0.042}{0.5\times9.81}+13.05u$

解得：$u=6.44\ m/s$

故气体通过ab段的流量为：

$q_v=\frac{\pi}{4}d^2u=\frac{\pi}{4}\times0.01^2\times6.44=5.05\times10^{-4}(m^3/s)=1.82\ m^3/h$

$\because Re=\frac{du\rho}{\mu}=\frac{0.01\times6.44\times0.5}{2\times10^{-5}}=1610<2000$

之假设成立，计算结果有效。

1-19 附：在如图所示的a、a'截面间列柏努利方程，以管路的轴线为基准面，得到：

$Z_1=Z_2\quad u_1=u_1\quad u_2=u_2\quad He=0$

$P_1-P_2=(\rho_{Hg}-\rho_{H_2O})gR=(13600-1000)\times9.81\times0.3=37081.8\ Pa$

$H_f=3\frac{u_2^2}{2g}=0.15\frac{u_2^2}{2g}$

据 $Z_1+\frac{u_1^2}{2g}+\frac{P_1}{\rho g}+He=Z_2+\frac{u_2^2}{2g}+\frac{P_2}{\rho g}+H_f$

$\therefore \frac{u_1^2}{2g}+\frac{P_1}{\rho g}=\frac{u_2^2}{2g}+\frac{P_2}{\rho g}+0.15\frac{u_2^2}{2g}$

代入数据并化简后可得：

$0.5625u_2^2 - 0.5u_1^2 = 37.082$ ……(1)

又：$\frac{u_2}{u_1} = (\frac{d_1}{d_2})^2 = (\frac{0.1}{0.05})^2 = 4$

∴ $u_2 = 4u_1$ ……(2)

联立(1)、(2)两式可解得：$u_1 = 2.06\ m/s$

由此可求得管路的输水量为：

$q_V = \frac{\pi}{4}d_1^2 u_1 = \frac{\pi}{4} \times 0.1^2 \times 2.06$

$= 0.0162\ (m^3/s) = 58.34\ (m^3/h)$

1-20解：转子流量计的计算公式：

$$q_V = C_R A_2 N \sqrt{\frac{2gV_f(\rho_f - \rho)}{A_f \rho}}$$

当转子的形状及大小均不改变时，仅改变其材质(ρ)，则流量的关系为有：

$$\frac{q_V'}{q_V} = N\sqrt{\frac{(\rho_f' - \rho)}{\rho_f - \rho}}$$

已知：$\rho_f' = 10670\ kg/m^3$　$\rho_f = 7920\ kg/m^3$　$\rho = 1000\ kg/m^3$

∴ $\frac{q_V'}{q_V} = N\sqrt{\frac{10670 - 1000}{7920 - 1000}} = 1.182$

由此可知：若所测量范围为 0.250～2.50 m^3/h，则更换转子后的测量范围为：0.296～2.96 m^3/h。

若用来测量乙醇（$\rho_2=789\ Kg/m^3$）

据 $\frac{q_{v,2}}{q_{v,1}}=\sqrt{\frac{\rho_1(\rho_f-\rho_2)}{\rho_2(\rho_f-\rho_1)}}$

已知：$\rho_1=1000\ Kg/m^3$ $\rho_f=10670\ Kg/m^3$ $\rho_2=789\ Kg/m^3$

$\therefore \frac{q_{v,2}}{q_{v,1}}=\sqrt{\frac{1000\times(10670-789)}{789\times(10670-1000)}}=1.138$

$\because q_{v,1}=0.296\sim2.96\ m^3/h$

故知测量乙醇时的流量范围为：

$q_{v,2}=1.138q_{v,1}=1.138\times(0.296\sim2.96)$

$=0.337\sim3.37\ (m^3/h)$

1-24解：由于使用的是微差压计，故此速度的计算式为：

$u=\sqrt{\frac{2Rg(\rho_{水}-\rho_{油})}{\rho_{气}}}$

已知：$\rho_{水}=998\ Kg/m^3$ $\rho_{油}=835\ Kg/m^3$ $R=0.08\ m$

据 $\rho_{气}=\frac{PM}{RT}$

已知 $P=98.66\times10^3-490$ $T=293$ $M=29\times10^{-3}$

$\therefore \rho_{气}=1.17\ Kg/m^3$

故空气在管中心处的流速为：

$$u=\sqrt{\frac{2\times0.08\times9.81\times(998-835)}{1.17}}=14.8\ (m/s)$$

1-22 解：当流体在圆管内作层流流动时：

$$u=u_{max}\left(1-\frac{r^2}{R^2}\right)$$

$\because \bar{u}=\frac{1}{2}u_{max}$ 依题意知 $u=\bar{u}$

$$\therefore 1-\frac{r^2}{R^2}=\frac{1}{2}$$

解得，$r=0.707R$

即皮托管安装在距管中心 0.707R 处可直接测得平均流速。

当 $R=\frac{1}{2}d=\frac{1}{2}\times300=150\ mm$ 时：

$$r=0.707\times150=106\ mm$$

即皮托管在距管中心 106 mm，距管壁 44 mm。

当流体在圆管内作湍流流动时：

$$u=u_{max}\left(1-\frac{r}{R}\right)^{\frac{1}{7}}$$

$\because \bar{u}=0.82u_{max}$ 且 $u=\bar{u}$

$$\therefore \left(1-\frac{r}{R}\right)^{\frac{1}{7}}=0.82$$

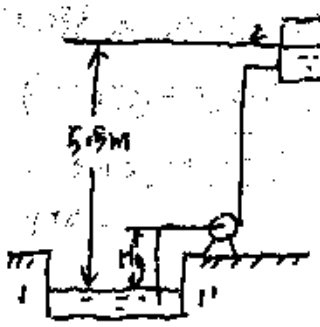
解得：$r=0.75R$

即皮托管安装在距管中心 0.75R 处时可直接测得平均流速。

当 $R=150mm$ 时，$r=0.75\times150=113(mm)$

故距离管道中心 113 mm，距管壁 37 mm。

1-23 解：如图所示，在 1.2 截面间列柏努利方程，并以截面 1 为基准面，依题意知：



$Z_1=0 \quad Z_2=5.5m \quad P_1=P_a$

$P_2=P_a+177\times10^3$

$u_1=u_2\approx0 \quad He=He$

$H_f=H_{f1}+H_{f2}=1+4=5\ m$

据：$Z_1+\frac{u_1^2}{2g}+\frac{P_1}{\rho g}+He=Z_2+\frac{u_2^2}{2g}+\frac{P_2}{\rho g}+H_f$

故泵的扬程为：

$$He=5.5+\frac{177\times10^3}{750\times9.81}+5=34.56(m)$$

据 $H_g=\frac{P_0-P_{in}}{\rho g}-\Delta h-H_{f0-1}$

故泵的允许安装高度为：

$$H_g=\frac{101325-80\times10^3}{750\times9.81}-2.6-1=-0.702(m)$$

若泵位于贮槽液面以下1m处，则泵的允许安装高度，故该泵能正常操作。

1-24 解：首先由孔板流量计确定实验中的流量：

据 $q_v = C_0 A_0 \sqrt{\frac{2Rg(\rho' - \rho)}{\rho}}$

已知 $C_0 = 0.75$ $A_0 = \frac{\pi}{4} d_0^2 = \frac{\pi}{4} \times 0.038^2 = 0.00113\ (m^2)$

$R = 0.75\ m$ $\rho' = 13600\ Kg/m^3$ $\rho = 998.2\ Kg/m^3$ (20℃)

$\therefore q_v = 0.75 \times 0.00113 \times \sqrt{\frac{2 \times 0.75 \times 9.81 \times (13600 - 998.2)}{998.2}}$

$= 0.0116\ (m^3/s)$

故吸入管路的流速为：

$u_入 = \frac{4q_v}{\pi d_入^2} = \frac{4 \times 0.0116}{3.14 \times 0.084^2} = 2.1\ (m/s)$

在吸入端液面与真空表所处截面之间列柏努利方程，并以吸入端液面为基准面，依题意知：

$Z_1 = 0$; $Z_2 = H_g$ $u_1 \approx 0$ $u_2 = u_入 = 2.1\ m/s$ $P_1 = P_a$

$P_2 = P_a - 7.331 \times 10^4$ $H_e = 0$ $H_f = H_{f入}$

据 $Z_1 + \frac{u_1^2}{2g} + \frac{P_1}{\rho g} + H_e = Z_2 + \frac{u_2^2}{2g} + \frac{P_2}{\rho g} + H_f$

由此可求得安装高度 H_g。

$$\frac{P_a}{\rho g} = H_g + \frac{2.1^2}{2\times 9.81} + \frac{P_a - 7.33\times10^4}{\rho g} + H_{f\lambda}$$

$$H_g = 7.26 - H_{f\lambda}$$

由于在此安装高度下泵恰好发生气蚀现象，故此安装高度为泵的最大安装高度，即：

$$H_{gmax} = 7.26 - H_{f\lambda}$$

而泵的最大安装高度 H_{gmax} 所对应的气蚀余量为最小气蚀余量 Δh_{min}，即：

$$H_{gmax} = \frac{P_0 - P_v}{\rho g} - \Delta h_{min} - H_{f\lambda}$$

已知 $P_0 = 1.013\times10^5\ Pa$　$P_V = 2238\ Pa$　$\rho = 998.2\ kg/m^3$

$$\therefore H_{gmax} = \frac{1.013\times10^5 - 2238}{998.2\times9.81} - \Delta h_{min} - H_{f\lambda}$$

$$= 10.12 - \Delta h_{min} - H_{f\lambda}$$

与前式比较后，为泵的最小气蚀余量为：

$$\Delta h_{min} = 10.12 - 7.26 = 2.86\ (m)$$

其允许气蚀余量为

$$\Delta h_{允} = \Delta h_{min} + 0.3$$

$$= 2.86 + 0.3 = 3.16\ (m)$$

1-25 附，经分析可知该管路为并联管路，以重力管路1，支管为管路2，依题意可知：

$q_{V2}=2.72\ m^3/h$　$l_1=2\ m$　$l_2=10\ m$　$\lambda_1=0.018$

$\lambda_2=0.03$　$d_1=0.3\ m$　$d_2=0.053\ m$

据 $\dfrac{q_{V1}}{q_{V2}}=\sqrt{\dfrac{d_1^5}{\lambda_1 l_1}}\Big/\sqrt{\dfrac{d_2^5}{\lambda_2 l_2}}$

