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# 第0章 绪论

1）

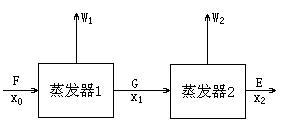


|  |  |  |  |
| --- | --- | --- | --- |
| 木材 |  | 木材Q 120(1-0.52)=(120-w)(1-0.25) |  |
|  |  |
|  | 照晒 | w=43.2kg |  |

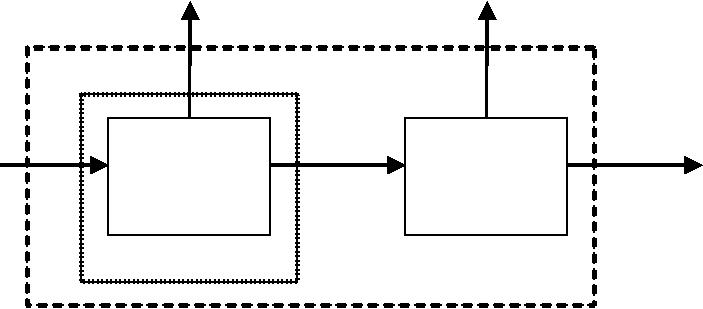


2） 以两个串联的蒸发器对 NaOH 水溶液予以浓缩，流程及各符号意义如图所示，F、G、E 皆为 NaOH 水溶液的质量流量，x 表示溶液中含 NaOH 的质量分数，

1. 表示各蒸发器产生水蒸汽的质量流量。若，， ，，问：W1、W2、E、x1 各为多少？



W1kg/s W2kg/s



|  |  |  |  |
| --- | --- | --- | --- |
| NaOH 水液 | G kg/s |  | E kg/s |
| F=6.2Kg/s | 蒸发器 1 | 蒸发器 2 | X2 =0.30 |

X0=0.105

W1:W2=1:1.15 , X---(Wt),x1,w1,w2,D,E=?

对控制体 I，NaOH 物料衡算：Fx0=Ex2

* 6.2×0.105=E×0.30 E=2.17 kg/s W1+W2=F-E=6.2-2.17=4.03 kg

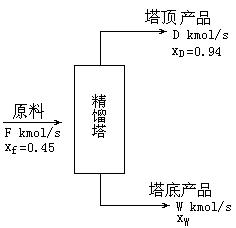
W1=4.03/2.15=1.87 kg/s ，W2=4.03-1.87=2.16 kg/s

对控制体 II，总的物料衡算：G=F-W1=6.2-1.87=4.33 kg/s

QFx0=Gx2 即 6.2×0.105=4.33x1, x1=0.15

3)某连续操作的精馏塔分离苯与甲苯。原料液含苯 0 . 4 5（摩尔分率，下同），塔顶产品含苯 0.94。已知塔顶产品含苯量占原料液中含苯量的 95%。问：塔底产品中苯的浓度是多少？按摩尔分率计。

[解]：



* + 0.94

Q 0.95= *FXF* = *F* 0.45

*D* 0.445, *W* 0.545*DXD D*



* + 1. *F*
  + *F* 0.45 *D*0.94 *WXW* 即0.45  0.45  0.94  0.545  *XW* *XW* 0.0413

4)导热系数的 SI 单位是 W/(m·℃)，工程制单位是 kcal/(m·h·℃)。试

* 1kcal/( m·h·℃)相当于多少 W/(m·℃)？并写出其因次式。

1kcal/(m.h.0C)=?J/(m.s.0C)写出导热系数的因次式。

∵1kcal=4.187×103J,1h=3600s

∴

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *kcal* | | 4.187 103 | |  | *J* | |  | *W* | |  |
| 1 |  |  |  |  |  |  |  |  1.163 |  |  |  |
| *m*. *h*.0 *C* | |  |  | *m*. *s*.0 *C* | | *m*.0 *C* | |  |
|  | 3600 | |  |  |  |

令各基本因次为： *M* — —质量， *L*— —长度， *T* — —温度， *τ* — —时间。

*M*（ *L*/ *τ*2） *L*

导热系数因次式  *MLτ*−3*T*−1





5)已知理想气体通用常数 物理大气压·升/(摩尔·K)，试求采

* J/(kmol·K)时 R 的数值。

解：写出以 J/（kmolk）的单位为理想气体通用常数 R 之值。

∵1 物理大气压=1.0133×105N/m2，1 升=10-3m3

∴

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| R=0.08205 | |  |  |  |  |  |  |  |  |  |
|  | 物理大气压.，升 |  0.08205 | 1.0133105 | 10−3（ *N*/ *m*2 ) *m*3 | | | |  8314 | *J* |  |
| 摩尔， *K* | 10−3 |  |  | *kmol*. *k* |  | *kmol*. *K* |  |
|  |  |  |  |  |  |

6） 水蒸汽在空气中的扩散系数可用如下经验公式计算：



式中 D——扩散系数，英尺 2/h；

p——压强，atm；

T——绝对压强，。

试将上式改换成采用 SI 单位的形式。各物理量采用的单位是：D—m2/s，p —Pa，T—K。

解:经验公式的单位换算:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1.46 10−4 | | |  | *T*2.5 | |  |  |  |
| *D*  |  |  |  |  |  |  |  |  |
| *P* | | *T* 441 | |  |  |  |
|  |  |  |  |  |
|  | |  |  | | |  |  |  |
| 物理量 | |  | 扩散系数 | | | 压强 | 绝对温度 |  |
|  | |  |  | | |  |  |  |
| 原来单位 | |  | 英尺 2/h | | | atm | 0R |  |
| 后来单位 | |  | M2/s | | | Pa | K |  |

∵1 英尺 2/h=0.30482/3600m2/s=2.58×10-5m2/s,1atm=1.0133×105pa, 温差 1k=1.80R

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ' |  | 1 | |  |  |  |  | 1.46 10−4 | | |  |  |  | (1.8*T*' )2.5 | |  |
| *D* | ( |  |  | )  | |  |  |  | |  |  | |  |  |  |  |
| 2.58 10−5 | | 1 | | | |  | | (1.8*T*')  441 |  |  |
|  |  |  |  |  |  |  | *P*'( | |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | 5 ) |  |  |  |  |  |
|  |  |  |  |  |  | 1.013310 | | | | |  |  |  |  |  |
| *D*' | | | 9.218 10−4 | |  |  | | ( *T*')2.5 | |  |  |  |  |  |  |  |
| *P*' | | | *T*'245 | | |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |

7） 在冷凝器中蒸汽与冷却水间换热，当管子是洁净的，计算总传热系数的经验式为：



式中 K——总传热系数，Btu/(ft2·h·℉)；

u——水流速，ft/s。

试将上式改换成采用 SI 单位的形式。各物理量采用的单位是：K—W/(m·℃)，u—m/s。

解：经验公式的单位换算：

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | 1 |  0.00040  | | 1 |  |  |  |
|  | 268 *u*0.8 | |  |  |
|  | *K* | |  |  |  |
| 物理量 | | | 传热系数 | | | 流速 |  |
|  | | |  | | |  |  |
| 原来单位 | | | BUT/ft2.h.0F) | | | ft/s |  |
| 后来单位 | | | W/（m2.K） | | | m/s |  |

∵1BUT/(ft2.h.0F)=5.678W/(m2.K),1ft/s=0.3048m/s

# 第1章 流体流动

1 某敞口容器内盛有水与油。[如图](file:///C:\I\chapter1image1-1.jpg)。已知水及油的密度分别为 1000 和 860kg/m3，解：h1=600mm，h2=800mm，问 H 为多少 mm？

*h*1600 *mm*, *h*2800 *mm*, *ρ*水103 *kg*/ *m*3

*ρ*油  860 *kg*/ *m*3 , *h*  ?

* 860  9.81 0.60  103  9.81 0.80  103  9.81*h*

*h* 1.32 *m*

2.有一幢 102 层的高楼，每层高度为 4m。若在高楼范围内气温维持 20℃不 变。设大气静止，气体压强为变量。地平面处大气压强为 760mmHg。试计算楼顶的大气压强，以 mmHg 为单位。

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | | *d* | *p* | − *ρgdz*− − −① | | |  |
| 解： | | |  |  |  |  |  |
|  |  | | *p*29 /(8314293.2)1.19010−5 *p*− − −② | | | | |  |
|  | *ρ*  | |  |
| ②代入①，得 | | | |  |  | *dz* |  |  |
| *P* *dp*  −9.811.190 10−5 | | | | | |  |  |
|  |  |  |  |  |  | 408 |  |  |
| 1 |  |  |  |  |  | ∫0 |  |  |
|  |  |  |  |  |  |  |
| ∫*P* | *p* | |  |  |  |  |  |  |
| 2 | *Ln*( *p* / 760)−9.811.19010 | | | | | | −5  408  −0.04763, *P*  724.7 *mmHg* |  |
|  |  |
|  | 1 | |  |  |  |  | 1 |  |

3.某水池，水深 4 米，水面通大气，水池侧壁是铅垂向的。问：水池侧壁平面每

3 米宽度承受水的压力是多少 N？外界大气压为 1atm。

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 4 | ( *P*  *ρ* *gz*) *dz*  31.013105 | |  4  3103  9.81 42 | / 2  1.45105 | *N* |  |
| *F* 3 |  |
| ∫0 | 0 | 水 |  |  |  |  |

4．4．外界大气压为 1atm，试按理想气体定律计算 0.20at（表压）、20℃干空气的密度。空气分子量按 29 计。

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | *PM* | | (1.013105  0.20  0.81104 )  29 | 3 |  |
| 解： *ρ*  |  |  |  |  1.439 *Kg*/ *m* |  |
|  | 8314  293.2 |  |
|  | *RT* | |  |  |

5．5．有个外径为 R2、内径为 R1 为的空心球，由密度为ρ’的材料制成。若将该球完全淹没在某密度为ρ的液体中，若球能在任意位置停留，试求该球的外径与内径之比。设球内空气重量可略。

解：(4 / 3) *π*（ *R*23 − *R*13 ) *ρ*' *g*  (4 / 3) *πR*23 *ρg*

*R*2/ *R*1(1− *ρ*/ *ρ*')−1/ 3

6．6．为放大以 U 形压差计测气体压强的读数，采用倾斜式 U 形压差计。[如图](file:///C:\I\chapter1image1-6.jpg)。指示液是ρ=920kg/m3 的乙醇水溶液。气体密度为 1.20kg/m3。读数 R=100mm。问 p1 与 p2 的差值是多少 mmHg？

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 解 : *P* − *P*  ( *ρ* | *i* | − *ρ*) *gR*sin 200 |  (920 −1.20)  9.81 0.1sin 200 |  308.3 *Pa*＝2.31mmHg |  |
| 12 |  |  |  |  |

采用微差 U 形压差计测压差。[如图](file:///C:\I\chapter1image1-7.jpg)。已知 U 形管内直径 d 为 6mm，两扩大室半径均为 80mm，压差计中用水和矿物油作指示液，密度分别为 1000 及 860kg/m3。当管路内气体压强 p 与外界大气压 p0 相等时，两扩大室油面齐平，U 形管两只管内油、水交界面亦齐平。现读得读数 R=350mm，试计算：（1）气体压强 p（表）。（2）若不计扩大室油面高度差，算得的气体压强 p 是多少？（3）若压差计内只有水而不倒入矿物油，如一般 U 形压差计，在该气体压强 p 值下读数 R0 为多少？

|  |  |  |  |
| --- | --- | --- | --- |
| 解：① *P*− *P* ( *ρ* − *ρ* ) *gR* *ρ gR*( *d*/ *D*)2 | | | |
| 0 | 2 | 1 | 1 |

* (1000 − 860)  9.81 0.35  860  9.81 0.35(6 /160）2  484.8 *Pa*

② *P*− *P* ≈( *ρ* − *ρ* ) *gR* (1000−860)9.810.35

0 2 1

480.7 *Pa*

③ *P*− *P*  *ρ gR*

0 1 0

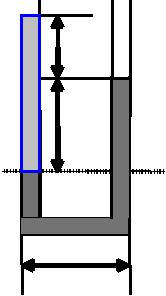
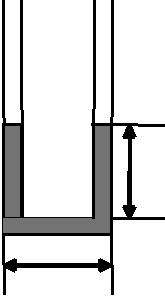
即484.8  1000  9.81 *R*0 *R*00.0493 *m*

7．7．某倾斜的等径直管道内有某密度ρ的液体流过。[如图](file:///C:\I\chapter1image1-8.jpg)。在管道的 A、B 截面设置了两套 U 形压差计测压差，下测用的是一般 U 形压差计，上测用的是复式 U 形压差计，所用的指示液均为密度是ρ1 的同一种液体。复式压差计中两段指示液之间的流体是密度为ρ的流过管道内的液体。试求读数 R1 与 R2、R3的关系。

解： Q( *ρi* − *ρ*) *gR*1  ( *ρi* − *ρ*) *gR*2  ( *ρi* − *ρ*) *gR*3

*R*1 *R*2 *R*3

9)将水银倒入到图示的均匀管径的 U 形管内，水银高度 h1=0.25m。然后将水从左支管倒入，测得平衡后左支管的水面比右支管的水银面高出 0.40m。试计算 U 形管内水与水银的体积比。



|  |  |
| --- | --- |
| 解： | R1=0.4m |

R2

h1=0.25m 1 1

L=0.015m L

习题 9 附图

如图所示 1--1 为等压面, p1=p1’

ρ 水 g(R1+R2) = ρ 水银 gR2

103(0.4+R2) = 13.6103R2

R2 = 0.0317m

*π*



V 水银 = 4 d2(2h1+L)

*π*



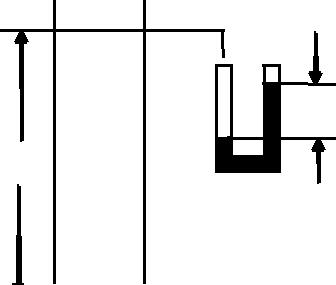
V 水 = 4 d2(R1+R2)

V 水银 / V 水 = (2h1+L)/ (R1+R2) = (20.25+0.015)/(0.4+0.0317) =

1.19

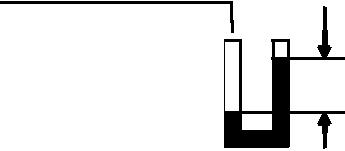
1. 一直立煤气管，在底部 U 形压差计 h1=120mm，在 H=25m 高处的 U 形压差计

h2=124.8mm。U 形管指示液为水。管外空气密度为 1.28kg/m3。设管内煤气及管外空气皆静止，求管内煤气的密度。



h2

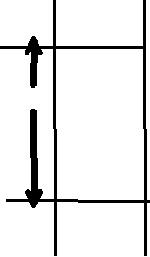
H



h1

习题 10 附图

p2 p2’



解：

H

p1 p1’

p1－p1’= ρ 水 gh1 (1)

p2－p2’= ρ 水 gh2 (2)

(1)减(2)，得

(p1－p2)－(p1’－p2’) = ρ 水 g(h1－h2) (3)

其中 p1－p2 = ρ 煤 gH，p1’－p2’ = ρ 空 gH，代入(3)式,得：

ρ 煤 gH－ρ 空 gH = ρ 水 g(h1－h2)

* ρ 煤 = ρ 水 (h1－h2)/H＋ρ 空 = 103(0.120－0.1248)/25＋1.28
  + 1.088 kg/m3

11．以 2”的普通壁厚的水煤气钢管输送 15℃的清水，水在管内满流。已知水流速 u=1.5m/s，求水的质量流量、质量流速和体积流量。

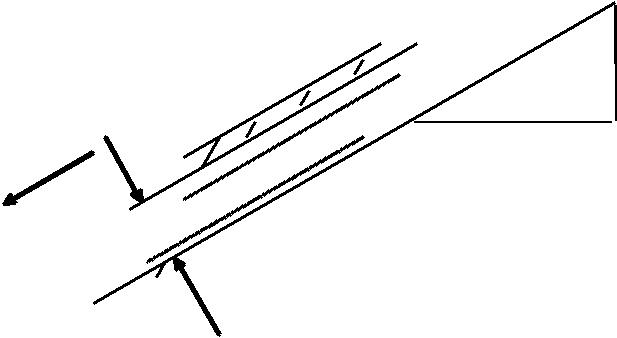
解：管子，查得外径60 *mm*, 壁厚横截面积 *A* ( *π* / 4)  (0.060 − 2  0.0035)2  2.206 10−3 *m*2 水的密度 *ρ*  999 *Kg*/ *m*3

体积流量 *V*  *uA*1.52.20610−33.30910−3 *m*3/ *s*

质量流量W  UA *ρ*  1.5  2.2076 10−3  999  3.306 *Kg*/ *s* 质量流速 *G*  *uρ* 1.59991499 *kg*/( *s m*2)

12．[如图所示](file:///C:\I\chapter1image1-12.jpg)，质量为 3.5kg，面积为 40×46cm2 的一块木板沿着涂有油的斜面等速向下滑动。已知 v=1.2m/s，σ=1.5mm（油膜厚度）。求滑油的粘度。

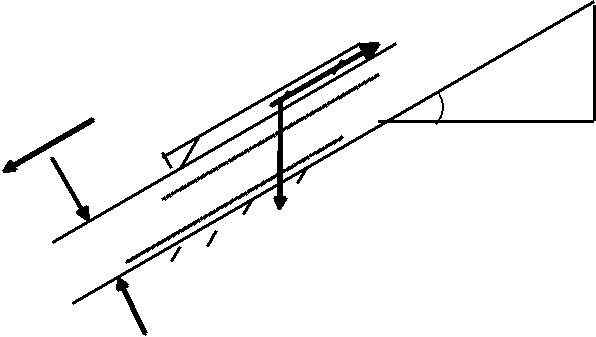
13 5



12

δ

13



解： τ

 5

V

 α

G

12

δ

从受力分析 Gsinα = τA

mg sinα = τA

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | *mg*sin *α* | | |  |  | 5 |  |
| τ = | | | *A* | |  | =3.59.81 13 /(404610-4) = 71.77 N/m2 | | |
|  | *dv* | |  | *V* | |  |  |  |
|  |  |  |  |  |  |  |  |  |

τ =  *dy* =  *δ* *τδ*



= *V* = 71.771.510-3/1.2 = 0 0897 Pa s

13．以压缩空气将某液体自储槽压送到高度 H=5.0m、压强 p2 为 2.5at（表压）的容器内，[如图](file:///C:\I\chapter1image1-13.jpg)。已知液体密度ρ=1800kg/m3，流体的流动阻力为 4.0J/kg。问：所需的压缩空气压强 p1 至少为多少 at（表压）？

解： *H* 5.0 *m*, *P*22.5 *at*(表）,*ρ* 1800 *kg*/ *m*3

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ∑ | | | *h* | *f* |  4.0 | |  |  | 1 | |  |  |  |
|  |  |  |  | *J* / *kg*, *P* ? | | | |  |  |  |
|  | *P* | |  |  |  |  | *P* | | *u*2 | | *u*2 | |  |
|  | 1 |  | |  | *gH*  |  | 2 |  | 2 | ∑ *hf* (略去 | 2 | ) |  |
|  |  |  |  | 2 | 2 |  |
|  | *ρ* | |  |  |  |  | *ρ* | |  |  |  |

*P*(表)1800(9.815.02.59.811044.0)



1

1800

* 3.407 105 *Pa*

14．水以 70m3/h 的流量流过倾斜的异径管通。[如图](file:///C:\I\chapter1image1-14.jpg)。已知小管内径 dA=100mm，大管内径 dB=150mm，B、A 截面中心点高度差 h=0.3m，U 形压差计的指示液为汞。若不计 AB 段的流体流动阻力，试问：U 形压差计哪一支管内的指使液液面较高？

1. 为多少？

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | ( *P* ) | |  | *U*2 | | | |  | ( *P* ) | | *B* |  |  |  | *U*2 | | | |  |  |  |  |  |  |  |  |
| 解： *m* | | | *A* |  | *A* | |  |  |  | *m* |  |  |  | *B* | | | − − − ① | | |  |  |  |  |  |  |
| 2 |  |  |  | *ρ* |  | 2 | |  |  |  |  |  |  |  |
|  |  | *ρ* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ( *Pm*) *A* − ( *Pm*) *B*  ( *ρi* − *ρ*) *gR*− − − −② | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |
| *UA*  | |  | 70 / 3600 | | | | |  |  |  2.48 *m*/ *s* | | | | | | | | | *UB* | | 70 / 3600 | | |  |  1.10 *m*/ *s* |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| ( *π* / 4)(0.15) | | | | | | 2 | | ( *π* / 4)(0.15) | | 2 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | （ *ρ* | | | *i* − *ρ*) *gR* | | | | | | |  |  | *U*2*B* − *U*2*A* | | | |  |  |  |  |  |  |
| 由①，②式得 | | | | | |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | |  |  | *ρ* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 | | | |  |  |  |  |  |  |  |  |
| （13.6 −1.0) 10 | | | | | | | | 3  9.81 *R* | | | | | | | 1.102 | | | | − 2.482 | | | | |  |  |  |
| 即 |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | |  |  | 103 | | |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

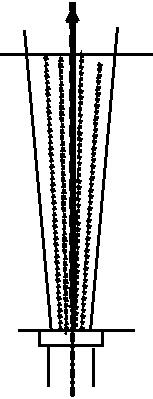


*R* −0.020 *m*,可见，左支管内指示液位比右支管内的高。

15．水以 6.4×10-4m3/s 的流量流经由小至大的管段内。[如图](file:///C:\I\chapter1image1-15.jpg)。小管内径 d1=20mm，大管内径 d2=46mm。欲测 1、2 两截面处水的压差，为取得较大的读数 R，采用倒 U 形压差计。已知压差计内水面上空是ρ=2.5kg/m3 的空气，读数 R=100mm。求水由 1 至 2 截面的流动阻力∑hf。

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 解： *U*1 | |  |  |  | 6.4 10−4 | | | | | |  |  |  2.037 *m*/ *s* | | | |  |  |  |
| ( *π* / 4)(0.020)2 | | | | | | | | | |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| *U*2 |  | 6.4 10−4 | | | | |  |  |  0.385 *m*/ *s* | | | | | | | |  |  |  |
| ( *π* / 4)(0.046)2 | | | | | | | |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| ( *P* ） −（ *P* ) | | | | 1 | |  ( *ρ* | *i* | − *ρ*) *gR*  (1000 − 2.5)  9.81 0.10  978.5 *Pa* | | | | | | | | | | |  |
| *m* 2 |  | *m* | |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ∑ *hf* |  | ( *P* ) | | | 1 | − ( *P* ） | | | | |  | *U*2 | | | − 978.5 | | 2.0372 − 0.3852 |  1.02 *J* / *kg* |  |
|  |  | *m* |  | *m* | | | 2 |  |  |  | 1 |  |  |  |  |  |
|  |  |  |  | *ρ* |  |  |  |  | *U*2 | | 10 3 | 2 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |

16．水从喷嘴口 1-1 截面垂直向上喷射至大气。[如图](file:///C:\I\chapter1image1-16.jpg)。设在大气中流束截面保持圆形，已知喷嘴内直径 d1=20mm，出喷嘴口水流速 u1=15m/s。问：在高于喷嘴出口 5m 处水流的直径是多大？忽略摩擦阻力。



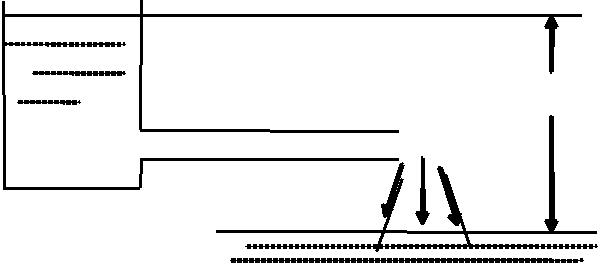
|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 解：1--1 与 2--2 之间列柏努利方程 | | 2 | 2 |  |
| gz1＋u12/2＋p1/ρ = gz2＋u22/2＋p2/ρ | |  |  |  |
| z1 = 0，z2 = 5m，p1 = p2 | |  |  |  |
| u12/2 = gz2＋u22/2 | |  |  |  |
| 152/2 = 9.81×5＋u22/2 | | 1 | 1 |  |
| u2 = 11.26m/s | |  |  |  |
| 又 | ， | u1d12 | = | u2d22 |
| 习题 16 附图 | |  |  |  |
| d2 | = (u1/u2)1/2d1 = 15 / 1126. 0.020 = 0.0231 m | |  |  |



17．高、低水库的水面高度差 H=42m，水流量为 30m3/s，水流的总阻力为 4.5mH2O。

[如图](file:///C:\I\chapter1image1-17.jpg)。已知透平的效率η=0.78，试计算透平的输出功率。

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 解：u1=u2=0，p1=p2，z2=0， | 1 | 1 |  |  |  |  |
| z1=H=42m |  |  |  |  |  |  |
| 1--1 与 2--2 间列柏努利方程 |  |  |  |  | H |  |
| gz1u12/2p1/ρWs = gz2u22/2p2/ρΣhf | |  |  |  |  |  |
|  |  |  |  |  |
| Ws =－gz1Σhf |  |  |  |  |  |  |
|  |  |  |  |  |  |
| =－9.8142＋4.59.81103/103 |  | 2 | 2 | | |  |
| =－368 J/kg |  |  |  |  |  |  |
| Na = Ws Vρ =－36830103=1.10107 W | |  |  |  |  |  |
| Ne= Na η = 1.101070.78=8.61106 | | W=8.61103 | kW | | |  |



18．某水溶液在圆直、等径管内层流动。管内半径为 R。设测点流速的探针头位

置与管轴线的距离为 r。问：测点相对位置 *r*1 / *R*为多少时该点的点流速等于平均流速？

解：一般式： *V*  *V*max[1−( *r*/ *R*)2]

* + - *r*1/ *R*时， *V*1 *U*  *V*max/ 2
  + *V*max/ 2 *V*max[1−( *r*1/ *R*)2]

*r*1/ *R*  2 / 2  0.707



19．以水平圆直管输送某油品。管内径为 d1，管两段压差为 。因管道腐蚀 ，拟更换管道。对新装管道要求如下：管长不变，管段压降为原来压降的 0.75，而流量加倍。设前后情况流体皆为层流。问：新管道内径 d2 与原来管内径 d1 之比为多少？

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 解：层流∆ *P* 32 | | | |  | *ul* | |  | | *v* |  |
|  |  |  | *d*4 |  |
|  |  |  |  |  | *d*2 | | |  |  |
| Q | ∆ *P*2 |  0.75  | *V*2 |  |  ( | *d*1 | | )4 | |  |
| ∆ *P* | *V* |  |  | |  |
|  |  |  |  |  | *d* |  |  |  |
| 1 | | 1 | | 2 | | | |  |  |  |

*d*2  1.28 *d*1



20．在机械工程中常会遇到流体在两平行固体壁的间隙中作一维定态流动的情况。[如图](file:///C:\I\chapter1image1-20.jpg)。设流动为层流。设间隙厚为 2y0，试证流体沿 y 轴向点流速呈如下抛



物线规律分布：

解：对长度 L，高度 y，宽度为 1 的流体元作受力与运动分析:

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ( | − *dPm* | ) *Ly*− (− ** | *dV* | *L*)0 | 即： *dV* ( | *dPm* | ) | 1 | *ydy* |  |
| *dx* |  |  |  |  |
|  |  | *dy* | |  | *dx * | | | |  |

*V* −1(− *dPm* ) *y*  *C*



** *dx* 2

1 − *dP*

又 *y*  *y* , *V* 0, *C*  ( *m* )( *y*2− *y*2)