$=\sqrt{\dfrac{0.3^5}{0.018\times2}}\Big/\sqrt{\dfrac{0.053^5}{0.03\times10}}=220$

由此可求得水在总（主）管路中的流量为：

$q_{V1}=220\,q_V=220\times2.72$

$=598.4\ (m^3/h)$

$$\frac{P_a}{\rho g} = H_g + \frac{2.1^2}{2\times 9.81} + \frac{P_a - 7.33\times 10^4}{\rho g} + H_{f\lambda}$$

$$H_g = 7.26 - H_{f\lambda}$$

由于在此安装高度下泵恰好发生气蚀现象，故此安装高度为泵的最大安装高度，即：

$$H_{gmax} = 7.26 - H_{f\lambda}$$

而泵的最大安装高度 H_{gmax} 所对应的气蚀余量为最小气蚀余量 Δh_{min}，即：

$$H_{gmax} = \frac{P_0 - P_v}{\rho g} - \Delta h_{min} - H_{f\lambda}$$

已知 $P_0 = 1.013\times 10^5\ Pa$　$P_v = 2238\ Pa$　$\rho = 998.2\ kg/m^3$

$$\therefore H_{gmax} = \frac{1.013\times 10^5 - 2238}{998.2\times 9.81} - \Delta h_{min} - H_{f\lambda}$$

$$= 10.12 - \Delta h_{min} - H_{f\lambda}$$

与前式比较后，对该泵的最小气蚀余量为：

$$\Delta h_{min} = 10.12 - 7.26 = 2.86\ (m)$$

其允许气蚀余量为

$$\Delta h_{允} = \Delta h_{min} + 0.3$$

$$= 2.86 + 0.3 = 3.16\ (m)$$

第一章 流体的流动及输送

1-1 解：据 $1\ kgf/cm^2 = 735.6\ mmHg = 0.9807\times10^5\ Pa$

已知 $P = 2.5\ kgf/cm^2$（表压）

故水银压差计的读数为：

$R = 2.5\times735.6 = 1839\ mmHg$（表压）

据：表压 = 绝压 − 大气压

已知大气压 $P_a = 0.980\times10^5\ Pa$

且：P(表压) $= \frac{1839}{760}\times101325 = 245180\ Pa$

故反应器的真实压强为：

P(绝压) $= P_a + P$(表压)

$= 0.980\times10^5 + 245180 = 3.432\times10^5\ Pa$

1-2 解：依题意知油水分离油液面内油、水的体积分别为：

油：$V_o = \frac{\pi}{4}D^2h_o$

水：$V_w = \frac{\pi}{4}D^2h_w$

已知 $V_o/V_w = 5/1$

$\therefore \frac{V_o}{V_w} = \frac{\frac{\pi}{4}D^2h_o}{\frac{\pi}{4}D^2h_w} = \frac{h_o}{h_w} = \frac{5}{1}$ ……（1）

油液面上压强为：

$P_{油} = P_a + \rho_o g h_o + \rho_w g h_w$

或：$p_{绝} = p_a + \rho_w g h_c$

$\therefore \rho_o h_o + \rho_w h_w = \rho_w h_c$

已知 $\rho_o = 800\ kg/m^3$ $\rho_w = 1000\ kg/m^3$ $h_c = 1.1\ m$

$\therefore 830 h_o + 1000 h_w = 1.1 \times 1000$ ……(2)

联立(1)、(2)两式可解得油水界面高为：

$h_w = 0.214\ m$

$\because h_o = 5 h_w = 5 \times 0.214 = 1.07\ (m)$

故液面总高度为：

$h_w + h_o = 0.214 + 1.07 = 1.284\ (m)$

1-3解：U如图所示

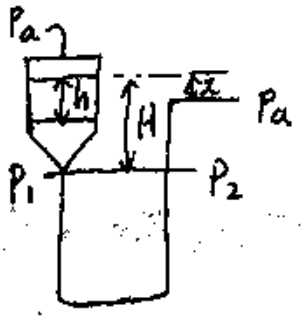
由于管内水的流速很慢，将其视为静止状态，故有：

$p_1 = p_2$

$\because p_1 = p_a + \rho_o g h + (H - h - x) g \rho_w$

$p_2 = p_a + (H - x) g \rho_w$

$\therefore x = \frac{\rho_w - \rho_o}{\rho_w} h$

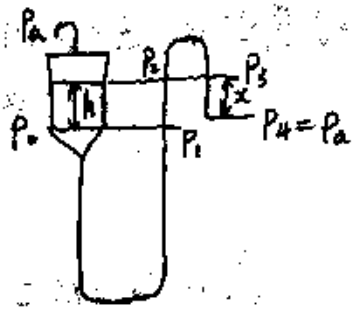


已知：$\rho_w = 1000\ kg/m^3$ $\rho_o = 800\ kg/m^3$ $h = 1\ m$

$\therefore x = \frac{1000 - 800}{1000} \times 1 = 0.2\ (m)$

故知若使①0<x<1m是必需的。

(2)如图所示，



依题意容内部水处理时静止状态，

则：$P_0 = P_1$　$P_2 = P_3$

$\therefore P_0 = P_a + \rho_0 g h$

$P_1 = P_2 + \rho_w g h$

$P_4 = P_3 + \rho_w g x = P_a$

$\therefore h = \frac{\rho_w}{\rho_w - \rho_0} x$

已知 $x = 0.1\,m$

$\therefore h = \frac{1000}{1000-800} \times 0.1 = 0.5\,(m)$

1-4解：由于空气的密度很小，忽略其产生的压强，依题意知：

$P_A = P_a + \rho_{Hg} g R_2 + \rho_{H_2O} g R_3$

已知：$R_2 = 0.045\,m$　$R_3 = 0.04\,m$

$\therefore P_A = 13600 \times 9.81 \times 0.045 + 1000 \times 9.81 \times 0.04$

$= 6396\,Pa$ (表压)

又：$P_B = P_A + \rho_{Hg} g R_1$

已知：$R_1 = 0.42\,m$

$\therefore P_B = 6396 + 13600 \times 9.81 \times 0.42 = 62431\,Pa$ (表压)

由此可得管头的局部阻力系数：

$$\zeta = \frac{2gH_{f2}}{u^2} = \frac{2\times 9.81\times 0.03}{1.17^2} = 0.43$$

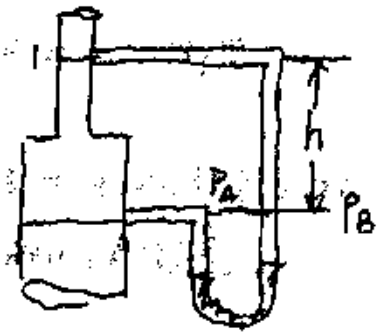
1-12 解：如图所示

在管路的 1、2 截面之间列柏努利方程，并以截面 2 为基准面，

依题意知：

$Z_1 = 1.5\,m$，$Z_2 = 0$，$u_2 = 2.2\,m/s$

$d_1 = 0.1\,m$，$d_2 = 0.2\,m$，$H_e = 0$



则：$u_1 = u_2\left(\frac{d_2}{d_1}\right)^2 = 2.2\times\left(\frac{0.2}{0.1}\right)^2 = 8.8\,m/s$

管路突然扩大，其阻力系数为：

$$\zeta = \left(1-\frac{A_1}{A_2}\right)^2 = \left[1-\left(\frac{d_1}{d_2}\right)^2\right]^2 = \left[1-\left(\frac{0.1}{0.2}\right)^2\right]^2 = 0.5625$$

故 $H_f = \zeta\frac{u_1^2}{2g} = 0.5625\times\frac{8.8^2}{2\times 9.81} = 2.22\,(m)$

据，$Z_1 + \frac{u_1^2}{2g} + \frac{P_1}{\rho g} + H_e = Z_2 + \frac{u_2^2}{2g} + \frac{P_2}{\rho g} + H_f$

则：$1.5 + \frac{8.8^2}{2\times 9.81} + \frac{P_1}{\rho g} = \frac{2.2^2}{2\times 9.81} + \frac{P_2}{\rho g} + 2.22$

第2章 热量传递习题选解

2-17解：(1) 依题意知 $b_1=0.2\,m$ $b_2=0.12\,m$ $b_3=0.006\,m$

$\lambda_1=1.07\,W/m\cdot^\circ C$ $\lambda_2=0.15\,W/m\cdot^\circ C$ $\lambda_3=45\,W/m\cdot^\circ C$

$t_1=1200^\circ C$ $t_4=28^\circ C$

据：$q=\dfrac{Q}{S}=\dfrac{t_1-t_4}{\frac{b_1}{\lambda_1}+\frac{b_2}{\lambda_2}+\frac{b_3}{\lambda_3}}$

故炉壁的热流量为：

$$q=\frac{1200-28}{\frac{0.2}{1.07}+\frac{0.12}{0.15}+\frac{0.006}{45}}=1187\,(W/m^2)$$