0 0

** *dx*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 1 | |  | − *dPm* | 2 | 2 |  |
| *V*  |  | ( |  | )( *y* | − *y* ) |  |
|  |  |  |
| 2 ** | | | *dx* | 0 |  |  |
|  |  |  |

21．粘度为μ，密度为ρ的液体沿铅垂向平壁膜状流下。[如图](file:///C:\I\chapter1image1-21.jpg)。设液体层流流动 ，液膜厚度为δ，平壁宽度为 B。试推导任一流动截面上液体点流速 v 随 y 的变化

*ρ gδ*3



规律，并证明平均流速 3 **

解：取宽为 B,长为 dx ,高为 y 的流体元作受力与运动分析:

*dV*

( *B dx y*) *ρ* *g* − (− ** *B dx*)0



即: *dV*  − *ρ* *g* *ydy*.*V*  − *ρ* *g* *y*2 *C*



* ** 2

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 又 *y*  *δ*, *V* 0, *C*  | | | | | | *ρ g* | *δ*2 | *V*  | | *ρ g* | | | | ( *δ*2 − *y*2 ) | | | |  |  |  |  |
|  |  |  | | |  |  |  |  |
|  |  |  |  |  | 2 ** | |  | 2 ** | | | | |  |  |  |  |  |  |  |  |  |
|  | *ρ gB* | |  | 2 | 2 | |  |  | *ρ gB* | | |  | 3 | |  | *δ*3 | | *ρ gB* | | 3 |  |
| *dV*  *V B dy*  |  |  | ( *δ* |  | − *y* ) *dy V*  | | | |  | |  | ( *δ* |  |  | − |  | )  |  | *δ* |  |  |
|  |  |  | |  |  |  | 3 ** |  |  |
| 2 ** | |  |  |  |  |  |  | 2 ** | | |  |  |  |  | 3 | |  |  |  |  |

*U*  *Vm*  *ρ gδ*3



*Bδ* 3 **

22)串联两管 1、2，d1=d2/2，L1=80m，Re1=1600，Σhf1 = 0.54m 液柱，Σhf2 = 56mm 液柱，求 L2。局部阻力可略。

4*Vρ* 1



解： ∵Re = *πd* *d* ，Re,2/ Re,1= d1/ d2=1/2，



Re,2 = Re,1 /2 = 1600/2 = 800，两管内皆为层流

*π*



又，Σhf = 32ul / (ρgd2) 32Vl / ( 4 d2ρgd2) l/d4 Σhf,2 /Σhf,1 = (d1/d2)4l2/l1 即 56/540 = (1/2)4l2/80 l2 = 133 m

23)原 ρ1=920kg/m3，1=1.30P，现 ρ2=860kg/m3，2=1.15P，层流，W2/W1=1.30求：∆pf1/∆pf2。局部阻力不计。

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *π* | | | | *W* | | |  |  |
|  |  |  |  |  | *ρ* |  | |  |  |
| 解：层流，∆pf = 32ul / d2= 32Wl / ( 4 d2d2) | | | | |  |  |
|  | | | 115. |  |  | | 920 |  |  |
| ∆pf,2 / ∆pf,1 = (2/1)(W2/W1)(ρ1/ρ2) = 130. 1.30 860 | | | | | | | | = 1.23 |  |

24) 24) 某牛顿型流体在圆、直、等径管内流动，在管截面上的速度分布可

表达为 v=24y−200y2，式 中 ：y 截面上任一点至管壁的径向距离，m；v该点的点流速，m/s。试求：(1)管半径中点处的流速。

(2)管壁处的剪应力。该流体的粘度为 0.045Pa s。

解：若为层流，v = vmax[1－(r/R)2] = vmax[(R2－r2)/ R2] = vmax(R－r)(R+r)/R2

= vmaxy(2R－y) / R2 = 2 vmaxy /R－vmaxy2/R2可见，该流型为层流

∵2vmax / R = 24，vmax / R2 = 200，二式相除，得 (vmax / R2) / (2vmax / R) = 1/(2R) = 200/24 R = 0.06m

i . y = 0.06/2 = 0.03m，v = 24y－200y2 = (240.03)－(2000.032) =0.54m/s

1. dv/dy = 24－400y , dv/dy y=0 = 24

τw = ( dv/dy )y=0 = 0.04524 = 1.08 N/m2

1. W= 35T/h，H= 20m，ϕ1084mm， = 2840cP，ρ = 952kg/m3，η = 50%， N= 85kW，求包括局部阻力当量管长的总管长。

解： W = 35T/h = 35103kg/h

d = 108－42 = 100mm = 0.1m ， = 2840cP = 2 84Pa s Ne = Nη = 851030.5 = 4.25104 W

Ws = Ne/W = 4.251043600/(35103) = 4371 J/kg 1--1 与 2--2 间列柏努利方程

gz1+u12/2+p1/ρ+ Ws = gz2+ u22/2+p2/ρ+Σhf

z1 = 0，z2 = H = 20m，u1= u2= 0，p1= p2

Ws = gH+Σhf

Σhf = Ws－gH = 4371－9.8120 = 4175 J/kg

*V* *W* *π*



u = *A*= *ρA* =35103/ (3600952 4 0.12) = 1.30 m/s

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | *duρ* | | | | 010.  130.  952 | | | | | | |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |
|  |  | **= | | | |  |  |  |  |  |  |  |  | |  |  |
| Re = | |  |  |  | 2.84 | | | = 43.6  2000 | | | 层流 |  |
|  | 64 |  | 64 | | |  |  |  |  |  |  |  |  |  |  |  |
| λ= Re = 436. = 1.47 | | | | | | | | | | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  | *l*Σ *le* | | | |  |  |  |  |  |
| ∵Σhf = λ | | | | | |  |  | *d* |  |  | u2/2 |  |  |  |  |  |
|  |  |  |  |  | Σ *hf d* | | | | | | | 4175  010. | |  |  |  |
| *l* Σ *le*= | | | | |  |  |  | *λ* |  | 2/u2 = | | 147. | | 2/1.302 | = 336 m |  |

26．某有毒气体需通过一管路系统。现拟用水在按 1/2 尺寸缩小的几何相似的模型管路系统中做实验予估实际气流阻力。实际气体流速为 20.5m/s，密度为1.30kg/m3，运动粘度为 0.16cm2/s。实验用水的密度为 1000kg/m3，运动粘度为

0.01cm2/s。为使二者动力相似，水流速应为多少？若模型实验测得流动阻力为

15.2J/kg，实际气体的流动阻力是多少？

欲满足动力相似，必须 Re,其=Re,水，设气体管径为 d,

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | *d*20.5 | | | |  |  | （ *d*/ 2) *U*水 | | | | | | |  |  |  |  |  |  |
| ( | |  |  |  |  | )气 （ | | | |  |  |  |  |  | )水 | *U*水2.56 *m*/ *s* | | | |  |
|  |  |  |  |  | 0.01 | | |  |  |
| 即 0.16 | | | | |  |  |  |  |  |  |  |  |  |
| 动力相似，必 *E* | | | | | | | |  |  |  |  *E* | |  | ， *E*  | | ∆ *Pm* |  | ∑ *hf* |  |  |
|  | 气 | |  |  |  |  |
|  |  |  |  |  |  |  | *U*, | |  | *U*, | 水 | | *U* | *ρU*2 |  | *U*2 | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | *h* | | |  |  | 15.2 | | | | |  |  |  |  |  |  |  |  |  |
| 即( | ∑ | | *f* | ) |  |  ( | )水 |  | ∑ *hf* ,气974.7 *kJ* / *kg* | | | | | |  |
|  | | 2 | 气 | 2 | | | | |  |  |
| 20.5 | | |  |  |  | 2..56 | | | | | |  |  |  |  |  |  |  |  |  |

27．某实验室拟建立流体通过圆直、等径管内的阻力测试装置，有两个方案，一个方案是采用 20℃清水为工质，水流速不超过 3.0m/s；另一方案以 p=1atm、20

℃空气（按干空气计）为工质，流速不超过 25.0m/s，要求最大 。问：两方案需要的管内径各为多少？若管子绝对粗糙度皆为 0.1mm，二者管长与管内径之比都是 150，采用以上算得的管径（需按无缝钢管选接近的规格），问：二者最大流速时管路阻力各为多少？

①方案一： *ρ*  1000 *kg*/ *m*3 , **  1*CP*, *u*  3.0 *m*/ *s*

*Re*  105  *d*3.01000 *d* 0.0333 *m*



0.001

采用 *ϕ*36 1 *mm*,无缝钢管 ， *ε*/ *d*  0.1/ 34  2.94 10−3

1.  3.0 *m*/ *s*时 ， *Re*  0.034  3.0 103 /10−3  1.02 105 查得 *λ*  0.0274

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ∑ *hf* | *λ* | 1 |  | *u*2 |  0.0274 150  | 32 |  18.4 *J* / *kg* |  |
| *d* 2 | | |  |  |
|  |  | 2 | |  |  |

②方案二： *ρ*  1.205 *kg*/ *m*3 , **  1.8110−5 *Pa s*, *u*  25 *m*/ *s*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *R* 105 |  | *d*251.205 | *d* 0.060 *m* |  |
|  |  |
| *e* |  | 1.8110−5 | |  |
|  |  |  |

采用 *ϕ*68  3 *mm*,无缝钢管， *ε* / *d*  0.1/ 62  1.6110−3

1.  25 *m*/ *s*时， *Re*  0.062  25 1.205 /(1.8110−5 )  1.03105 查得 *λ*  0.024

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | ∑ *hf*  *λ* | | | | | | | | 1 | |  | *U*2 |  0.024 150  | 252 | |  1125 *J* / *kg* | | |  |  |  |  |
|  |  | |  |  | |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | *d* 2 | | |  |  | 2 |  |  |  |  |  |  |  |
| 28．试证明流体在圆管内层流时，动能校正系数 | | | | | | | | | | | | | | | | | | | 。 |  |  |  |
|  |  |  | 1 |  |  | ∫ |  | 3 | |  |  |  |  |  |  |  |  | 2 |  |  |  |  |
| 解： *α*  | | |  |  |  | *V* |  |  | *dA*LL( *A*− −流动面积， *A* *πR* ) | | | | | | | | |  |  |  |  |
| 3 | *A* | |  |  |  |  |  |  |
|  |  |  | *U* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 层流： *V*  *V* | | | | | |  | [1 − ( *r*/ *R*)2 ], *U*  *V* / 2 | | | | | | | |  |  |  |  |  |  |  |  |
|  |  |  |  | max | | |  |  |  |  |  |  | max | |  |  |  |  |  |  |  |  |
| *α*  | 1 |  |  | {*V* | | |  | [1 − ( *r*/ *R*)2 ]}3 2*πrdr*  | | | | | | |  | 3 |  | [1 − ( *r*/ *R*)2 | | ]3 | *rdr* |  |
|  | *R* |  | 2 *πV*max | | *R* |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *U*3 *A*∫0 | | |  |  | max | |  |  |  |  |  |  |  | *U*3 *A* ∫0 | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |



|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 令 *r*/ *R* sin *θ*,则1−( *r*/ | | | | | | | | | | | | | | | | | | | | | | | | | *R*)2 | | | |  *Cos*2 *θ*,当 *r* 0, *θ* 0; *r*  *R*, *θ*  *π* / 2 | | | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  | 3 |  |  |  |  |  |  |  |  | *Cos*6 | | | | *θ*( *R*sin *θ*)( *RCosθ* *dθ*) | | | | | | | | | | | | | |  |  |
| *α*  2 *πV*max | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | *π* / 2 | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  | | |  | ∫0 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | *U*3 *A* | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 2 *πV*max3 *R*2 | | | | | | | | | | | |  |  | *π* / 2 | | |  |  |  |  |  |  | 7 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | ∫0 | |  |  | − *Cos θ dCosθ* | | | | | | | | | | | | | | | | | |  |  |  |  |  |
|  |  | *U* | | 3 | |  | *A* | | | |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 其中∫ | | | | | | |  | *Cos*8 *θ* | | | | | | | |  |  | 0 | | |  |  |  1/ 8 | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | 8 | | |  |  | *π* / 2 | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  | 2 *π*(2*U*)3 *R*2 | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *α*  | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  2 | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | 8*U* | | | | | | 3 | *π* | | |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | *R* | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 29．试按 | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 规律推导湍流的 | | | | | | | | | 值。 |  |
|  |  |  |  | *R* | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | *R* |  |  |  |  |  |  | 1 | |  |  |  |
| *VS* ∫0 | | | | |  |  | *V*2 *π rdr* 2 *πV*max∫0 | | | | | | | | | | | | | | | | | | | | | | |  |  | (1 − *r*/ *R*) 7 *rdr* | | | | | | |  |  |
| 令1 − *r*/ | | | | | | |  | *R*  *x*, *r*  *R*(1− *x*）， *dr* − *Rdx* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 0 | | 1 | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | | |  |  |
| *VS* | | |  2 *πV*max ∫1 | | | | | | | | | | | | | | | *x* 7 *R*(1− *x*)(− *Rdx*)2 *πR*2 *V*max∫0 | | | | | | | | | | | | | | | | | | | | | ( *x*1/ 7 − *x*8 / 7) *dx* |  |
|  |  |  |  |  |  |  | 7 | | | |  |  | 8 / 7 | | |  |  | 7 | | | |  |  | 15 / 7 | |  | 1 | |  | 7 7 | | | | | | 49 | |  |  |  |
| 其中∫ [ | | | | | | | | |  |  |  | *x* | | | |  | − | |  |  | |  | *x* | |  | ] | 0 | |  |  |  |  | − | |  |  |  |  |  |  |
| 8 | |  | 15 | | |  | 8 | 15 | 120 |  |  |
| 则 | | *U* | | |  |  |  | | |  |  |  |  | *VS* | | | |  |  |  | | |  | 2  49 | | | |  |  |  | 49 | | |  |  |  |  |  |  |  |
| *V* |  |  |  |  | *πR*2 *V* | | | | | | | |  | |  | 120 | | |  |  | 60 | | | |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | max | | |  |  |  |  |  |  |  |  |  |  |  |  | max | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |



30．某牛顿型流体在圆、直、等径管内流动，管子内半径为 50mm。在管截面上

的流速分布可表达为 ，式中：y——截面上任一点至管壁的径向距离，m；v——该点的点流速，m/s。试求：（1）流型；（2）最大点流速 vmax。

|  |  |  |
| --- | --- | --- |
|  | *R*− *r* | |
| 解：设 v = vmax (1－r/R)1/6= vmax( | *R* | )1/6 = (vmax/R1/6) y1/6，故该流型为湍流 。 |
| 又 ∵vmax/R1/6 = vmax/(0.050)1/6 | = 2.54vmax = 1.54 m/s | |

31．某直管路长 20m，管子是 1”普通壁厚的水煤气钢管，用以输送 38℃的清水 。新管时管内壁绝对粗糙度为 0.1mm，使用数年后，旧管的绝对粗糙度增至 0.3mm，若水流速维持 1.20m/s 不变，试求该管路旧管时流动阻力为新管时流动阻力的倍数。

解：①新管： *Re* 0.0271.20992.9 /(0.681410−3)4.72104

*ε* / *d*  0.1/ 27  3.70 10−3 ,查得 *λ*  0.041

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| ∑ *hf* |  0.0296 | 20 |  | 1.202 |  15.8 *J* / *kg* |  |
|  |  |  |
|  | 0.027 | | 2 | |  |  |

②旧管 : *Re*  4.72 104 , *ε* / *d*  0.3 / 27  0.011.查得 *λ*  0.041

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| ∑ *hf* |  0.041 | 20 |  | 1.202 |  21.9 *J* / *kg* |  |
|  |  |  |
|  | 0.027 | | 2 | |  |  |

旧管阻力/ 新管阻力  21.9 /15.8  1.39

32．某流体在光滑圆直管内湍流流动，设摩擦系数可按布拉修斯公式计算。现欲使流量加倍，管长不变，管内径比原来增大 20%，问：因摩擦阻力产生的压降为原来的多少倍。

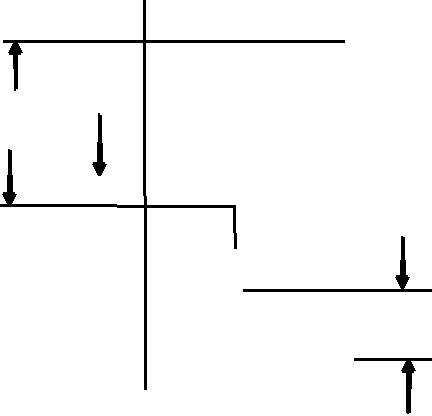
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 解：∑ *hf*  | 8 *λ* | | *lV*2 | | | | 0.3164 | | |  | 8 *lV*2 | | | | | *V*1.75 | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *π* | 2 | *d* | 5 |  | 4*Vρ* |  | 0.25 | *π* | 2 | *d* | 5 | *d* | 4.75 |  |
|  |  |  | ( | | ) |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

*π d*

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 当 *V* 2*V* , *d* | |  1.2 *d* .则 | ∑ *hf* 2 |  ( | *V*2 | )1.75 ( | *d*1 | )4.75  |  | 21.75 |  1.41 |  |
| ∑ *hf*1 | *V*1 | *d*2 | 1.24.75 | |  |
| 2 | 12 | 1 |  |  |  |  |  |

33．[如图所示](file:///C:\I\chapter1image1-33.jpg)，某液体在光滑管中以 u=1.2m/s 流速流动，其密度为 920kg/m3，粘度为 0.82cP。管内径为 50mm，测压差管段长 L=3m。U 形压差计以汞为指示液。试计算 R 值。

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1 |  | 1 |  |  |  |
|  |  |
| L |  |  |  |  |  |
| 2 |  | 2 |  |  |  |
|  |  |  |  | R |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
| 习题 33 附图 | |  |  |  |  |
|  |  |  |  |
|  |  |  |  |
| 解：在 1--1 与 2--2 间列柏努利方程： | | | | |  |
| gz1+u12/2+p1/ρ = gz2+ | | u22/2+p2/ρ+Σhf 或(pm,1 －pm,2)/ρ = Σhf (u1= | | |  |



u2)

*l*



(ρi－ρ)gR/ρ = (0.3164/Re0.25) *d*  u2/2

*duρ*



其中 Re = **= 0.051.2920/(0.8210-3) = 6.73104

则(13.6-0.92)1039.81R/920=[0.3164/(6.73104)0.25](3/0.050)(1.22/2) R = 6.2810-3 m

34．有一高位水槽，其水面离地面的高度为 H。[如图](file:///C:\I\chapter1image1-34.jpg)。水槽下面接有 2”普通壁厚水煤气钢管 130m 长，管路中有 1 只全开的闸阀，4 只全开的截止阀，14 只标

* 90°弯头。要求水流量为 10.5m3/h，设水温 20℃，ε=0.2mm，问：H 至少需多少米？

解：管子规格： *ϕ*60  3.5 *mm*, *d*  53 *mm*

1.  10.5 / 3600  1.32 *m*/ *s*, *Re*  0.0531.32 103 / 0.001  7.0 104 *π* (0.053)2



4

*ε* / *d*  0.2 / 53  3.77 10−3，查得 *λ*  0.0292

截止阀（全开） *ξ*＝6.4， le＝17m

闸 阀（全开） *ξ*＝0.17， le＝0.34m

900 标准弯头 *ξ*＝0.75， le＝1.6m

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 突然缩小（ *A*小/ *A*大≈0） | | | | | | *ξ*＝0.5 | | | |  |  |  |  |  |  |  |  |  |  |
| 1.32 | | | | 2 |  |  |  |  |  | 130  0.34  4 17 14 1.6 | | | | |  | 1.322 |  |  |  |
| 方法一：g *H*  1.5  | |  |  |  |  0.0292  | | | | |  |  |  |  |  |  |  |  |  |  |
|  |  |  | 0.053 | | | | | 2 |  |  |  |
| 2 | | | |  |  |  |  |  |  |  |  |  |  |
| *H* 10.93m | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 130 | | | | | | 1.32 | | 2 |  |  |  |  |  |  |  | 1.322 | | |  |
| 方法二：g *H*  0.0292 | | |  |  |  |  |  |  | ＋（0.17  4  6.4  14  0.75＋1.5） | | | | | | | |  | |  |
|  |  |  |  |  |  | |  |
| 0.053 | | | | | | 2 | |  |  |  |  |  |  |  |  | 2 | | |  |
| *H* 9.71m | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 35．承第 34 题，若已知 H=20m，问水流量多少 m3/h？ | | | | | | | | | | | | | | | |  |  |  |  |
| 解：设 *λ*  0.029 | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 130  0.34  4  17 14 1.6 | | | | | | | | | | | |  | *U*2 | | |  |  |  |  |
| 9.81 20  (1.5  0.029 |  |  |  |  |  |  |  |  |  |  | | ) |  | , *U*  1.79 *m*/ *s* | |  |  |  |  |
|  |  |  |  |  | 0.053 | | | |  | | 2 |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

*Re* 0.0531.79103/ 0.0019.49104, *ε* / *d* 0.2 / 533.7710−3.查得 *λ* 0.029

所设 *λ*正确，计算有效。 *V*  *π* (0.053)21.79360014.2 *m*3/ *h* 4



36．有两段管路，管子均为内径 20mm、长 8m、绝对粗糙度 0.2mm 的直钢管，其中一根管水平安装，另一根管铅垂向安装。若二者均输送 20℃清水，流速皆为 1.15 m/s。竖直管内水由下而上流过。试比较两种情况管两端的额修正压强差与压强差。要用计算结果说明。

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 解：R *e*  0.020 1.15 10 | | | | | | 3 | / 0.001 |  2.3104 , *ε* / *d*  0.2 / 20  0.01,查得 *λ*  0.0405 |  |
| ∑ *hf* 0.0405 |  | 8 | 1.15 | | | 2 |  10.7 | *J* / *kg*（与管向无关） |  |
|  |  |  |  | 2 |  |  |
| 0.020 | | |  |  |  |  |  |  |
| ①水平管： *P* | | − *P* |  |  |  *P* − *P* | | |  |  |
| *m*,1 | | *m*,2 | | |  | 1 | 2 |  |  |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *Pm*,1 | |  | *U*2 | | |  | *Pm*,2 | |  | *U*2 | | |  |  |  |  |  |  |  |
| Q |  |  |  |  | 1 |  |  |  |  |  |  | 2 | ∑ *hf* L(*U*1 *U*2) | | | |  |  |  |  |
|  | *ρ* |  |  |  | *ρ* |  | 2 |  |  |  |  |
|  |  | 2 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *P* | | | − *P* | |  |  |  *P* − *P*  *ρ* | | | | | | | *h* |  1000 10.7  1.07  1.07 10 | | | 4 *P* |  |  |
|  |  | *m*,1 |  | *m*,2 | | |  |  | 1 | 2 |  |  | ∑ | *f* |  |  |  | *a* |  |  |
| ②铅垂管。流体向上流动： | | | | | | | | | | | | | | |  |  |  |  |  |  |
| *P* | | − *P* | | |  1.07 104 | | | | | | | *Pa*LL(计算同①） | | | | |  |  |  |  |
| *m*,1 | |  | *m*,2 | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Q *P* | | | − *P* | |  |  |  ( *P*  *ρ* *gZ* ) − ( *P*  *ρ* *gZ* ) | | | | | | | | | |  |  |  |  |
|  |  | *m*,1 |  | *m*.,2 | | |  |  | 1 |  |  | 1 | |  | 2 | 2 |  |  |  |  |
| *P* − *P* ( *P* | | | | | | | | | − *P* | | | )  *ρ* *g*( *Z* − *Z* )  1.07 104 | | | | | 103  9.81 8  8.92 104 | | *Pa* |  |
| 1 | | | 2 |  |  |  | *m*,1 | |  | *m*,2 | |  |  |  | 2 | 1 |  |  |  |  |

37．有 A、B 两根管道并联。已知：lA=8m，dA=50mm，lB=12m，dB=38mm（上述 l 中包含了局部阻力，d 指内径）。流体工质是常压、20℃的空气（按干空气计）。总流量是 200kg/h。问：B 管的质量流量是多少？分支点与汇合点的局部阻力可略。ε皆为 0.2mm。

[解]空气： *ρ*  1.205 *kg*/ *m*3 , **  1.8110−5 *Pa s*

*A*管： *ε*/ *dA* 0.2 / 500.004,在阻力平方区， *λA* 0.0285

*B*管： *ε*/ *dB* 0.2 / 385.2610−3,在阻力平方区， *λλB* 0.031

* *λA*  0.0285, *λB*  0.031



|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *W* | |  |  | *d*5 | *λ l* | | | *B* | (50 / 89)5  0.03112 | | | |  |  |  |  |  |  |  |  |
|  | *A* |  |  |  | *A* |  | *B* |  |  |  |  |  |  2 54 | | | | |  |  |  |
|  | *W* | | *d*5 | *λ* | *A* | *l* | *A* |  |  | 0.0285  8 |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *B* | |  |  | *B* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *WA* 200(2.54 / 3.54）143.5 *Kg*/ *h* | | | | | | | | | | | | | |  |  |  |  |  |  |  |
|  | *R* | |  | 4 143.5 / 3600 | | | | | | | |  |  5.61 10 4 , *ε*/ *d*  0.004,查得 *λ*' | | | | | |  0.0302 | |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  | *e*, *A* | |  | *π*  0.050 1.8110−5 | | | | | | | | |  |  |  |  |  | *A* |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *WB* 200−143.556.5 *kg*/ *h* | | | | | | | | | | | | | |  |  |  |  |  |  |  |
|  | *R* | |  | 4  56.5 / 3600 | | | | | | | |  |  2.91104 , *ε*/ *d* | | | *B* | |  5.26 10−3 ,查得 *λ*' | |  0.034 |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  | *e*, *B* | |  | *π*  0.038 1.8110−5 | | | | | | | | |  |  |  |  | *B* |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 再设 *λA*  0.0302, *λB*  0.034,算得 *WA* / *WB*  2.58 | | | | | | | | | | | | | | | | | | |  |  |  |
|  | *WA* 144 *Kg*/ *h*, *WB* 56 *kg*/ *h*, *Re*, *A* 5.6310 | | | | | | | | | | | | | | 4 | |  | ‘ |  |  |  |
|  |  |  | ,查得 *λ*  0.0302, | | |  |  |
|  | *R* | |  2.88 10 | | | | | 4 ,查得 *λ*' | | | |  0.034 | |  |  |  |  |  |  |  |  |
|  | *e*, *B* | |  |  |  |  |  |  |  |  | *B* |  |  |  |  |  |  |  |  |  |  |

因核算得的 *λA*, *λB*值与原设的一致，故 *WA*  144 *Kg*/ *h*, *WB*  56 *Kg*/ *h*

38．某水塔供水流程[如附图的 a)图所示](file:///C:\I\chapter1image1-38.jpg)，管长为 L。现需增加 50%的流量，拟采

* b)流程。b)流程中各管管径均与 a)流程的相同，其 L/2 管长为两管并联。设局部阻力不计，所有管内流体流动的摩擦系数λ值均相等且为常数。问：b)方案能否满足要求。

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 解：(*A*) *H*  | 8 *λlV*2 | ( *B*) *H*  | 8 *λ*(1/ 2)(*V* / 2)2 |  | 8 *λ*(1/ 2)*V*2 |  |
| *π*2 *gd*5 | *π*2 *gd*5 | *π*2 *gd*5 |  |
|  | 1 |  | 2 |  | 2 |  |

*V*121 *V*221 *V*22, *V*21.265*V*1



2 4 2

( *B*)不满足流量增加50 0 0 的要求。



39．某七层的宿舍楼，第四至第七层楼生活用水均来自房顶水箱。[如图](file:///C:\I\chapter1image1-39.jpg)。若总输

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 1 | 1 | '' |  | 1 | ' ' |  |
|  | 普通壁厚水煤气钢管，各层楼自来水支管为 2 | |  |
| 水管为 2 | |  | 普通壁厚水煤气钢 |  |