(2) 据 $Q=\dfrac{\text{总推动力}}{\text{总阻力}}=\dfrac{\Delta t}{R_{总}}=\dfrac{t_1-t_4}{R_{壁}+R_{层间}}$

$\because R_{总}=\dfrac{t_1-t_4}{Q_{实}}=\dfrac{1200-28}{q_{实}S}=\dfrac{1200-28}{620S}=\dfrac{1.89}{S}$

$$R_{壁}=\frac{t_1-t_4}{Q}=\frac{1200-28}{qS}=\frac{1200-28}{1187S}=\frac{0.987}{S}$$

$\therefore R_{层间}=R_{总}-R_{壁}=\dfrac{1.89}{S}-\dfrac{0.987}{S}=\dfrac{0.903}{S}$

故层间热阻占总热阻的比例为：

$$\frac{R_{层间}}{R_{总}}=\frac{0.903/S}{1.89/S}=0.478=47.8\%$$

2-2解：依题意知 $b_1=0.12m$ $b_2=0.24m$ $b_3=0.06m$

$\lambda_3=0.2\ W/m\cdot^\circ C$ $t_1=800^\circ C$ $t_2=680^\circ C$ $t_3=410^\circ C$ $t_4=60^\circ C$

据 $q=\dfrac{t_3-t_4}{b_3/\lambda_3}$

$\therefore q=\dfrac{410-60}{0.06/0.2}=1166.7\ (W/m^2)$

$\because \Delta t_1:\Delta t_2:\Delta t_3=R_1:R_2:R_3=\dfrac{b_1}{\lambda_1}:\dfrac{b_2}{\lambda_2}:\dfrac{b_3}{\lambda_3}$

已知 $\Delta t_2=t_2-t_3=680-410=270^\circ C$

$\Delta t_3=t_3-t_4=410-60=350^\circ C$

$\therefore \dfrac{0.24/\lambda_2}{0.06/0.2}=\dfrac{270}{350}$

解得 $\lambda_2=1.037\ (W/m\cdot^\circ C)$

又 $\Delta t_1=t_1-t_2=800-680=120^\circ C$

$\therefore \dfrac{0.12/\lambda_1}{0.24/1.037}=\dfrac{120}{270}$

解得 $\lambda_1=1.167\ W/m\cdot^\circ C$

未加石棉保温层时：

$q'=\dfrac{t_1-t_3}{\frac{b_1}{\lambda_1}+\frac{b_2}{\lambda_2}}$

已知 $t_1=800^\circ C$ $t_3=120^\circ C$

此时知其热流密度为：

$$q' = \frac{800-120}{\frac{0.12}{1.167}+\frac{0.24}{1.039}} = 2034.3\ (W/m^2)$$

包加石棉层后热损失减少为：

$$\frac{q'-q^*}{q'} = \frac{2034.3-1166.7}{2034.3} = 0.426 = 42.6\%$$

2-3解：依题意知 $b_1 = b_3 = 0.015\ m$ $b_2 = b_2$

$\lambda_1 = \lambda_3 = 0.107\ W/m\cdot°C$ $\lambda_2 = 0.04\ W/m\cdot°C$ $q = 10\ W/m^2$

$t_1 = 21°C$ $t_4 = -12°C$

据 $q = \frac{t_1 - t_4}{\frac{b_1}{\lambda_1}+\frac{b_2}{\lambda_2}+\frac{b_3}{\lambda_3}}$

$$\therefore \frac{21-(-12)}{2\times\frac{0.015}{0.107}+\frac{b_2}{0.04}} = 10$$

故知软木层的最小厚度为：

$b_2 = 0.1208\ m$

$$\because \sum R_{总} = \frac{b_1}{\lambda_1}+\frac{b_2}{\lambda_2}+\frac{b_3}{\lambda_3} = 2\times\frac{0.015}{0.107}+\frac{0.1208}{0.04} = 3.3$$

$$\sum R_{软} = \frac{b_2}{\lambda_2} = \frac{0.1208}{0.04} = 3.02$$

故软木层的热阻占总热阻的分数为：

$$\frac{R_{软}}{R_{总}} = \frac{3.02}{3.3} = 0.915 = 91.5\%$$

2-4解：依题意知 $t_1=170℃$ $t_3=30℃$ $Q/L=60W/m$

$r_1=0.05m$ $r_2=0.1m$ $r_3=r_3$ $\lambda_1=0.06W/m\cdot℃$ $\lambda_2=0.1W/m\cdot℃$

据 $Q=\frac{2\pi L(t_1-t_3)}{\frac{1}{\lambda_1}\ln\frac{r_2}{r_1}+\frac{1}{\lambda_2}\ln\frac{r_3}{r_2}}$

$$\frac{2\pi(170-30)}{\frac{1}{0.06}\ln\frac{0.1}{0.05}+\frac{1}{0.1}\ln\frac{r_3}{0.1}}=60$$

可解得：$r_3=0.136(m)$

故所包的石棉泥的厚度为：

$\Delta r_2=r_3-r_2=0.136-0.1=0.036(m)=36(mm)$

2-5解：依题意应有以下关系：

$$\begin{cases} r_2-r_1=r_3-r_2 \\ r_2+\frac{r_3-r_2}{2}=2\left(r_1+\frac{r_2-r_1}{2}\right) \end{cases}$$

由以上两式可得：

$$\frac{r_2}{r_1}=3 \qquad \frac{r_3}{r_2}=\frac{5}{3}$$

设内层的导热系数 $\lambda_1=\lambda$，则 $\lambda_2=2\lambda$

据 $Q=\frac{2\pi L(t_1-t_3)}{\frac{1}{\lambda_1}\ln\frac{r_2}{r_1}+\frac{1}{\lambda_2}\ln\frac{r_3}{r_2}}$

则材料位置调换前

$$Q=\frac{2\pi L(t_1-t_3)}{\frac{1}{\lambda_1}\ln\frac{d_2}{d_1}+\frac{1}{\lambda_2}\ln\frac{d_3}{d_2}}=\frac{2\pi L(t_1-t_3)}{1.354/\lambda}$$

材料的位置调换后：

$$Q'=\frac{2\pi L(t_1-t_3)}{\frac{1}{\lambda_2}\ln\frac{d_2}{d_1}+\frac{1}{\lambda_1}\ln\frac{d_3}{d_2}}=\frac{2\pi L(t_1-t_3)}{1.06/\lambda}$$

故材料调换前后热损失的改变为：

$$\frac{Q'}{Q}=\frac{1.354}{1.06}=1.28$$

即：$Q'=1.28Q$

加保温层的作用是为了减少热损失，由计算结果可以看出：无论保温材料导热系数小，保温性能好的材料包在内层（前一种情况），有利于保温。

2-7解：依题意已知 $d=0.021m$ $u=0.3m/s$

$\rho=1230 Kg/m^3$ $\mu=4\times10^{-3} Pa.s$

$\therefore Re=\frac{du\rho}{\mu}=\frac{0.021\times0.3\times1230}{4\times10^{-3}}=1937<2300$

故流体在圆管内呈强制层流。

又知：$C_p=2.85\times10^3 J/Kg.^\circ C$ $\lambda=0.57 W/m.^\circ C$

$\therefore Pr=\frac{\mu C_p}{\lambda}=\frac{4\times10^{-3}\times2.85\times10^3}{0.57}=20$

又：$0.6<Pr<6700$

而 $\frac{d_i}{L}=\frac{0.021}{3}=0.007$

$\therefore Re\cdot Pr\frac{d_i}{L}=1937\times20\times0.007=271.2>100$

因此可用(2-33)式求取 α，即：

$$\alpha=1.86\frac{\lambda}{d}Re^{1/3}Pr^{1/3}\left(\frac{d_i}{L}\right)^{1/3}\left(\frac{\mu}{\mu_w}\right)^{0.14}$$

$$=1.86\times\frac{0.57}{0.021}\times271.2^{1/3}\times\left(\frac{4\times10^{-3}}{3\times10^{-3}}\right)^{0.14}$$

$$=340.2\ (W/m^2\cdot^\circ C)$$

设盐水的出口温度为 T_2，由例2-6知：

$$\ln(T_W-T_2)=\ln(T_W-T_1)-\frac{4L\alpha}{d\rho u_b C_p}$$

已知：$T_W=65^\circ C$ $T_1=-5^\circ C$ $u_b=0.3m/s$

$$\therefore \ln(65-T_2)=\ln[65-(-5)]-\frac{4\times3\times340.2}{0.021\times1230\times0.3\times2.85\times10^3}$$

解得：$T_2=6.82\,^\circ C$

2-117 解：设油的质量流量与比热容分别为 q_{mh}、c_{ph}；

水的质量流量与比热容分别为 q_{mc}、c_{pc}；

生产任务改变后，水的出口温度为 t_2，可忽略热损失，可列出如下热量衡算式：

任务改变前：$Q=q_{mh}c_{ph}(150-100)=q_{mc}c_{pc}(45-20)$

任务改变后：$Q'=q_{mh}c_{ph}(150-80)=q_{mc}c_{pc}(t_2-20)$

由比可解得：$t_2=55\,^\circ C$

任务改变前的传热温差：$150\longrightarrow100$

$20\longrightarrow45$

$\Delta t_1=130\,^\circ C \quad \Delta t_2=55\,^\circ C$

$$\therefore \Delta t_m=\frac{\Delta t_1-\Delta t_2}{\ln\frac{\Delta t_1}{\Delta t_2}}=\frac{130-55}{\ln\frac{130}{55}}=87.2\,^\circ C$$