管。所用的阀皆为截止阀。水箱内水深 2m。有关尺寸示于附图。试计算：（1）只开七楼的阀且阀全开时，V7 为多少？（2）当四楼及七楼的阀都全开，五、六楼的阀全关，V4 及 V7 及各为多少？计算支管阻力时只计入局部阻力，直管阻力可略。设λ皆为 0.040。

解：总管为 *φ*48  3.5 *mm*, *d*总  41 *mm*.支管为 *φ*21.25  2.75 *mm*,

*d* 15.75 *mm*,全开阀门阀， *ζ* 6.4;突然缩小（ *A*小/ *A*大≈0），

*ζ*  0.5,三通（直入旁出）,*Le*  1.2 *m*;三通（直通）， *Le*  0.35 *m*

①只开七楼得阀：

总管 *U* (15.75 / 41)2 *U*70.1476*U*7

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1.2 | |  | *U*7 | | 2.2 |  | (0.1476*U* )2 |  |
| 9.81 4.2  (6.4  0.04 |  | 1) | 2 |  (0.5  0.04 |  | ) | 7 |  |
|  |  |  | 2 |  |
| 0.01575 | | 2 | |  | 0.041 | |  |

*U*72.81*m*/ *sV*75.4710−4 *m*3/ *s*

②只开四.七楼的阀 :

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  | 2.2 |  | 8(*V*  *V* )2 | | | | | |  |  |  |  |  |
| (9.8115.6) − (0.5  0.04 | | | | | |  |  |  | ) |  | 4 | | 7 |  |  |  |  |  |  |  |
| 0.041 | | | *π*2 (0.041)4 | | | |  |  |  |  |  |  |  |
|  |  | 1.2 |  |  |  |  |  | 8*V*2 | | | | |  |  |  |  |  |  |  |  |
|  (6.4  0.04 | |  |  | 1) | | | |  |  |  | 7 |  |  (9.8111.4) | | |  |  |  |  |  |
| 0.01575 |  | *π*2 (0.01575)4 | | | | |  |  |  |  |  |
| 11.4  3 0.35 | | | |  |  |  |  | 8*V*2 |  |  |  |  | 1.2 | | |  |  |  | 8*V*2 |  |
|  (0.04 |  |  |  | ) |  |  |  | 4 |  |  |  |  (6.4  0.04 | | |  | 1) |  |  | 4 |  |
|  |  |  | *π* | 2 | | (0.041) | | | 4 |  | *π* | 2 | 4 |  |
| 0.041 | | |  |  |  |  |  |  | 0.01575 | | |  |  | (0.01575） |  |

化简，得153.04 − 7.59 105 (*V*4  *V*7 )2

* 111.8 1.376 108 *V*72  1.411108 *V*42

经试差得： *V*41.03510−3 *m*3/ *s*, *V*75.34810−4 *m*3/ *s*

40．用离心泵将水由水槽送至水洗塔内。水槽敞口。塔内表压为 0.85at。水槽水面至塔内水出口处垂直高度差 22m。已知水流量为 42.5m3/h，泵对水作的有效功为 321.5J/kg，管路总长 110m（包括局部阻力当量管长），管子内径 100mm。试计算摩擦系数λ值。

解：1--1 与 2--2 间列柏努利方程：

gz1+u12/2+p1/ρ+Ws = gz2+ u22/2+p2/ρ+Σhf

z1= 0，z2= 22 m，u1= 0，p1(表)= 0

1. *π*

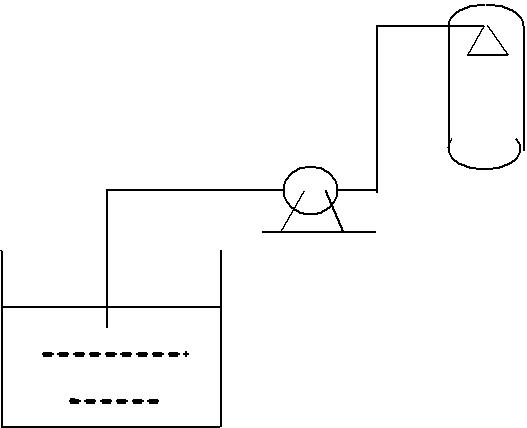


u2= *A*=42.5/(40.123600) = 1.50 m/s

p2= 0.85at = 0.859.81104 = 8.34104 Pa

Ws= gz2+u12/2+p2/ρ+Σhf 即 321.5= 9.8122+1.502/2+8.34104/103+Σhf Σhf = 21.2 J/kg

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *λ* | *l* *le* |  | *λ* | 110 |  |  |  |
|  |  | 01. 1.502/2 = 21.2 *λ*= 0.0171 | | |  |
| Σhf = |  | *d* u2/2 = | |  |  |
|  |  |  |  | 2 | | | 2 |  |

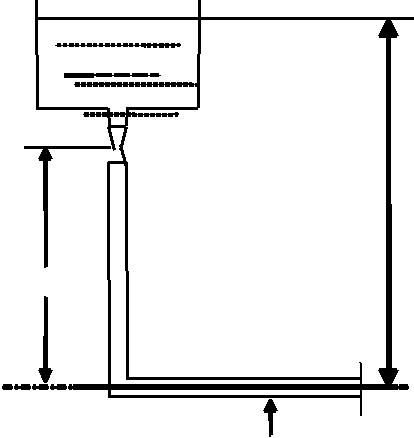


1 1

41．35℃的水由高位槽经异径收缩管向下流动。[如图](file:///C:\I\chapter1image1-41.jpg)。若不考虑流动阻力，为保证水在流经收缩管时不发生汽化现象，收缩管的管径应限制在多大尺寸以上？当地大气压为 1atm，35℃的水的密度为 994kg/m3，饱和蒸汽压为 5.62kPa。H=12m，h=8m，d=150mm（内直径）。

1. 1

2 2



H

d 3

3

习题 41 附图

解：1] “1--1”至“3--3”列柏努利方程 gz1+ p1/ρ+u12/2= gz3+ p3/ρ+ u32/2 ∵p1= p3，z3 = 0，u1 = 0

u3 =  2 *gz*1 =  2  9.81  12 = 15.3 m/s



2] “2--2”至“3--3”列柏努利方程

gz2+ p2/ρ+u22/2= gz3+ p3/ρ+ u32/2

2 截面刚液体汽化时，p2= 5.62kPa，则

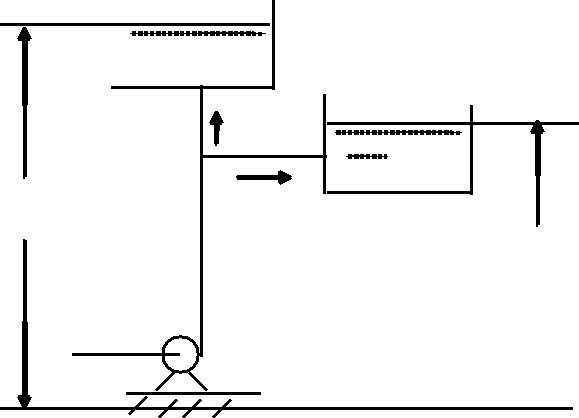
9.818+5.62103/994+u22/2 = 1.013105/994+15.32/2 u2 = 16.4 m/s

3] ∵u3d32 = u2d22 即 15.31502 = 16.4d22 d2 = 145 mm

42．[如附图所示](file:///C:\I\chapter1image1-42.jpg)，水泵抽水打进 B、C 水槽。已知各管内径相等，且 A—B 段、A —C 段和 OA 段（不包括泵内阻力）的管道长与局部阻力当量管长之和 

相等。设摩擦系数λ值皆相同，过程定态。求 。

C



水

VC

B

A

水

VB

8.0m 5.0m

O

|  |  |
| --- | --- |
|  | 习题 42 附图 |
| 解：由“A→B”与“A→C”可列下式 | |
| EA－EC = α VC2 |  |
| EA－EB = α VB2 | EC－EB = α (VB2－VC2) |
| 代入数据：9.81(8.0－5.0) = α (VB2－VC2) | |
| 即： | 29.4 = α (VB2－VC2)……(1) |
| 由“O→B”得 |  |



Ws= EB+ α (VC+VB)2+ αVB2

代入数据：150 = 9.815.0+ α (VC+VB)2+ αVB2

即： 101 = α (VC+VB)2+ αVB2 ……(2)

1. 



(2)/(1) ，得 29.4 [(VC+VB)2+VB2]/( VB2 － VC2)= [(VC/VB+1)2+1]/[1 － (VC/VB)2]

解得：VC/VB = 0.387

43．在φ108×4mm 的圆直管内用毕托管测点流速。已知管内流体是平均分子量

* 35 的混合气体，压强为 200mmH2O（表压），外界大气压为 1atm，气温为 32 ℃，气体粘度为 0.02cP。在测管轴心处 vmax 时，U 形压差计读数 R 为 10mm，压差计指示液为水。问：管内气体流量是多少 m3/h?

解： *ρ*  (0.20 103  9.81  1.013105 )  35  1.43 *kg*/ *m*3



|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 8314  (273  32) | | | |  |  |
| *V*  | 2( *ρi* − *ρ*) *gR* |  |  | 2(1000 −1.43)  9.81 0.010 |  11.7 *m*/ *s* |  |
|  |  |  |
| max | *ρ* | |  | 1.43 |  |  |
|  |  |  |  |



|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *R* |  | 11.7  0.10 1.43 |  8.37 104 ,查得 | *U* |  0.81 |  |
| 0.20 10−3 |  |  |
| max |  |  | *V* | |  |
|  |  |  |  | max | |  |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | *V*  | *π* |  0.12  9.48  3600  268 *m*3 / *h* |  |
| *U* 0.8111.99.48 *m*/ *s* |  |  |
| 4 | |  |  |

44．在内径为 50mm 的圆直管内装有孔径为 25mm 的孔板，管内流体是 25℃清水。按标准测压方式以 U 形压差计测压差，指示液为汞。测得压差计读数 R 为 500mm，求管内水的流量。



|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | *π* | 2 | 2(13.6 −1)  9.81 0.50 | | −3 3 |  |
| *V*  |  |  (0.025）  0.62 |  |  3.38 10 | *m* / *s* |  |
|  | 1 |  |
| 4 | |  |  |  |  |

*Re*1  4  3.38 10−3  997 1000  9.60 104 , *m*  0.25



*π*  0.050  0.8937

查的 *CO* 0.62,原设正确，计算有效。

45.某转子流量计，刻度是按常压、20℃空气实测确定的。现用于测常压下 15℃

的氯气，读得刻度为 2000 。已知转子的密度为 2600kg/m3，问：氯气流量多少？

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 1.013105  71 | | |  | 3 |  |
| 解： *ρc*12 |  |  |  |  |  3.0 *kg*/ *m* |  |
|  |  |  |  |
|  |  | 8314  (273 15） | | | |  |
| *V* 2000 | | | (2600 − 3.0)1.20 |  |  1264 *l*/ *h* |  |
|  |  |
| *r* |  |  | 3.0(2600 −1.20) | |  |  |
|  |  |  |  |  |



46．已知某容器的容积 V=0.05m3，内储压缩空气，空气密度为 8.02 kg/m3。[如图](file:///C:\I\chapter1image1-46.jpg)。在打开阀门时，空气以 285m/s 流速冲出，出口面积 A=65mm2。设容器内任一时刻空气性质是均匀的。外界大气密度为 1.2 kg/m3。求打开阀门的瞬时容器内空气密度的相对变化率。

[解] A U *ρ*0 *dt*  *V ρ*1 *dρ*

*dρ*  *AUρ*0  − 65 10−6  285 1.2  −9.7310−4



*dt* *Vρ*1 0.05  8.02

# 第2章流体输送机械

1）某盛有液体的圆筒容器，容器轴心线为铅垂向，液面水平，如附图中虚线所示。当容器以等角速度ω绕容器轴线旋转，液面呈曲面状。试证明：

①液面为旋转抛物面。

②。

③液相内某一点（r，z）的压强。式中ρ为液体密度。

解 题给条件下回旋液相内满足的一般式为

*P* *ρ gz*− *ρω*2 *r*2 *C*



1. （常量）

取圆柱坐标如图，当 Z=0,r=0,P=P0,∵C=P0

*ρω*2

*p* *ρ gz*− *r*2 *p*0



故回旋液体种，一般式为

* ① 液面为 P=P0 的等压面

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| *ρ gz*− | *ρω*2 | *r*2 |  0, *Z*  | *ω*2 |  | *r*2 |  |
|  | 2 *g* | |  |
| 2 | |  |  | ，为旋转抛物面 |  |

*H*  *ω*2 *R*2



* 2 *g*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 2 | *r* | *πω*2 | *r* 3 | *π ω*2 *R*4 |  |
| 又 *π R* | *h*0∫0 *Z*2*π rdr*  |  | ∫0 *r dr*  |  |  |
| *g* | 4 *g* |  |

*ω*2 *R*2



即：h0= 4 *g*

∴H=2h0

③某一点（r,Z）的压强 P:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *P*  *P* − *ρ gh* | *ρω*2 | *r*2 *P*  *ρ g*( | *ω*2 *r*2 | − *Z*) |  |
|  |  |  |
| 0 | 2 | 0 | 2 *g* |  |  |
|  |  |  |  |

2）直径 0.2m、高 0.4m 的空心圆桶内盛满水，圆筒定该中心处开有小孔通大气，液面与顶盖内侧面齐平，如附图所示，当圆筒以 800rpm 转速绕容器轴心线回旋，问：圆筒壁内侧最高点与最低点的液体压强各为多少？