任务改变后的传热温差为：$150\longrightarrow80$

$20\longrightarrow55$

$\therefore \Delta t_1'=130\,^\circ C \quad \Delta t_2'=25\,^\circ C$

$$\therefore \Delta t_m'=\frac{\Delta t_1'-\Delta t_2'}{\ln\frac{\Delta t_1'}{\Delta t_2'}}=\frac{130-25}{\ln\frac{130}{25}}=63.7\,^\circ C$$

根总传热方程式：

$Q = KA\Delta t_m$

$Q' = K'A'\Delta t_m'$

依题意知：$K = K'$

$\therefore \frac{Q'}{Q} = \frac{K'A'\Delta t_m'}{KA\Delta t_m} = \frac{A'\Delta t_m'}{A\Delta t_m}$

即：$\frac{q_{mh}c_{ph}(150-80)}{q_{mh}c_{ph}(150-100)} = \frac{63.7A'}{87.2A}$

$\therefore \frac{A'}{A} = \frac{\pi dL'}{\pi dL'} = 1.916$

已知：$L = 1.5\ m$

$\therefore L' = 1.5 \times 1.916 = 2.874\ (m)$

2-12 附：设重油的流量与比热容分别为 q_{mh}、c_{ph}；

原油的流量与比热容分别为 q_{mc}、c_{pc}；

当设为逆流操作时，重油的出口温度为 T_2，原油的出口温度为 t_2。对换热过程中忽略热损失，则依题意可对操作设备前后列热量衡算式为：

$Q = q_{mh}c_{ph}(243-167) = q_{mc}c_{pc}(157-128)$

$Q' = q_{mh}c_{ph}(243-T_2) = q_{mc}c_{pc}(t_2-128)$

化简后可得：$T_2 = 578.4 - 2.62t_2$

并流操作之传热温差为：$243 \longrightarrow 167$

$128 \longrightarrow 157$

$\because \Delta t_1 = 115^\circ C \quad \Delta t_2 = 10^\circ C$

$$\therefore \Delta t_m = \frac{\Delta t_1 - \Delta t_2}{\ln \frac{\Delta t_1}{\Delta t_2}} = \frac{115 - 10}{\ln \frac{115}{10}} = 43\ ^\circ C$$

逆流操作之传热温差为：$243 \longrightarrow 578.4 - 2.62t_2$

$t_2 \longleftarrow 128$

$$\because \Delta t_1' = 243 - t_2 \quad \Delta t_2' = 578.4 - 2.62t_2 - 128 = 450.4 - 2.62t_2$$

$$\therefore \Delta t_m' = \frac{\Delta t_1' - \Delta t_2'}{\ln \frac{\Delta t_1'}{\Delta t_2'}} = \frac{243 - t_2 - (450.4 - 2.62t_2)}{\ln \frac{243 - t_2}{450.4 - 2.62t_2}}$$

$$= \frac{1.62t_2 - 207.4}{\ln \frac{243 - t_2}{450.4 - 2.62t_2}}$$

根据传热方程式：

$$Q = KA\Delta t_m$$

$$Q' = K'A'\Delta t_m'$$

依题意知：$K = K' \quad A = A'$

$$\therefore \frac{Q}{Q'} = \frac{\Delta t_m}{\Delta t_m'}$$

即：$$\frac{q_{mc} c_{pc} (157 - 128)}{q_{mc} c_{pc} (t_2 - 128)} = \frac{43}{\frac{1.62t_2 - 207.4}{\ln \frac{243 - t_2}{450.4 - 2.62t_2}}}$$

化简后有

$$1.62t_2 - 207.4 = 1.483(t_2 - 128)\ln\frac{243 - t_2}{450.4 - 2.62t_2}$$

采用试差法解得 t_2

当 $t_2 = 161$ 时：左边 $= 53.42$　右边 $= 51.56$

$t_2 = 162$ 时：左边 $= 55.04$　右边 $= 57.4$

$t_2 = 161.4$ 时：左边 $= 54$　右边 $= 53.8$

故知原油的出口温度 $t_2 = 161.4°C$

重油的出口温度为：

$$T_2 = 578.4 - 2.62t_2 = 578.4 - 2.62 \times 161.4 = 155.5°C$$

$243 \longrightarrow 155.5$

$161.4 \longleftarrow 128$

$\Delta t_1' = 81.6$　$\Delta t_2' = 27.5$

故知逆流操作时的传热推动力为

$$\Delta t_m' = \frac{\Delta t_1' - \Delta t_2'}{\ln\frac{\Delta t_1'}{\Delta t_2'}} = \frac{81.6 - 27.5}{\ln\frac{81.6}{27.5}} = 49.7°C$$

2-13解：设冷却水的出口温度为t_2，对逆流操作：

$90 \longrightarrow 50$　　$\Delta t_1 = 90 - t_2$

$t_2 \longleftarrow 18$　　$\Delta t_2 = 50 - 18 = 32\,℃$

$$\therefore \Delta t_m = \frac{\Delta t_1 - \Delta t_2}{\ln \frac{\Delta t_1}{\Delta t_2}} = \frac{90 - t_2 - 32}{\ln \frac{90 - t_2}{32}} = \frac{58 - t_2}{\ln \frac{90 - t_2}{32}}$$

依题意知换热器所交换的热量为：

$$Q = q_{mh} C_{ph} (T_1 - T_2)$$

$$= \frac{1900}{3600} \times 2.98 \times 10^3 \times (90 - 50) = 6.291 \times 10^4 \,(W)$$

已知 $A = 6\,m^2$　$K = 230\,W/m^2 \cdot ℃$

据 $Q = KA\Delta t_m$

$$\therefore 230 \times 6 \times \frac{58 - t_2}{\ln \frac{90 - t_2}{32}} = 6.291 \times 10^4$$

化简后得：

$$58 - t_2 = 45.6 \ln \frac{90 - t_2}{32}$$

采用试差法：$t_2 = 30$　左边 $= 28$　右边 $= 28.7$

$t_2 = 27.5$　左边 $= 30.5$　右边 $= 30.5$

故知 $t_2 = 27.5\,℃$（冷却水的出口温度）

冷却水的用量为：

$$q_m \times 4.18 \times 10^3 \times (27.5 - 18) = 6.291 \times 10^4$$

$$\therefore q_m = 1.58\,kg/s = 5.69 \times 10^3\,kg/h$$

2-14 解：依题意知 $\alpha_i = 0.85\times10^3$　$\alpha_o = 1.7\times10^3$

$\lambda = 45$　$b = 0.0025$　$d_o = 0.025$　$d_i = 0.02$

$$d_m = \frac{d_o - d_i}{\ln\frac{d_o}{d_i}} = \frac{0.025-0.02}{\ln\frac{0.025}{0.02}} = 0.0224$$

据 $\frac{1}{K} = \frac{d_o}{\alpha_i d_i} + \frac{b d_o}{\lambda d_m} + \frac{1}{\alpha_o}$

$$\therefore \frac{1}{K} = \frac{0.025}{850\times0.02} + \frac{0.0025\times0.025}{45\times0.0224} + \frac{1}{1700}$$

解得 $K = 471.5\ W/m^2\cdot°C$

对于逆流操作：　$80 \longrightarrow 30$

$50 \longleftarrow 20$

$\Delta t_1 = 80-50 = 30$　$\Delta t_2 = 30-20 = 10$

$$\therefore \Delta t_m = \frac{\Delta t_1 - \Delta t_2}{\ln\frac{\Delta t_1}{\Delta t_2}} = \frac{30-10}{\ln\frac{30}{10}} = 18.2(°C)$$

依题意知交换的热量为：

$Q = 1.5\times1.9\times10^3\times(80-30) = 1.425\times10^5\ (W)$

故冷却水的消耗量为：

$q_m\times4.174\times10^3\times(50-20) = 1.425\times10^5$

$q_m = 1.14\ Kg/s$

$$S_o = \frac{Q}{K\Delta t_m} = \frac{1.425\times10^5}{471.5\times18.2} = 16.6\ (m^2)$$

2-15 解：假定空气加热时的定性温度为：

$t = \frac{20+85}{2} = 52.5\,^{\circ}C$，查得该温度下空气的物性数据

$C_p = 1.017\times10^{3}\ J/kg\cdot{}^{\circ}C \quad \lambda = 2.826\times10^{-2}\ W/m\cdot{}^{\circ}C$

$\mu = 1.96\times10^{-5}\ Pa\cdot s \quad P_r = 0.698$

$\because \rho_0 = 1.293\ kg/m^3 \quad Q_v = 55\ m^3/h$

$\therefore \rho = \rho_0 \frac{P}{P_0}\frac{T_0}{T} = 1.293 \times \frac{3.026\times10^{5}}{1.013\times10^{5}} \times \frac{273}{325.5} = 2.17\ kg/m^3$

$u = \frac{4Q_v}{\pi d^2} = \frac{4\times55}{3600\times3.14\times0.05^2} = 7.78(m/s)$

$Re = \frac{d u \rho}{\mu} = \frac{0.05\times7.78\times2.17}{1.96\times10^{-5}} = 4.31\times10^{4} > 10^{4}$

$\because L/d_i = \frac{3}{0.05} = 60$

$\therefore \alpha = 0.023\frac{\lambda}{d_i} Re^{0.8} P_r^{n}$

空气在管内被加热，式中 $n = 0.4$

故空气对管壁的对流传热系数为：

$\alpha = 0.023 \times \frac{2.826\times10^{-2}}{0.05} \times (4.31\times10^{4})^{0.8} \times 0.698^{0.4}$

$= 57.42\ (W/m^2\cdot{}^{\circ}C)$

2-16附件：依题意知甲烷气的定性温度为 $t=\frac{120+30}{2}=75^{\circ}C$，

由有机混合物甲烷气的物性数据得：$\mu=0.0115\times10^{-3}\ Pa\cdot S$，

$\lambda=0.0407\ W/m\cdot{}^{\circ}C$，$C_p=2.5\times10^{3}\ J/Kg\cdot{}^{\circ}C$