*P* *ρ gz*− *ρω*2 *r*2 *C*



解 2

取圆柱坐标如图，当 Z=0,r=0,

P=P0 ,∴C=P0

*p* *ρ gz*− *ρω*2 *r*2 *p*0



2

故回旋液体种，一般式为

1. 点：

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | *ρω*2 | 2 | 1000 | |  | 800 |  | 2 | 2 | | |  |  |  |  |  | 4 |  |  |  |  |  |
|  | *P* − *P*  | | |  |  | *R*  |  |  | ( |  | 2*π*) |  |  0.1 | |  |  3.5110 | | | | |  | *Pa* |  |  |  |  |
|  | 2 | | 2 | | 60 |  |  |  |  |  |  |
| Z=0,r=R=0.1m, *B* | | 0 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | C 点:Z=- | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 0.4m,r=0.1m, | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | *ρω*2 | | 2 | |  |  |  |  |  |  |  | 1000 | |  | 800 | |  | 2 |  |  | 2 |  | 4 |  |  |
| *P* | − *P* − *ρ gZ*  |  |  | *r* −10009.81(−0.4) | | | | | | | | |  |  |  | ( |  | 2*π*) |  |  0.1 | | |  3.90 10 |  | *Pa* |  |
|  |  |  |  |  |  |  |  |  |
| *C* | 0 | 2 |  |  |  |  |  |  |  |  |  |  | 2 | |  | 60 | |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

3）以碱液吸收混合器中的 CO2 的流程如附图所示。已知：塔顶压强为 0.45at （表压），碱液槽液面与塔内碱液出口处垂直高度差为 10.5m，碱液流量为 10m3/h，输液管规格是φ57×3.5mm，管长共 45m（包括局部阻力的当量管长），碱液密

度，粘度，管壁粗糙度。试求：①输送每千克质量碱液所需轴功，J/kg。②输送碱液所需有效功率，W。

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  | *W* |  |  *gh* | | | *P* − *P* |  |  | *l* *l* | | *U* | 2 | *J* / *Kg* |  |
|  |  |  |  |  |  |  |  |  |  | 20 |  ( | *λ* | *e* | 1) |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | *S* | |  |  |  | *ρ* |  |  | *d* | | 2 | |  |  |
| 解 |  |  |  |  |  |  |  | ① | |  |  |  |  |  |  |  |  |
|  |  |  |  | 10 | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *U*  | |  | | 3600 | | | |  |  1.41*m*/ *s* | | | | | |  |  |  |  |  |  |  |  |
|  | |  | |  | |  |  |  |  |  |  |  |  |  |
|  |  |  | *π* | | | |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | (0.050) | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 4 | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *R*  | | | | | 0.050 1.411200 | | | | | | |  4.23 104 | | | |  |  |  |  |  |  |
|  |  | | | | | | |  |  |  |  |  |  |
|  |  |  | *e* | | | |  | 2 10−3 | | | |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *ε* |  | | | 0.2 | |  |  4 10 | | | −3 | | ,查得 *λ*  0.031 | | | |  |  |  |  |  |  |  |
| *d* |  |  |  | 50 | | |  |  |  |  |  |  |  |  |  |  |  |  |



|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *W* 9.8110.5 | | 0.45  9.81104 | |  (0.031 | 45 |  1) | 1.412 |  168.5 *J* / *Kg* |  |
|  |  | 0.050 |  |  |
| ∴ *S* | 1200 | | |  | 2 | |  |  |
| *W*  | 10 | | 1200 168.5  561.7*W* | | |  |  |  |  |
|  | |  |  |  |  |
| *S* | 3600 | |  |  |  |  |  |  |  |
| ② *Ne*  *VP* |  |  |  |  |  |  |  |

4）在离心泵性能测定试验中，以 2 泵汲入口处真空度为 220mmHg，以孔板流量计及 U 形压差计测流量，孔板的孔径为 35mm，采用汞为指示液，压差计读

数，孔流系数，测得轴功率为 1.92kW，已知泵的进、出口截面间的垂直高度差为 0.2m。求泵的效率η。

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *H* | |  |  |  ( *Z* − *Z* )  | | |  | *P* − *P* | | | | | 1.2  9.8110 | | | 4  220 133.3 |  15.2 *m* | |  |
| *e* | |  | 21 | |  0.2  | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
| 解 | |  | 2 | 1 |  | *ρ g* | | | | | 1000 | | |  9.81 |  |  |  |
|  |  |  |  |  |  |  |  |  |
| *V*  | *π* | | *d* | | 2 *C* | 2( *ρ* − *ρ*) *gR* | | |  | | *π* | (0.035)2  0.63 | | | 2(13.6 −1)  9.81 0.85 | | |  8.79 10−3 *m*3 / *s* |  |
|  | |  | | |  |  | | |  |
| 4 0 | | | | | 0 | *ρ* | | 4 | | | |  |  |  |  | 1 |  |  |  |

*Ne*  *VP gHe* 8.7910−31039.8115.21.31103 *W*

*η*  *Ne* *Nm*  1.311.92  68.2 0 0



5）IS65-40-200 型离心泵在时的“扬程～流量”数据如下：

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| V | m3/h | 7.5 | 12.5 | 15 |
| He | m | 13.2 | 12.5 | 11.8 |
|  |  |  |  |  |

用该泵将低位槽的水输至高位槽。输水管终端高于高位槽水面。已知低位槽水面与输水管终端的垂直高度差为 4.0m，管长 80m（包括局部阻力的当量管长），输

水管内径 40mm，摩擦系数。试用作图法求工作点流量。

解

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 管路特性曲线： *H*' *H*  | | | 8 *λ*K *lvs*2 |  4.0  |  | 8  0.02  80 | *V*2 |  4.0  1.29 10 | 6 *V* |  |
|  |  |  |  |
| *e* | 0 |  | *π*2 *gd*5 |  | *π*2 |  9.81 0.0405 | *s* |  | *s* |  |
|  |  |  |  |  |  |  |  |
| 将流量的单位改为m3 / *h*,以V表示以便同泵的特性曲线一致，则 | | | | | | | |  |  |  |
| *H*'*e* 4.01.29105( | *V* | )2  4.0  0.0995*V*2 | | | |  |  |  |  |  |
| 3600 |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |

* *He*'~ *V*"计算数据结果列于下表 ：

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| V | m3/h | 7.5 | 12.5 | 15 |
| H’e m | | 9.60 | 19.5 | 26.4 |
| He | m | 13.2 | 12.5 | 11.8 |
|  |  |  |  |  |

由作图法得，工作点流量 V=9.17m3/h

6）IS65-40-200 型离心泵在时的“扬程～流量”曲线可近似用



|  |  |
| --- | --- |
| 如下数学式表达： | ，式中 He 为扬程，m，V 为流量，m3/h。 |
| 试按第 5 题的条件用计算法算出工作点的流量。 | |
| 泵的特性曲线：H *e* |  13.67 − 8.30 10−3 *V*2 |

|  |  |
| --- | --- |
|  | 管路特性曲线：He'  4.0  0.0995*V*2 |
| [解] | 令H *e*  *H*'*e*,解得 *V*  9.47 *m*3 / *h* |

7）某离心泵在时的“扬程～流量”关系可用

表示，式中 He 为扬程，m，V 为流量，m3/h。现欲用此型泵输水。已知低位槽水面和输水管终端出水口皆通大气，二者垂直高度差为8.0m，管长 50m（包括局部阻力的当量管长），管内径为 40mm，摩擦系数

。要求水流量 15 m3/h。试问：若采用单泵、二泵并连和二泵串联，何种方案能满足要求？略去出口动能。

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| [解] 管路特性曲线：H' |  8.0  |  | 8  0.02  50 | *V*2 |  8.0  8.07 10 | 5 *V*2 |  |
|  |  |  |
| *e* |  | *π* 2 |  9..81 0.0405 | *S* |  | *S* |  |
|  |  |  |  |  |  |

* 8.0  0.0623*V*2 , *m*(单位： *VS* − *m*3 / *s*, *V* − *m*3 / *h*)

①单泵：*He* 13.67−8.3010−3 *V*2

1. *H*'*e* 8.00.0623*V*2

令H *e*  *H*'*e*解得 *V*  8.96 *m*3 / *h*

②二泵串联：H *e*，串  2(13.67 − 8.30 10−3 *V*2  27.34 −1.66 10−2 *V*2

1. *H*'*e* 8.00.0623*V*2

* *He*,串 *H*'*e*,解得 *V*串15.7 *m*3/ *h*

③二泵并联：H *e*,并  13.67 − 8.30 10−3 (*V*并 / 2）2  13.67 − 2.075 10−3 *V*并2

1. *H*'*e* 8.00.0623*V*2

* *He*,并 *H*'*e*,解得 *V*并9.38 *m*3/ *h*

可见，只有二泵串联可满足V  15m3 / *h*的要求。

8）有两台相同的离心泵，单泵性能为，m，式中 V 的单位是 m3/s。当两泵并联操作，可将 6.5 l/s 的水从低位槽输至高位槽。两槽皆敞

口，两槽水面垂直位差 13m。输水管终端淹没于高位水槽水中。问：若二泵改为串联操作，水的流量为多少？

[解] 并联：扬程 H *e*,并  45 − 9.2 105 (6.5 10−3 2 ）2  35.3 *m* KK管路特性方程：H'*e*  13  *K*(6.5 10−3）2，



* *H*'*e* 35.3 *m K* 5.28105

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 串联：H | *e*,串 |  （245 − 9.2 10 | 5 *V*2) |  |
|  |  | *S* |  |

*He*'135.28105 *VS*2

* *He*,串 *H*'*e*,解得V*S* 5.7010−3 *m*3/ *s*

9）承第 5 题，若泵的转速下降 8%，试用作图法画出新的特性曲线，并设管路特性曲线不变，求出转速下降时的工作点流量。

[解] 设原来转速为 n，后来转速 n’=0.92n,前后各有关参量的关系为：

*V*'/ *V*  *n*'/ *n*, *He*'/ *He* ( *n*'/ *n*)2

可由原来的（He,V）数据一一对应算出新转速时的（H’e V’）数据 ，如下表所示：

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 转速 n | V m3/h | | | 7.5 | 12.5 | 15 |  |
|  | He | m |  | 13.2 | 12.5 | 11.8 |  |
|  |  |  |  |
|  |  |  |  | |  |  |  |  |
|  | 转速 n’ | V’ | m3/h | | 6.9 | 11.5 | 13.8 |  |
|  | H’e | | m | 11.17 | 10.58 | 9.99 |  |
|  |  |  |
|  | 管路特性曲线： | | | |  |  |  |  |
| He =4.0+0.0995V2 | | | | m | ,(V—m3/h), | |  |  |

可作图法得（V,He’’ ）,数据如下：（ 6.9,8.74）,(11.5,17.16) ,(13.3,22.9)

由作图法得，工作点 V=8.8m3/h

10）用离心泵输送水，已知所用泵的特性曲线方程为：。



当阀全开时的管路特性曲线方程： （两式中 He、He’— m，V—m3/h）。

问 ：①要求流量 12m3/h，此泵能否使用？②若靠关小阀的方法满足上述流量要求 ，求出因关小阀而消耗的轴功率。已知该流量时泵的效率为 0.65。

解: (1) He=36－0.02V2

He‘=12＋0.06V2 ∵He=He’，解得 V=17.3m3/h 适用

1. 当 V=12m3/h He=36−0.02122=33.12m ， He ‘ =12 ＋ 0.06V2=12 ＋ 0.06122=20.64m

∆ *N* ∆ *HeVρg* 1210009.81(3312.−20.64)627.8*W*



|  |  |
| --- | --- |
| *η* | 0.65  3600 |

11）用离心泵输水。在 n = 2900 r/min 时的特性为 He = 36－0.02V2，阀全开时管路特性为 He’

= 12＋0.06V2 (两式中 He、He’--m , V--m3/h)。试求：①泵的最大输水量；②要求输水量为最大输水量的 85 %，且采用调速方法，泵的转速为多少？

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 解：(1) He=36−0.02V2 | | |  |  |  |  |
| He’=12+0.06V2 | | | ∵He=He’，解得 V=17.3m3/h | | |  |
| (2) V’=0.85V=14.7m3/h，令调速后转速为 n r/min | | | | | |  |
|  | *n* |  |  | *n* | *V* |  |
| H’=( 2900 )2H | | |  |  |
| V’= 2900 | | |  |
| 泵: (29002/n2)H’=36−0.02(29002/n2)V’2 | | | | | |  |

H’=36 n2/(29002)−0.02V’2

当 V=14.7m3/h

则 H’=( n2/29002)36−0.0214.72

He’=12+0.06V’2 =12+0.0614.72=24.97m

由 He=He’，解得 n=2616r/min

12)12)用泵将水从低位槽打进高位槽。两槽皆敞口，液位差 55m。管内径 158mm。当阀全开时，管长与各局部阻力当量长度之和为 1000m。摩擦系数 0.031。泵的性能可用 He = 131.8－0.384V 表示(He--m , V--m3/h)。试问：①要求流量为 110m3/h，选用此泵是否合适？②若采用上述泵，转速不变，但以切割叶轮方法满足 110m3/h 流量要求，以 D、D’ 分别表示叶轮切割前后的外径，问 D’/D 为多少？

解：(1)管路 He=H0+KV2

=∆z+[8λ(l+Σle)/(π2gd5)]Vs2=55+2.601104Vs2=55+0.00201V2

=55+[80.0311000/(π29.810.1585)] Vs2

由 He=131.8−0.384V

He=55+0.00201V2 得 V=122.2 m3/h 110 m3/h 适用

(2) H=(D/D’)2H’ V=(D/D’)V’

切削叶轮后：(D/D’)2H’=131.8−0.384(D/D’)V’

即 H’=(D’/D)2131.8−0.384(D’/D)V’

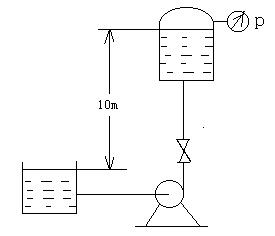
V=110 m3/h 时，H’=(D’/D)2131.8−0.384(D’/D)V’=(D’/D)2131.8− 0.384(D’/D) 110