甲烷气在壳程内流动时的当量直径为：

$$d_e=4\times\frac{\frac{\pi}{4}\times0.19^2-\frac{\pi}{4}\times0.019^2\times37}{\pi\times0.19+\pi\times0.019\times37}=0.0255\ (m)$$

将其视为理想气体，故密度为：

$$\rho=\frac{PM}{RT}=\frac{101325\times16\times10^{-3}}{8.314\times348}=0.56\ (Kg/m^3)$$

已知 $u=10\ m/S$

$$\therefore Re=\frac{d_e u\rho}{\mu}=\frac{0.0255\times10\times0.56}{0.0115\times10^{-3}}=12425$$

$$Pr=\frac{C_p\mu}{\lambda}=\frac{2.5\times10^{3}\times0.0115\times10^{-3}}{0.0407}=0.706$$

甲烷气在壳程被冷却，取 $n=0.3$

$$\therefore \alpha=0.023\frac{\lambda}{d_e}Re^{0.8}Pr^{0.3}$$

$$=0.023\times\frac{0.0407}{0.0255}\times12425^{0.8}\times0.706^{0.3}=62.4\ (W/m^2\cdot{}^{\circ}C)$$

据：$\frac{1}{K}=\frac{d_o}{\alpha_i d_i}+\frac{bd_o}{\lambda d_m}+\frac{1}{\alpha_o}$

忽略管壁及污垢热阻，且 $d_i=0.015\,m$ $d_o=0.019\,m$

$\alpha_i=850\,W/m^2\cdot^\circ C$ $\alpha_o=62.4\,W/m^2\cdot^\circ C$

$$\therefore \frac{1}{K}=\frac{d_o}{\alpha_i d_i}+\frac{1}{\alpha_o}=\frac{0.019}{850\times0.015}+\frac{1}{62.4}$$

由此可求得总传热系数为：

$K=57.1\,W/m^2\cdot^\circ C$

2-17 附：当水的流速为 1.1 m/s 时，水对管壁的传热系数为 α，

据：$\alpha=0.023\frac{\lambda}{d}Re^{0.8}Pr^n$

知 $\alpha\propto u^{0.8}$

当水的流速为 1.5 m/s 时，水对管壁的传热系数为：

$\alpha'=1.5^{0.8}\alpha=1.38\alpha$

依题意知：$u=1\,m/s$ 时

$$\frac{d_o}{\alpha_i d_i}+\frac{b\,d_o}{\lambda d_m}+\frac{1}{\alpha_o}=\frac{1}{2115}\quad\cdots\cdots(1)$$

当 $u=1.5\,m/s$ 时：

$$\frac{d_o}{1.38\alpha_i d_i}+\frac{b\,d_o}{\lambda d_m}+\frac{1}{\alpha_o}=\frac{1}{2660}\quad\cdots\cdots(2)$$

$\because d_i=0.02\,m$ $d_o=0.025\,m$

$$d_m=\frac{d_o-d_i}{\ln\frac{d_o}{d_i}}=\frac{0.025-0.02}{\ln\frac{0.025}{0.02}}=0.0224\,(m)$$

联立(1)(2)两式可得：

$\alpha_{i}=3548.5\ W/m^2\cdot℃$

将 α_i 代入到(1)式中可求得蒸气冷凝时的传热系数为：

$\alpha_o=1643.6\ W/m^2\cdot℃$

2-187 解：在加热过程某一时刻 $\tau \to \tau+d\tau$，流体的温度由 $t \to t+dt$，根据热量衡算可得热量衡算式：

$$KA(T-t)d\tau = q_m c_p dt$$

已知 $K=600\ W/m^2\cdot℃$ $A=1m^2$ $T=120\ ℃$

$q_m=1000\ Kg$ $c_p=3.8\times10^3\ J/Kg\cdot℃$

$$\therefore\quad 600\times1\times(120-t)d\tau = 1000\times3.8\times10^3\,dt$$

$$\text{或}\quad d\tau = 6.33\times10^3\times\frac{dt}{120-t}$$

两边积分且知边界条件为：$\tau_1=0$ $t_1=25℃$

$\tau_2=\tau$ $t_2=90℃$

$$\therefore\ \tau = -6.33\times10^3\ln(120-t)\Big|_{t_1}^{t_2}$$

$$= 6.33\times10^3\ln\frac{120-t_1}{120-t_2} = 6.33\times10^3\ln\frac{120-25}{120-90}$$

$$= 7.3\times10^3(0.5) = 2.03\ (h)$$

即物料由25℃加热至90℃所需的时间为2.03 h。

2-19解：将逆壁气由95℃冷却至30℃放出的热量为：

$Q_{冷却} = q_m(H_1 - H_2) = 180 \times (1647 - 1467) \times 10^3$

$= 3.24 \times 10^7 (J/h) = 9 \times 10^3 (W)$

30℃的壁气冷凝至30℃时放出的热量为：

$Q_{冷凝} = 180 \times (1467 - 323) \times 10^3$

$= 2.059 \times 10^8 (J/h) = 5.72 \times 10^4 (W)$

设循环水的用量为 q_{mc}，依题意有：

$q_{mc} c_{pc} (27 - 15) = 5.72 \times 10^4 + 9 \times 10^3 = 6.62 \times 10^4$

已知 $c_{pc} = 4.183 \times 10^3 J/kg \cdot ℃$

$\therefore q_{mc} = \frac{6.62 \times 10^4}{4.183 \times 10^3 \times 12} = 1.319 (kg/s)$

设冷却段与冷凝段汇聚处水的温度为 t，依题意有：

$1.319 \times 4.183 \times 10^3 \times (t - 15) = 5.72 \times 10^4$

解得：$t = 25.4℃$

2种逆流操作　$15 \longrightarrow 25.4$　$\Delta t_1 = 15$

$30 \longleftarrow 30$　$\Delta t_2 = 4.6$

故冷凝段的平均温度为：

$\Delta t_m = \frac{\Delta t_1 - \Delta t_2}{\ln \frac{\Delta t_1}{\Delta t_2}} = \frac{15 - 4.6}{\ln \frac{15}{4.6}} = 8.8 (℃)$

2种冷却段：$25.4 \longrightarrow 27$　$\Delta t_1' = 68$

$30 \longleftarrow 95$　$\Delta t_2' = 4.6$

改为却段的平均传热温差为：

$$\Delta t_m = \frac{\Delta t_1' - \Delta t_2'}{\ln \frac{\Delta t_1'}{\Delta t_2'}} = \frac{68 - 41.6}{\ln \frac{68}{41.6}} = 23.5\ (^\circ C)$$

2-21解：若忽略热损失时，设传热过程 $\tau \to \tau + d\tau$ 时刻内，流相的温度由 $t \to t + dt$，由传热基本方程可列出热量衡算式：

$$KA(T - t)\,d\tau = q_m c_p\,dt$$

已知，$K = 600\ W/m^2 \cdot ^\circ C$　$A = 1.2\ m^2$　$T = 120^\circ C$

$q_m = 1000\ Kg$　$c_p = 3.8 \times 10^3\ J/(Kg \cdot ^\circ C)$

$$\therefore\ 600 \times 1.2\,(120 - t)\,d\tau = 1000 \times 3.8 \times 10^3\,dt$$

故 $$d\tau = 5.28 \times 10^3 \times \frac{dt}{120 - t}$$

两边积分且知边界条件为：$\tau_1 = 0$　$t = 20^\circ C$

$\tau_2 = \tau$　$t = 95^\circ C$

$$\therefore \tau = -5.28 \times 10^3 \ln(120 - t)\Big|_{t_1}^{t_2}$$

$$= 5.28 \times 10^3 \ln \frac{120 - t_1}{120 - t_2}$$

$$= 5.28 \times 10^3 \ln \frac{120 - 20}{120 - 95}$$

$$= 7.32 \times 10^3\,(S) = 2.03\,(h)$$

若考虑热损失时，依题意知热量衡算式为：

$KA(T-t)d\tau - \alpha A_{外表}(t-t_{环境})d\tau = q_m c_p dt$

已知 $\alpha = 8\ W/m^2\cdot℃$ $A_{外表} = 9.5\ m^2$ $t_{环境} = 20℃$

$\therefore 600\times1.2\times(120-t)d\tau - 8\times9.5\times(t-20)d\tau = 1000\times3.8\times10^3 dt$

化简后：$(87920-796t)d\tau = 3.8\times10^6 dt$

变换：$d\tau = 3.8\times10^6 \frac{dt}{87920-796t}$

两边积分且积分边界条件为：$\tau_1 = 0$ $t_1 = 20$

$\tau_2 = \tau$ $t_2 = 95$

$$\therefore \tau = -\frac{3.8\times10^6}{796}\ln\frac{87920-796t_2}{87920-796t_1}$$

$$= \frac{3.8\times10^6}{796}\ln\frac{87920-796\times20}{87920-796\times95}$$

$$= 8.436\times10^3(s) = 2.34(h)$$

2-22解：依题意知换热过程的传热量为：

$Q = q_{mh}r = 0.84\times3.56\times10^5 = 2.99\times10^5(W)$

设冷却水的出口温度为 t，依题意知：

$19.5\times4.174\times10^3\times(t-32) = 2.99\times10^5$

解得：$t = 35.7℃$

传热过程的平均温度差为：

32 → 35.7　　$\Delta t_1 = 19.7$

51.7 → 51.7　　$\Delta t_2 = 16$

$$\Delta t_m = \frac{\Delta t_1 + \Delta t_2}{2} = \frac{19.7+16}{2} = 17.9\ ^\circ C$$

计算列管内冷却水的传热系数，按30℃查得水的物性数据分别为：$\rho = 995.7\ Kg/m^3$　$C_p = 4.175\times10^3\ J/Kg\cdot ^\circ C$

$\lambda = 0.618\ W/m\cdot ^\circ C$　$\mu = 0.801\times10^{-3}\ Pa\cdot s$

$P_r = 5.42$

选择列管内冷却水的流速。据资料 $u = 0.5 \sim 3\ m/s$。因考虑到管外是有机蒸气冷凝，其传热系数 α_o 一般比管内水作强制对流时的传热系数 α_i 小。α_i 不是主要热阻，所以不必选择很大，只要保证 $Re > 10^4$，这里选 $u = 0.5\ m/s$。

已知 $d_i = 0.02\ m$

则 $$Re = \frac{d_i u \rho}{\mu} = \frac{0.02\times0.5\times995.7}{0.801\times10^{-3}}$$

$$= 1.243\times10^4 > 10^4$$

据 $\alpha = 0.023 \frac{\lambda}{d_i} Re^{0.8} P_r^{\ n}$

列管内冷却水被加热，设 $n = 0.4$

$$\therefore \alpha_i = 0.023\times\frac{0.618}{0.02}\times(1.243\times10^4)^{0.8}\times5.42^{0.4}$$

$$= 2631\ (W/m^2\cdot ^\circ C)$$

第3章 传质物质通量习题解

3-1解：依题意已知 $T_b = 561\,K$　$T_2 = 448\,K$

据 $\lg(1.013\times10^5) - \lg P_2^* = -\frac{88T_b}{2.303R}\left(\frac{1}{T_b} - \frac{1}{T_2}\right)$

$\therefore \lg(1.013\times10^5) - \lg P_2^* = -\frac{88\times561}{2.303\times8.314}\left(\frac{1}{561} - \frac{1}{448}\right)$

解得：$P_2^* = 7020\,Pa$

$= 94280\,Pa$（真空度）$= 94.28\,KPa$（真空度）

3-2解：可用正戊烷和正己烷的沸点来估算值，取其相对挥发度：

$\because t = \frac{36.1+68.7}{2} = 52.4\,^\circ C$

$\therefore \lg P_1^* = 6.852 - \frac{1065}{52.4+232}$

解得：$P_1^* = 1280.2\,mmHg$

而 $\lg P_2^* = 6.878 - \frac{1172}{52.4+224.4}$

解得：$P_2^* = 440.4\,mmHg$

$\therefore \alpha = \frac{P_1^*}{P_2^*} = \frac{1280.2}{440.4} = 2.91$

由此可知气液平衡组成与液相组成关系为：

$$y=\frac{\alpha x}{1+(\alpha-1)x}=\frac{2.91x}{1+1.91x}$$

3-5解：依题意已知 $x_f=0.84$ $F=235\ Kmol/h$

$x_d=0.98$ $x_w=0.002$

据：$\begin{cases} F=D+W \\ Fx_f=Dx_d+Wx_w \end{cases}$

$\therefore \begin{cases} 235=D+W \\ 0.84\times235=0.98D+0.002W \end{cases}$

可解得：$D=201.4\ Kmol/h$（t塔顶采出量）

$W=33.6\ Kmol/h$（t塔釜采出量）

3-6解：依题意已知 $x_f=0.31$ $F=8716\ kg/h$

$x_d=0.98$ $x_w=0.012$

据：$\begin{cases} F=D+W \\ Fx_f=Dx_d+Wx_w \end{cases}$

$\therefore \begin{cases} 8716=D+W \\ 0.31\times8716=0.98D+0.012W \end{cases}$

可解得：$D=2683.2\ kg/h$

$W=6032.8\ kg/h$

按算成摩尔流量，

$$D=\frac{2683.2\times0.98}{78}+\frac{2683.2\times0.02}{92}=34.3(Kmol/h)$$

$$W=\frac{6032.8\times0.012}{78}+\frac{6032.8\times0.988}{92}=65.7(Kmol/h)$$

(2) 已知 $R=\frac{L}{D}=2.5$

故精馏段的回流液量为:

$L=2.5D=2.5\times34.3=85.75\ (Kmol/h)$

据 $V=L+D$

故精馏段上升的蒸气量为:

$V=85.75+34.3=120\ (Kmol/h)$

3-7 解: 据进料热状态参数 q 的定义:

$$q=\frac{\text{气化 1 kmol 料液所需热量}}{\text{料液汽化潜热}\ \Delta H_v}$$

$$\therefore q=\frac{1\times167.5\times(94-45)+1\times30397.6}{30397.6}=1.27$$

据 $y=\frac{q}{q-1}x-\frac{1}{q-1}x_f$

已知 $x_f=0.45$

$$\therefore y=\frac{1.27}{1.27-1}x-\frac{1}{1.27-1}\times0.45=4.7x-1.67$$

3-9解：先画出平衡线方程和q-l线方程求 x_q、y_q：

已知 $\alpha=2$，故平衡线方程为：

$$y=\frac{\alpha x}{1+(\alpha-1)x}=\frac{2x}{1+x}$$

又q线方程为：$y=6x-1.5$

联立以上两式可解得：$x_q=0.333$

$y_q=0.5$

故可求得最小回流比：

$$R_{min}=\frac{x_d-y_q}{y_q-x_q}=\frac{0.96-0.5}{0.5-0.333}=2.75$$

操作回流比为：

$R=1.5R_{min}=1.5\times2.75=4.13$

故精馏段的操作线方程为：

$$y_{n+1}=\frac{R}{R+1}x_n+\frac{1}{R+1}x_d=\frac{4.13}{4.13+1}x_n+\frac{1}{4.13+1}\times0.96$$

$$=0.805x_n+0.187$$

(2) 已知 $W=100\ Kmol/h$　$x_d=0.96$　$x_W=0.03$

由 $y=\frac{q}{q-1}x-\frac{1}{q-1}x_F=6x-1.5$

可解得：$\begin{cases}q=1.2\\x_F=0.3\end{cases}$

据 $\begin{cases} F = D + W \\ Fx_f = Dx_d + Wx_w \end{cases}$

$\therefore \begin{cases} F = D + 100 \\ 0.3F = 0.96D + 0.03 \times 100 \end{cases}$

解得：$D = 40.9\ kmol/h$（塔顶产品量）

$F = 140.9\ kmol/h$（进料量）

(3) 据 $R' = \frac{x_f - x_w}{x_d - x_f}(R+q) + q$

$\therefore R' = \frac{0.3 - 0.03}{0.96 - 0.3}(4.13 + 1.2) + 1.2 = 3.38$

据：$y_{m+1} = \frac{R'}{R'-1}x_m - \frac{1}{R'-1}x_w$

对提馏段的操作线方程有：

$$y_{m+1} = \frac{3.38}{3.38-1}x_m - \frac{1}{3.38-1} \times 0.03$$

$$= 1.42x_m - 0.0126$$

3-10 解：在精馏操作中，气一液相平衡关系指出的是气一液两相平衡时气相组成 y 与液相组成 x 之间的关系；而操作线方程指出的是两块塔板气液相组成间的关系，即下一块塔板的气相组成 y 与上一块塔板液相组成 x 的关系。

RA2.04—04.6

3-11 解：已知 $x_f=0.4$ $\alpha=1.5$ $x_d=0.95$ $q=1.2$

对应线方程为：

$$y=\frac{q}{q-1}x-\frac{1}{q-1}x_f=\frac{1.2}{1.2-1}x-\frac{1}{1.2-1}\times0.4$$

$$=6x-2$$

气液相平衡方程为：

$$y=\frac{\alpha x}{1+(\alpha-1)x}=\frac{1.5x}{1+0.5x}$$

联立以上两式可得：$x_q=0.42$

$y_q=0.52$

故最小回流比为：

$$R_{min}=\frac{x_d-y_q}{y_q-x_q}=\frac{0.95-0.52}{0.52-0.42}=4.3$$

3-12 解：已知 $x_f=0.835$ $x_d=0.986$ $x_w=0.049$

$\alpha=1.16$ $q=1$

$$\therefore y_f=\frac{\alpha x_f}{1+(\alpha-1)x_f}=\frac{1.16\times0.835}{1+(1.16-1)\times0.835}=0.854$$

由于是泡点进料，故最小回流比为：

$$R_{min}=\frac{x_d-y_f}{y_f-x_f}=\frac{0.986-0.854}{0.854-0.835}=6.95$$

据：$$N_0=\frac{\lg\left[\left(\frac{x_d}{1-x_d}\right)\left(\frac{1-x_w}{x_w}\right)\right]}{\lg\alpha}-1$$

故最小理论塔板数（含塔釜）为：

$$N_0=\frac{\lg\left[\left(\frac{0.986}{1-0.986}\right)\left(\frac{1-0.049}{0.049}\right)\right]}{\lg 1.16}-1=47.6$$