=131.8(D’/D)2−42.24(D’/D)

He’=55+0.00201V’2 =55+0.002011102=79.32 m ，由 He’=H’，解得D’

/D=0.952

13）13）某离心泵输水流程如附图示。泵的特性曲线方程为：He=42−7.8104V2 (He--m , V--m3/s)。图示的 p 为 1kgf/cm2(表)。流量为 12 L/s 时管内水流已进入阻力平方区。若用此泵改输 ρ=1200kg/m3 的碱液, 阀开启度、管路、液位差及 P 值不变，求碱液流量和离心泵的有效功率。



习题 13 附图

解：p=1kgf/cm2=9.807104Pa V=12L/s=0.012m3/s

管路 He’=H0+KV2=10+(9.807104)/(9.8071000)+KV2=20+K0.0122 He=42−7.81040.0122=30.77 m ∵He=He’ K=7.48104 ∵改输碱液阀门开度、管路不变 K=7.48104 不变

管路: He’=∆z+p/(ρg)+KV2=10+9.81104/(9.811200)+7 48104V2 =18.33+7.48104V2

泵 He=42−7.8104V2 ∵He=He’ ，解得：V=0.0124m3/s ∵He=42−7.8104V2=42−7.81040.01242=30.0 m Ne= HegVρ=30.09.810.01241200=4.38103W

14)14)某离心泵输水，其转速为 2900r/min，已知在本题涉及的范围内泵的特性曲线可用方程 He = 36−0.02V 来表示。泵出口阀全开时管路特性曲线方程为： He’ = 12 + 0.05V2(两式中 He、He’ m，V m3/h)。①求泵的最大输水量。②当要求水量为最大输水量的 85 %时，若采用库存的另一台基本型号与上述泵相同，但叶轮经切削 5 %的泵，需如何调整转速才能满足此流量要求？

解：(1)由 He=36−0.02V

He’=12+0.05V2 令 He=He’ 解得 V=21.71m3/h

(2)D’/D=0.95 V’=0.85V=0.8521.71=18.45m3/h 另一泵：He=360.952−0.020.95V=32.49−0.019V调整转速后：He=32.49(n/2900)2−0.019(n/2900)V

=32.49(n/2900)2−0.019(n/2900) 18.45

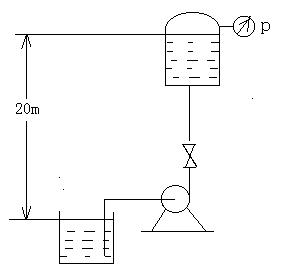
=32.49(n/2900)2−0.351(n/2900)

又 He’=12+0.05V2 =12+0.0518.452=29.02 m，由 He=He’ 解得 n=2756 r/min 15)15)某离心泵输水流程如图示。水池敞口，高位槽内压力为 0.3at(表)。该泵的特性曲线方程为：He=48−0.01V2 (He m , V m3/h)。在泵出口阀全开时测得流量为 30m3/h。现拟改输碱液，其密度为 1200kg/m3，管线、高位槽压力等都不变，现因该泵出现故障，换一台与该泵转速及基本型号相同但叶轮

切削 5 %的离心泵进行操作，问阀全开时流量为多少？

解：p=0.3at=2.94104 Pa

管路 He’=∆z+p/(ρg)+KV2=20+2.94104/(9.811000)+KV2=23+KV2 V=30m3/h 时 He=48−0.01V2=48−0.01302=39 m



习题 15 附图

He’=23+KV2=23+K302 由于 He=He’ K=0.0178

管路 He’=23+0.0178V2

泵: He=48(D’/D)2−0.01V2=480.952−0.01V2=43.32−0 01V2

改泵后管路: He’=∆z+p/(ρg)+KV2=20+2.94104/(9.811200)+0.018V2

=22.5+0.018V2 He=43.32−0.01V2 He‘=22.5+0.018V2

得 V=27.3 m3/h

16)16)IS100-80-160 型离心泵， P0=8.6mH2O,水温 150C,将水由低位槽汲入泵，有管路情况基本的性能，知 V=60m3/h,查的△h,允=3.5m,已知汲入管阻力为2.3m,H2O,求最大安装高度

[ 解 ] 150C 清 水 ： ρ =9999kg./m3,PV=1705.16Pa

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *Hg*,max |  | *P* | |  |  |  | *P* |  | −∑ *H f* ,0−1− ∆ *h*, |  |  |
|  | | 0 |  | − |  | *v* |  |  |  |
|  |  | *ρ* | |  | 允 |  |
|  |  | *ρ* | | *g* | | *g* | |  |  |
|  8.6 − | | 1705.16 | | | |  | − 2.3 − 3.5  2.63 *m* | | |  |  |
|  | | | |  |  |  |
|  | 999  9.81 | | | | | | |  |  |  |  |

17)17)100KY100-250 型离心泵，P0=8.6mH2O,水温 150C,将水由低位槽汲入泵，已知工作点流量为 100m3/h,查得[HS]=5.4m,汲水管内径为 100mm,汲水管阻力为5.4mH2O。求 Hg,max

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  | 解： *HS*,允[ *HS* | | | ] −10  0.24 | | | *P*0 |  | − | *PV* |  |  |
|  |  |  |  |  |  | *ρ* |  | *ρ g* | |  |
|  |  |  |  |  |  |  |  |  |  |  | *g* | |  |
|  |  |  |  |  |  |  5.4 −10.33  0.24  8.6 −1705.16 /(999  9.81） 3.97 *m* | | | | | | | | | |  |
| *U*  | 100 / 3600 | | |  3.54 *m*/ *s* | | |  |  |  |  |  |  |  |  |  |  |
|  | | |  |  |  |  |  |  |  |  |  |  |
| 2 |  | *π* | (0.10)2 |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | 4 | *U*2 | |  | 3.542 | | |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  | −∑ *H f* ,0−1 |  |  |  |  |  |  |  |
| *Hg*,max *HS*,允− | | | | | 2 |  3.97 − |  |  | − 5.4  −2.30 *m* | | | |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  | 2 *g* | |  | 2  9.81 | | | |  |  |  |  |  |  |

18）大气状态是 10℃、750mmHg(绝压)。现空气直接从大气吸入风机，然后经内径为 800mm 的风管输入某容器。已知风管长 130m，所有管件的当量管长为80m，管壁粗糙度 *ε*  0.3mm ，空气输送量为 2×104m3/h (按外界大气条件计)。该

容器内静压强为 1.0×104Pa(表压 )。库存一台 9-26 型 No.8 离心式风机，

2900rpm ，当流量为 21982 m3/h， *H*T  1565 mmH2O，其出风口截面为 0.392× 0.256m2。问：该风机能否适用？

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 解：大气： *t* 10 | 0 *C*, *P* |  750 *mmHg*(绝）， *ρ*  | 750 133.3 29 |  1.23 *Kg*/ *m*3 |  |
|  |  |
|  | 0 | 0 | 8314  283 |  |  |
|  |  |  |  |  |

风量： *V* 2104 *m*3/ *h*(按 *ρ*0计）， *W* 21041.232.46104 *Kg*/ *h P* 1,0104 *Pa*(表）1.10105 *Pa*（绝）， ** 1.7710−5 *Pa s*

2

计算 *P* （:按100 *C*等温过程计算）

1

*G* 2.46104/[3600( *π* / 4)0.82]13.59 *Kg*/( *s*, *m*2)

*Re*  *dG*/ ** 0.8013.59 /(1.7710−5)6.14105

*ε* / *d*  0.3 / 800  3.75 10−4 查得 *λ*  0.0168

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 计算式： *G*2 | | | |  | *P* | |  |  |  | *P*2 | | − *P*2 | | | *lG*2 | |  |  |  |  |  |  |  |  |  |  |
| *Ln* | 1 |  |  | |  | 2 | | 1 | *λ* |  |  |  0( *P V*  *RT* / *H*) | | | | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | *P*2 | |  |  |  |  | 2 *P*2 *V*2 | | | | 2 *d* | | 2 | 2 | |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 13.592 *Ln* | |  |  | *P* | | |  |  |  | (1.10 105 )2 | | | | | − *P*2 | | |  |  |  | 210 13.59 | 2 |  |  |  |  |
|  |  | 1 |  |  |  |  | |  |  |  |  |  | 1 | |  0.0168 | | | |  |  |  0 | |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  | | 2  0.80 |  |  |  |
|  | 1.10 105 | | | | | |  |  |  | 2  8314  283 / 29 | | | | | | | |  |  |  |  |  |  |  |  |
| 经试差，得P  1.103105 *Pa*（绝） | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  | 5 |  |  | [2.46 104 | | | /(3600  0.392  0.256)]2 |  |
| 要求的H | *T* | |  ( *P* − *P* )  *G* /(2 *ρ* )  (1.10310 | | | | | | | | | | | | | | | |  | − 750 133.3)  | | | |  |  |  |
|  |  |  |  |
|  |  | 1 | |  | 2 | |  |  |  | 0 | |  |  |  |  |  |  |  |  |  |  |  | 2 1.23 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

* 1.221104 *Pa*  1245 *mmH*2 *O*

折合到标准状态（ *ρ*  1.20 *Kg*/ *m*3 )

*V* 2104 *m*3/ *h*, *HT*,标12451.20 /1.231214 *mmH*2 *O*

库存离心式风机， *n* 2900 *rPm*,当V210892 *m*3/ *h*, *HT*,标1565 *mmH*2 *O*,适用。

19） 19） 离心式风机输送空气，由常压处通过管道水平送至另一常压处。流量 6250kg/h。管长 1100m(包括局部阻力)，管内径 0.40m,摩擦系数 0.0268。外界气压 1kgf/cm2，大气温度 20℃，。若置风机于管道出口端，试求风机的全风压。[提示：1. 风管两端压力变化(p1−p2)/p1 20 %时，可视为恒密度气体，其 ρM 值按平均压力(p1+p2)/2 计算。2. 为简化计算，进风端管内气体压力视为外界气压。3. 管道两端压差 104Pa ]

解: 以下以 H 表示管路的压降 (p1－p2)。

∵pm=[p0+(p0－H)]/2=p0－H/2

ρm=pm·M/(RT)=(p0－H/2)M/(RT)

H=λ(l/d)(u2/2) ρm=λ(l/d)( ρm u)2/(2ρm)

=λlW2/{[(π/4)d2]22dρm}

=8λlW2RT/[π2d5(p0－H/2)M]

* C=8λlW2RT/(π2d5M)

则上式为 H2－2p0H+2C=0

其 中

C=80.02681100(6250/3600)28314293.2/(π20.40529)=5.912108

* H2－(29.81104)H+(25.912108)=0 解得 H=6222 Pa

校核：H/p1=6222/(9.81104)=0.063  0.20，把气体密度视为常量是可以的。

则风机的全风压 H 全=H=6222 Pa

20） 20） 离心泵、往复泵各一台并联操作输水。两泵“合成的”性能曲线方程为：He = 72.5－0.00188(V−22)2，V 指总流量。 阀全开时管路特性曲线方程为：He’= 51+KV2, (两式中：He、He’--mH2O，V--L/s)。现停开往复泵，仅离心泵操作，阀全开时流量为 53.8L/s。试求管路特性曲线方程中的 K 值。

解：只开离心泵时 He=72.5−0.00188V2

V=53.8 L/s 时 He=72.5−0.00188V2=72.5－0.0018853.82=67.06 m He’=51+KV2=51+K53.82

∵He= He’ K=0.00555 m/(L/s)2

# 第3章 颗粒流体力学基础与机械分离

1）1）有两种固体颗粒，一种是边长为 a 的正立方体，另一种是正圆柱体，其高

度为 h，圆柱直径为 d。试分别写出其等体积当量直径 和形状系数的计算式。



1



[解]( *a*) Q( *π* / 6) *d*3*e*, *v*  *a*3 *de*, *v* (6 / *π* )3 *a*

* 1. 2

*ψ*  *π de*, *v*  *π*(6 / *π*）3 *a*2(*π* / 6)13

6 *a*226*a*



|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ( *b*) Q(*π* / 6) *d*3*e*, *v* （ *π* / 4) *d*2 *h de*, *v* | | | | |  [(3 / 2) *d*2 | | 1 |  |
| *h*]3 |  |
| 2 | |  | 1 | |  |  |  |  |
| *ψ*  | *π*[(3 / 2) *d*2 *h*] 3 |  |  | (18 *dh*2 ) | 3 |  |  |  |
| 2(*π* / *d*) *d*2  *π* *dh* | | 2 *h* *d* |  |  |  |  |
|  |  |  |  |  |  |



2）2）某内径为 0.10m 的圆筒形容器堆积着某固体颗粒，颗粒是高度 h=5mm，

直径 d=3mm 的正圆柱，床层高度为 0.80m，床层空隙率 、若以 1atm，

25℃的空气以 0.25 空速通过床层，试估算气体压降。

[解] 圆柱体：

1



*de*, *v* [(3 / 2) *d*2 *h*]3, *ψ* (18 *dh*2)3(2 *h* *d*)

*ψ de*, *v* 3 *dh*/(2 *h* *d*)335 /(253)3.46 *mm* 空气（1*atm*,250 *C*) : *ρ*  1.185 *kg*/ *m*3 , **  1.835 10−5 *Pa s*

按欧根公式计算压降：

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | 2 |  | (1 − *ε*) |  | 2 |  |  |
| ∆ *P*  *L*[150 | (1 − *ε*）** *u* |  1.75  |  | *ρ u* | ] |  |
|  |  |  |  |
| *m* | *ε*3 (*ψ* *de*, *v* )2 |  | *ε*2 | | *ψ de*, *v* | |  |
|  |  |  |

* 0.80[150  (1 − 0.52)2  1.835 10−5  0.25 1.75  1 − 0.52  1.185  0.252 ]

0.523−3 )20.5233.46 10−3(3.4610



* 177.7 *Pa*

3）拟用分子筛固体床吸附氯气中微量水份。现以常压下 20℃空气测定床层水力特性，得两组数据如下：

|  |  |  |  |
| --- | --- | --- | --- |
| 空塔气速0.2 | ， | 床层压降 | 14.28mmH2O |
| 0.6 |  |  | 93.94mmH2O |



试估计 25℃、绝对压强 1.35atm 的氯气以空塔气速 0.40 通过此床层的压降。



（含微量水份氯气的物性按纯氯气计）氯气 ，

[解]常压下， 200 *C*空气： *ρ*  1.20 *Kg*/ *m*3 , **  0.018 *cP*.