3-14 解：依题意已知 $V=90\ \text{Kmol/h}$ $D=30\ \text{kmol/h}$

$x_d=0.95$ $\alpha=2$

据 $V=L+D$

∴ $L=V-D=90-30=60\ (\text{Kmol/h})$

$$R=\frac{L}{D}=\frac{60}{30}=2$$

$$y_{n+1}=\frac{R}{R+1}x_n+\frac{1}{R+1}x_d=\frac{2}{2+1}x_n+\frac{1}{2+1}\times0.95$$

$$=0.667x_n+0.317$$

∵ $y_1=x_d=0.95$

而 $$y_1=\frac{\alpha x_1}{1+(2-1)x_1}=\frac{2x_1}{1+x_1}=0.95$$

∴ $x_1=0.905$

$y_2=0.667x_1+0.317$

$=0.667\times0.905+0.317=0.92$

而 $y_2 = \frac{2x_2}{1+x_2} = 0.92$

故从第1层塔板上升蒸气的组成为：

$x_2 = 0.852$

3-15 解：用芬斯克公式和吉利兰图求解理论塔板数。

已知：$x_f = 0.3$ $x_d = 0.9$ $x_w = 0.2$ $R = 1.8R_{min}$

$\therefore (T_b)_A = 138.35\,^\circ C + 273.15 = 411.5\ K$

$(T_b)_B = 139.1 + 273.15 = 412.25\ K$

据 $\lg\alpha = 0.178\left[\frac{(T_b)_A - (T_b)_B}{(T_b)_A + (T_b)_B}\right]$

$\therefore \lg\alpha = 0.178\left[\frac{411.5 - 412.25}{411.5 + 412.25}\right]$

$\alpha = 1.02$

$\because y_f = \frac{\alpha x_f}{1+(\alpha-1)x_f} = \frac{1.02\times0.3}{1+(1.02-1)\times0.3} = 0.304$

由于进料为泡点进料，$q=1$，故：

$R_{min} = \frac{x_d - y_f}{y_f - x_f} = \frac{0.9-0.304}{0.304-0.3} = 149$

$\therefore R = 1.8R_{min} = 1.8\times149 = 268.2$

据芬斯克公式：

$$N_0 = \frac{\lg\left[\left(\frac{x_d}{1-x_d}\right)\left(\frac{1-x_w}{x_w}\right)\right]}{\lg\alpha} - 1$$

$$\therefore N_0 = \frac{\lg\left[\left(\frac{0.9}{1-0.1}\right)\times\left(\frac{1-0.2}{0.2}\right)\right]}{\lg 1.02} - 1 = 181$$

$$\frac{R-R_{min}}{R+1} = \frac{268.2-149}{268.2+1} = 0.443$$

根此在吉利兰图中可查得：

$$\frac{N-N_0}{N+2} = 0.28$$

由此可知此精馏塔的理论塔板数为：

$$N_T = N = 252 \text{ (块)}$$

已知该精馏塔全塔板效率 $E_T = 80\% = 0.8$

求得 $E_T = \frac{N_T}{N}$

故该塔的实际塔板数为：

$$N = \frac{N_T}{E_T} = \frac{252}{0.8} = 315 \text{ (块)}$$

3-16 解：依题意已知 $x_f=0.4$ $x_d=0.95$ $x_w=0.05$

$\alpha=2.41$ $R=1.2R_{min}$

$$\therefore y_f=\frac{\alpha x_f}{1+(\alpha-1)x_f}=\frac{2.41\times0.4}{1+(2.41-1)\times0.4}=0.616$$

由于泡点进料，故：

$$R_{min}=\frac{x_d-y_f}{y_f-x_f}=\frac{0.95-0.616}{0.616-0.4}=1.54$$

$\therefore R=1.2R_{min}=1.2\times1.54=1.85$

由此可得精馏操作线方程为：

$$y_{n+1}=\frac{R}{R+1}x_n+\frac{1}{R+1}x_d=\frac{1.85}{1.85+1}x_n+\frac{1}{1.85+1}\times0.95$$

$$=0.649x_n+0.333$$

气相平衡线方程为：

$$y=\frac{\alpha x}{1+(\alpha-1)x}=\frac{2.41x}{1+(2.41-1)x}$$

可改写为：

$$x=\frac{y}{2.41-1.41y}$$

$\because y_1=x_d=0.95$

$$\therefore x_1=\frac{y_1}{2.41-1.41y_1}=\frac{0.95}{2.41-1.41\times0.95}=0.887$$

$y_2 = 0.649x_1 + 0.333$

$= 0.649 \times 0.887 + 0.333 = 0.909$

依次可计算出精馏段各塔板上的汽液相组成如表：

	1	2	3	4	5	6	7	8	9
y	0.95	0.909	0.856	0.794	0.733	0.678	0.636	0.606	
x	0.887	0.805	0.711	0.616	0.532	0.466	0.42	0.389	

由于 $x_8 = 0.389 < x_f = 0.4$，故第9块塔板在提馏段内，而第8块塔板即为加料板。

据 $R' = \frac{x_f - x_w}{x_d - x_f}(R+q) + q$

$\therefore R' = \frac{0.4 - 0.05}{0.95 - 0.4} \times (1.85+1) + 1 = 2.81$

据 $y_{m+1} = \frac{R'}{R'-1}x_m - \frac{1}{R'-1}x_w$

$\therefore y_{m+1} = \frac{2.81}{2.81-1}x_m - \frac{1}{2.81-1} \times 0.05$

$= 1.55x_m - 0.028$

$\therefore y_9 = 1.55x_8 - 0.028$

$= 1.55 \times 0.389 - 0.028 = 0.575$

和 $x_9 = \frac{y_9}{2.41 - 1.41y_9} = \frac{0.575}{2.41 - 1.41 \times 0.575} = 0.359$

依次可计算出提馏段内各块塔板的气液相组成如表

	9	10	11	12	13	14	15	16	17
y	0.575	0.529	0.465	0.383	0.289	0.196	0.114	0.051	
x	0.359	0.318	0.265	0.205	0.144	0.092	0.051	0.022	

由表中数据可知，当 $x_{16}=0.022<x_W=0.05$，已经能够满足分离的要求，因此该塔所需理论板数：$N_T=16$ 块。

3-18解：已知 $x_f=0.44$ $x_d=0.97$ $\alpha=2.5$

操作时的气液混合物，其中蒸气量占 $\frac{1}{3}$（物质的量之比），由q的定义可知，$q=\frac{2}{3}$。

提 $y=\frac{q}{q-1}x-\frac{1}{q-1}x_f$

故加料线（q线）方程为：

$$y=\frac{2/3}{2/3-1}x-\frac{1}{2/3-1}\times 0.44$$

$$=1.32-2x$$

气液平衡线方程为：

$$y=\frac{\alpha x}{1+(\alpha-1)x}=\frac{2.5x}{1+1.5x}$$

若进料的气液两相呈平衡，则q线方程与气相平衡方程的交点 (x_q, y_q) 即为原料的气液相组成。

RA2.04—04.6

联立两方程可解得：

$x_q = 0.365$（原料中的液相组成）

$y_q = 0.59$（原料中和气相组成）

据 $R_{min} = \dfrac{x_d - y_q}{y_q - x_q}$

故最小回流比为：

$$R_{min} = \frac{0.97 - 0.59}{0.59 - 0.365} \approx 1.69$$

3-19题. 已知 $x_d = 0.97$ $\alpha = 3$ $R = 2.5$

$x_1 = 0.5$ $x_2 = 0.4$

据：$E_{MG} = \dfrac{y_2 - y_3}{y_2^* - y_3}$

$$y_2 = \frac{R}{R+1}x_1 + \frac{1}{R+1}x_d = \frac{2.5}{2.5+1} \times 0.5 + \frac{1}{2.5+1} \times 0.97 = 0.634$$

$$y_3 = \frac{R}{R+1}x_2 + \frac{1}{R+1}x_d = \frac{2.5}{2.5+1} \times 0.4 + \frac{1}{2.5+1} \times 0.97 = 0.563$$

$$y_2^* = \frac{\alpha x_2}{1+(\alpha-1)x_2} = \frac{3 \times 0.4}{1+(3-1) \times 0.4} = 0.667$$

$$\therefore E_{MG(2)} = \frac{0.634 - 0.563}{0.667 - 0.563} = 0.683$$

3-20 解：已知 $F=100\ kmol/h$　$x_f=0.44$　$x_d=0.98$

$x_w=0.024$　$R=3.5$

据 $\begin{cases} F=D+W \\ Fx_f=Dx_d+Wx_w \end{cases}$

$\therefore \begin{cases} 100=D+W \\ 100\times0.44=0.98D+0.024W \end{cases}$

可解得：$D=43.5\ kmol/h$

$W=56.5\ kmol/h$

$\because R=\frac{L}{D}=3.5$

$\therefore L=3.5D=3.5\times43.5=152.25\ kmol/h$

$\because V=L+D$

$\therefore V=152.25+43.5=195.75\ kmol/h$

操作条件为：$P=101.3\ KPa$　$T=273+90=363\ K$

此条件塔顶上升蒸汽的体积流量为：

$$q_V=\frac{195.75\times10^3}{3600}\times22.4\times10^{-3}\times\frac{363}{273}=1.62\ (m^3/s)$$

已知空塔气速 $u=0.8\ m/s$

此塔的塔径为：

$$d=\sqrt{\frac{4q_V}{\pi u}}=\sqrt{\frac{4\times1.62}{3.14\times0.8}}=1.6\ (m)$$

3-22 解：依题意知 $P_A^* = 0.987\ KPa$ $P_{总} = 101.3\ KPa$

$$x_A = \frac{1/17}{1/17 + 100/18} = 0.0105$$

据 $P_A^* = E x_A$

$$\therefore E = \frac{P_A^*}{x_A} = 94\ KPa$$

据 $m = \frac{E}{P_{总}}$

故相平衡常数为：

$$m = \frac{94}{101.3} = 0.928$$

据 $H = \frac{\rho_S}{E M_S}$

已知 $\rho_S = 998.2\ Kg/m^3$ $M_S = 18\ Kg/Kmol$

故溶解度常数为：

$$H = \frac{998.2}{94 \times 18} = 0.59$$

3-23解：依题意已知 $P_A = 21\,KPa$ $N_A/A = 0.144\,kmol/m^2 \cdot h^{-1}$

$C_A = 1\times10^{-3}\,Kmol/m^3$ $k_G = 0.0144\,Kmol/m^2 \cdot kPa$

据 $N_A/A = k_G(P_A - P_{Ai})$

$\therefore P_A - P_{Ai} = \dfrac{N_A}{A k_G} = \dfrac{0.144}{0.0144} = 10\,(KPa)$

据 $P_A^* = \dfrac{C_A}{H}$

当 $P_A^* = 8\,KPa$ 时，$C_A = 1\times10^{-3}\,Kmol/m^3$

$\therefore H = \dfrac{C_A}{P_A^*} = \dfrac{1\times10^{-3}}{8} = 1.25\times10^{-4}\,(Kmol/m^3 \cdot KPa)$

据 $N_A/A = K_G(P_A - P_A^*)$

$\therefore K_G = \dfrac{N_A/A}{P_A - P_A^*} = \dfrac{0.144}{21-8} = 0.0111$

据 $\dfrac{1}{K_G} = \dfrac{1}{k_G} + \dfrac{1}{H k_L}$

$\therefore \dfrac{1}{0.0111} = \dfrac{1}{0.0144} + \dfrac{1}{1.25\times10^{-4} k_L}$

得 $k_L = 384\ m/h$

据 $\dfrac{1}{K_L} = \dfrac{H}{k_G} + \dfrac{1}{k_L}$

$\therefore \dfrac{1}{K_L} = \dfrac{1.25\times10^{-4}}{0.0144} + \dfrac{1}{384}$

解得：$K_L = 88.6\ m/h$

据：$N_A/A = K_L(C_A^* - C_A)$

$\therefore C_A^* - C_A = \frac{N_A/A}{K_L} = \frac{0.1144}{88.6} = 1.625\times10^{-3}\ (Kmol/m^3)$

∵ 总阻力为 $1/K_G$，气膜阻力为 $1/k_G$

故气膜阻力占总阻力的百分率为：

$$\frac{1/k_G}{1/K_G} = \frac{K_G}{k_G} = \frac{0.0111}{0.0144} = 0.77 = 77\%$$

3-24 解：已知 $k_G = 0.003\ Kmol/h\cdot m^2\cdot KPa$　$k_L = 0.45\ m/h$

$P_{总} = 106.4\ KPa$　$y = 32.0\%$

由 $y = 32.0\%$ 可知，$m = 320$

据 $m = \frac{E}{P_{总}}$

$\therefore E = mP_{总} = 320\times106.4 = 34048\ KPa$

据 $H = \frac{\rho_s}{EM_s}$

已知 $\rho_s = 1000\ Kg/m^3$　$M_s = 18\ Kg/Kmol$

$\therefore H = \frac{1000}{34048\times18} = 1.631\times10^{-3}\ (Kmol/m^3\cdot KPa)$

据 $\frac{1}{K_G} = \frac{1}{k_G} + \frac{1}{Hk_L}$

$$\therefore \frac{1}{K_G} = \frac{1}{0.003} + \frac{1}{1.631\times10^{-3}\times0.45}$$

$$\therefore K_G = 5.9\times10^{-4}\ kmol/h\cdot m^2\cdot KPa$$

据 $K_G = H K_L$

$$\therefore K_L = \frac{K_G}{H} = \frac{5.9\times10^{-4}}{1.631\times10^{-3}} = 0.362$$

据 $K_Y = P_{总}\cdot K_G$

$$\therefore K_Y = 106.4\times5.9\times10^{-4} = 6.28\times10^{-2}\ (kmol/h\cdot m^2)$$

据 $K_X = C_{总}\cdot K_L$

而 $C_{总} \approx \frac{\rho_s}{M_s}$

$$\therefore K_X = \frac{1000}{18}\times0.362 = 20.1\ (kmol/h\cdot m^2)$$

3-25 解：依题意知 $y_1 = 0.02$ $y_2 = 0.001$ $E = 5.52\times10^4 KPa$

$P_{总} = 101.3\ KPa$ $X_2 = 0$（清水）

$$\therefore Y_1 = \frac{y_1}{1-y_1} = \frac{0.02}{1-0.02} = 0.0204$$

$$Y_2 = \frac{y_2}{1-y_2} = \frac{0.001}{1-0.001} = 0.001$$

$$m = \frac{E}{P_{总}} = \frac{5.52\times10^4}{101.3} = 545$$

据 $(\frac{L}{V})_{min} = \frac{Y_1 - Y_2}{\frac{Y_1}{m} - X_2}$

$\therefore (\frac{L}{V})_{min} = \frac{0.0204 - 0.001}{\frac{0.0204}{545} - 0} = 518.3$

$\because L = 1.2 L_{min}$

$\therefore (\frac{L}{V}) = 1.2 (\frac{L}{V})_{min} = 1.2 \times 518.3 = 622$

据 $\frac{L}{V} = \frac{Y_1 - Y_2}{X_1 - X_2}$

又 $\frac{0.0204 - 0.001}{X_1 - 0} = 622$

$\therefore X_1 = 3.12 \times 10^{-5}$

若操作压强改为 1013 KPa，即 $P_{总}' = 1013$ KPa

又 $m' = \frac{5.52 \times 10^4}{1013} = 54.5$

$\therefore (\frac{L}{V})_{min}' = \frac{0.0204 - 0.001}{\frac{0.0204}{54.5} - 0} = 51.83$

$(\frac{L}{V})' = 1.2 \times 51.83 = 62.2$

而 $\frac{0.0204 - 0.001}{X_1' - 0} = 62.2$

$\therefore X_1' = 3.12 \times 10^{-4}$

3-26 解：已知 $H=6$ $m=2$ $y_1=0.05$ $X_2=0$（清水）

$y_2=y_2=0.00263$

对1：$Y_1=\frac{y_1}{1-y_1}=\frac{0.05}{1-0.05}=0.0526$

依题意可知

$$X_1=\frac{6.12/58}{93.88/18}=0.0202$$

$\therefore Y_1^*=mX_1=2\times0.0202=0.0404$

$Y_2^*=mX_2=0$

$\Delta Y_1=Y_1-Y_1^*=0.0526-0.0404=0.0122$

$\Delta Y_2=Y_2-Y_2^*=0.00263$

$$\Delta Y_m=\frac{\Delta Y_1-\Delta Y_2}{\ln\frac{\Delta Y_1}{\Delta Y_2}}=\frac{0.0122-0.00263}{\ln\frac{0.0122}{0.00263}}=0.0062$$

$$N_{OG}=\frac{Y_1-Y_2}{\Delta Y_m}=\frac{0.0526-0.00263}{0.0062}=8$$

依题意知：

$$V=\frac{2000}{22.4}\times\frac{273}{298}\times(1-0.05)=77.7\ (Kmol/h)$$

$$\Omega=\frac{\pi}{4}d^2=\frac{\pi}{4}\times0.8^2=0.5024\ (m^2)$$

据 $H=H_{OG}\times N_{OG}=\frac{V}{K_Ya\Omega}\times N_{OG}$

故气相体积总传质系数为：

$$K_Ya = \frac{VN_{OG}}{H\Omega} = \frac{77.7\times 8}{6\times 0.5024} = 206.2\ (Kmol/h\cdot m^3)$$

据 $N = V(Y_1 - Y_2)$

故每小时回收的丙酮量为：

$$N = 77.7\times(0.0526 - 0.00263) = 3.88(kmol/h)$$

3-27题：已知 $y_1 = 0.1$ $y_2 = 0.005$ $x_1 = 0.0006$ $X_2 = 0$

$E = 2\times10^5\ KPa$ $P_{总} = 2\times10^3\ KPa$

$$\therefore Y_1 = \frac{y_1}{1-y_1} = \frac{0.1}{1-0.1} = 0.111$$

$$Y_2 = \frac{y_2}{1-y_2} = \frac{0.005}{1-0.005} = 0.005$$

$$X_1 \approx x_1 = 0.0006$$

$$m = \frac{E}{P_{总}} = \frac{2\times10^5}{2\times10^3} = 100$$

$$\because \frac{L}{V} = \frac{Y_1 - Y_2}{X_1 - X_2} = \frac{0.111 - 0.005}{0.0006 - 0} = 176.67$$

依题意可知：$V = \frac{2240}{22.4}\times(1-0.1) = 90(Kmol/h)$

故每小时用水量为：

$$L = 176.67\times90 = 15900(kmol/h) = 286200kg/h = 286.2\ t/h$$

$\because X_1^* = \frac{Y_1}{m} = \frac{0.111}{100} = 0.00111$

$X_2^* = \frac{Y_2}{m} = \frac{0.005}{100} = 0.00005$

$\Delta X_1 = X_1^* - X_1 = 0.00111 - 0.0006 = 0.00051$

$\Delta X_2 = X_2^* - X_2 = 0.00005$

$\Delta X_m = \frac{\Delta X_1 - \Delta X_2}{\ln \frac{\Delta X_1}{\Delta X_2}} = \frac{0.00051 - 0.00005}{\ln \frac{0.00051}{0.00005}} = 0.000198$

$\therefore N_{OL} = \frac{X_1 - X_2}{\Delta X_m} = \frac{0.0006 - 0}{0.000198} = 3.03$

依题意已知 $K_X a = 2780\ Kmol/h \cdot m^3$

$\Omega = \frac{\pi}{4} d^2 = \frac{\pi}{4} \times 1.5^2 = 1.766\ (m^2)$

$\therefore H_{OL} = \frac{L}{K_X a \Omega} = \frac{15900}{2780 \times 1.766} = 3.24\ (m)$

故填料层的高度为：

$H = H_{OL} \times N_{OL} = 3.24 \times 3.03 = 9.81\ (m)$