欧根公式可化简为

∆ *P*  *A  u* *B ρ u*2 ( *A*, *B*为床层结构参量，为常量。）

试验条件 :14.28  *A* 0.018  0.20  *B*1.20  0.22 − − − −① 93.94  *A* 0.018  0.60  *B*1.20  0.62 − − − −②

联立①②式，解得： *A*1601 *B* 177.4

氯气 : ∆ *P*  1601 0.014  0.40 177.4 1.88  0.42  62.3 *mmH*2 *O*

3） 3） 令水通过固体颗粒消毒剂固定床进行灭菌消毒。固体颗粒的筛析数据是：

0.5～0.7mm，12%；0.7～1.0mm，25.0%；1.0～1.3，45%；1.3～1.6mm，10.0%；

1.6 ～ 2.0mm ， 8.0% （以上百分数均指质量百分数）。颗粒密度为 1875 。固定床高 350mm，截面积为 314mm2。床层中固体颗粒的总量为 92.8g。

* 20℃清水以 0.040 空速通过床层，测得压降为 677mmH2O，试估算颗粒的形状系数 值。

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 解： *ε*  1 | | | | | | | − (92.8 /1.875) /(35  3.14)  0.550 | | | | | | | | | | | | | | | | (体积均按 *cm*3计算） | | | | | |  |
|  | 1 |  |  |  |  | 0.12 | |  | | 0.25 |  | 0.45 | |  | 0.10 | |  | 0.08 | |  | *dm* 1.00 *mm* | | | | |  |  |  |  |
|  | *dm* | | | |  | |  |  |  | 1.45 | |  |  |  |  |  |  |
|  | 0.6 | | 0.85 | | | | 1.15 | | |  | 1.8 | | |  |  |  |  |  |  |  |  |  |  |
|  |  |  | 0 |  | *c*水： | | **  1*cP*,可设采用康尼方程： | | | | | | | | | | | | | | ∆ *p* | | 6 | | 2 |  | (1 − *ε*)2 | * u* |  |
| 20 | | |  |  |  |  5.0  ( | |  | ) |  |  |  |
|  |  |  | *ψdm* |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | *L* | |  |  |  | *ε*3 |  |  |
| 即 | | 677  9.81 | | | | | | |  5.0  ( | | | |  | 6 |  | )2  | | | (1 − 0.55)2 | | | |  0.001 0.040 | | | | |  |  |
|  | | | | | | |  |  |  |  | | | |  |  |
|  |  |  |  |  | 0.35 | |  |  |  |  |  |  | *ψ*  0.001 | | | | 0.553 | | | | | |  |  |  |  |  |  |  |

*ψ*  0.68

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 校核 *R* |  | *ψd* | *m* | *ρu* | | |  | | 0.68  0.001103  0.04 | | | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  10.07  2 | | | |  |  |
| ' |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *e* |  | 6(1 − *ε*) ** | | | | |  |  | 6  (1 − 0.55)  0.001 | | | | | |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  | ∆ *P* | |  |  |  | (1 − *ε*)2 | *u* | |  |  | (1 − *ε*) |  | *ρ u*2 |  |
| 适用欧根公式： | | | | | *m* | | |  150  | |  |  |  | 1.75  | |  |  |  |  |
|  | | | *ε*3 (*ψ*  *d* | | )2 | *ε*3 | *d ψ* |  |
|  |  |  |  |  | *L* | |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  | *m* |  |  |  |  |  | *m* |  |

* 677  9.81  150  (1 − 0.55)2  0.001 0.04 1.75  1 − 0.55  103  0.042

3 (*ψ*  0.001)20.553*ψ* 0.0010.350.55



经试差，解得 : *ψ*  0.851

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 校核 *R* |  | *ψd* | *m* | *ρu* | |  | 0.851 0.00110 | 3  0.04 |  |  |
|  |  |  |  |  12.6  400 | |  |
| ' |  |  |  |  |  |  |  |  |  |
| *e* |  | 6(1 − *ε*) ** | | | |  | 6  (1 − 0.55)  0.001 | | |  |
|  |  |  |  |

计算有效

4）4）以单只滤框的板框压滤机对某物料的水悬浮液进行过滤分离，滤框的尺寸为 0.20×0.20×0.025m。已知悬浮液中每 m3 水带有 45 ㎏固体，固体密度为

1820 。当过滤得到 20 升滤液，测得滤饼总厚度为 24.3mm，试估算滤饼的含水率，以质量分率表示。

[解] : 设滤饼空隙率为 *ε*，做物料衡算得 : 0.20  0.20  0.0243(1 − *ε*) 1820  45



20 10−3  0.20  0.20  0.0243*ε*

解得： *ε*  0.479

|  |  |  |  |
| --- | --- | --- | --- |
| 滤饼含水率  | 0.479 1000 |  0.336 *Kg*水 / *kg*滤饼 |  |
|  |  |
|  | 0.479 1000  (1 − 0.479) 1820 | |  |

6）某粘土矿物加水打浆除砂石后，需过滤脱除水份。在具有两只滤框的压滤机中做恒压过滤实验，总过滤面积为 0.080m2，压差为 3.0atm，测得过滤时间与滤液量数据如下：

过滤时间，分：1.20 2.70 5.23 7.25 10.87 14.88

滤液量，升： 0.70 1.38 2.25 2.69 3.64 4.38

试计算过滤常量 K，以 为单位，并计算 ，以 为单位。可采用

由积分式 导出的 求 K 与 。

* 为便于直接使用题给数据：改用

*τ* / *V*  *V* /( *A*2 *K*)  2*Ve* /( *A*2 *K*)式计算。

以 *y*代替 *τ* / *V*,以 *x*代替 *V*, *a*代替2*Ve* /( *A*2 *K*),用最小二乘法计算。

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |
|  |  |  |  |  |  | ( *Xi* | − *X*)( *yi* − | | | *y*) | |  |
| 组别 | Xi | Yi | ( *Xi* − *X*) | | |  |
|  |  |
| 1 | 0.70 | 1.714 | 3.265 | |  |  |  | 1.442 | | |  |  |  |
|  |  |  |  | |  |  |  |  | | |  |  |  |
| 2 | 1.38 | 1.957 | 1.270 | |  |  |  | 0.625 | | |  |  |  |
|  |  |  |  | | |  |  |  | | |  |  |  |
| 3 | 2.25 | 2.324 | 0.0660 | | |  |  | i0.0483 | | |  |  |  |
|  |  |  |  | | |  |  |  | | |  |  |  |
| 4 | 2.69 | 2.695 | 0.0335 | | |  |  | 0.0335 | | |  |  |  |
|  |  |  |  | |  |  |  |  | | |  |  |  |
| 5 | 3.64 | 2.986 | 1.284 | |  |  |  | 0.537 | | |  |  |  |
|  |  |  |  | |  |  |  |  | | |  |  |  |
| 6 | 4.38 | 3.397 | 3.508 | |  |  |  | 1.658 | | |  |  |  |
|  |  |  |  | |  |  |  |  | | |  |  |  |
| ∑ | 15.04 | 15.073 | 9.427 | |  |  |  | 4.344 | | |  |  |  |

1. ∑ *Xi* / *n* 15.04 / 6\2.507, *y* 15.073/ 62.512



|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *b*  | | ∑( *Xi* − *X*)( | *yi* | − *y*) |  | 4.344 |  0.461 | *a*  |  |  |  |  |  |
| *y*− *bX* 2.512−0.4612.5071.356 | | | |  |
|  |  |  |  |  |
|  |  | ∑( *Xi* − *X*) | | | 9.427 | |  |  |  |  |  |  |  |
| *V*  *a*/ 2 *b* 1.356 /(20.461)1.47 | | | | | | | | *l* 1 4710−3 *m*3 | | | | |  |
|  | *e* | | | |  |  |  |  |  |  |  |  |  |
| *q*  *V* / *A*1.4710−3 | | | | | / 0.080  0.0184 *m*3 / *m*2 | | | | | | | |  |
| *e* |  | *e* | | |  |  |  |  |  |  |  |  |  |



*K* 1/( *b A*2)1/(0.4610.0802)338.9 *l*2/(min *m*4)5.6510−6 *m*2/ *s*

7）欲过滤分离某固体物料与水构成的悬浮液，经小试知，在某恒压差条件下过

滤常量 ，滤布阻力 ，每 1m3 滤饼中含

485 ㎏水，固相密度为 2100 ，悬浮液中固体的质量分率为 0.075。

现拟采用叶滤机恒压差过滤此料浆，使用的滤布、压差和料浆温度均与小试时的相同。每只滤叶一个侧面的过滤面积为 0.4m2，每次过滤到滤饼厚度达 30mm 便停止过滤，问：每批过滤的时间为多少？

若滤饼需以清水洗涤，每批洗涤水用量为每批滤液量的 1/10，洗涤压差及洗涤水温均与过滤时的相同，问：洗涤时间是多少？

[解] 已知：

|  |  |  |
| --- | --- | --- |
| *K* 8.2310−5 *m*2/ *s*, *q* 2.2110−3 *m*3/ *m*2,滤饼空隙率 *ε* 485 /10000.485 | | |
|  | *e* |  |
| 设1 *m*3滤饼对应的滤液量为 *Xm*3 ,由物料横算得： | | |
| （1 − 0.485)  2100  | 0.075 | *X* 12.85 *m*3滤液/ *m*3滤饼 |
| 485 1000 *X* | 1 − 0.075 |  |



①叶滤机过滤 : (以一只滤叶的单侧面为基准）

过滤终了时， *q* 0.40.03012.85 / 0.40.3855 *m*3/ *m*2

* *q*22 *q qe*  *K τ* 即0.3855220.38552.2110−38.2310−5 *τ* 每批过滤时间 *τ*  1826 *s*  30.4 min

②洗涤时间：

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *dq* | |  | *K* |  | 8.23 | 10−5 |  |
| 过滤终了式的过滤速度（ |  | ) *E* |  |  |  |  |  |  |
| *dτ* | 2( *q* *q* ) | 2(0.3855 |  0.00221) |  |
|  |  |  |  | *e* |  |  |  |  |

* 1.06 10−4 *m*3 /( *s m*2 )

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 洗涤时间 *τw*  | *qw* |  | 0.1 0.3855 |  363.7 *S*  6.06 min |  |
| ( *dq*/ *dτ*) *E* | 1.06 10−4 |  |
|  |  |  |  |

8）某悬浮液用叶滤机过滤，已知洗涤液量是滤液量的 0.1 倍(体积比)，一只滤叶侧面积为0.4m2，经过小试测得过滤常数 *K* =8.23×10-5m2/s ,不计滤布阻力，所得滤液与滤饼体积之比为 12.85 m3 滤液/m3 滤饼，按最大生产率原则生产，整理、装拆时间为 20 分钟,求每只滤叶的最大生产率及每批过滤的最大滤饼厚度。

解：过滤： *q*2 *K τF* *τF*  *q*2/ *K*

洗涤： *τW*  *J q*/( *K* / 2 *q*)( *q*2/ *K*)2 *J*

最大生产率原则： *τF*  *τW*  *τD*

* *q*2(12 *J*) / *K*  *τD*

代入数据：[*q*2 /(8.2310−5 )] (1  2  0.1)  20  60 *q* 0.2869 *m*3/ *m*2

*G*max0.286920.4 /(22060)9.5610−5 *m*3/ *s* 0.3442 *m*3/ *h*

每批过滤最大滤饼厚度*δ* （30 / 0.3855)  0.2869  22.3 *mm* 或由每 *m*3滤饼对应的12.85 *m*3滤液算出：

*δ*  0.2869 /12.85  0.0223  22.3 *mm*

9 ）有一叶滤机，在恒压下过滤某种水悬浮液时，得到如下过滤方程：

，其中 ， 。在实际操作中，先在 5 分钟内作恒压过滤，此时过滤压差升至上述试验压强，然后维持恒压过滤，全部过滤时间为 20 分钟，试求：①每一循环中每 m2 过滤面积所得滤液量？②过滤后再用

相当于滤液总量的 水进行洗涤，洗涤时间为多少？

解：①∵ q2＋30q = 300τ

∴ qe=15 m3/m2 K=300 m2/min

恒速过程 q12＋qeq1=(K/2)τ1

∴q1=20.9 m3/m2

恒压过程 (q2－q12)＋2qe(q－q1)=K(τ－τ1)

∴q=60.7 m3/m2

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| dq | | |  | K |  198. |  |
|  |  |  |  |  |
|  |  |  |
| ② dτ | | | E | 2(q  q e ) | m3/(m2·min) |  |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| τW  |  | VW |  |  | Jq E A |  |  | 0.2  60.7 |  613. |  |
|  | dV | dq | |  |  |  |
|  |  |  |  | 198. | |  |  |
|  |  | dτW |  |  |  | A |  |  |  |  |
|  |  |  | dτ |  |  | min |  |
|  |  |  |  |  | W |  |  |  |  |



dq dτ



dq





W dτ E

10）用某板框压滤机恒压过滤，滤框尺寸为 810×810×25mm。经过小试测得过

滤常数 ， ，操作时的滤布，压差及温度与小试时相同。滤饼刚充满滤框时停止过滤，求：①每批过滤时间？②若以清

水洗涤滤饼，洗涤水用量为滤液的 ，洗涤压差及水温与过滤时相同，求过滤时间？③若整理、装卸时间为 25 分钟，求每只滤框的生产率？

[解]①每批过滤时间：

1*m*3滤饼对应滤液量12.85 *m*3 ,滤饼刚充满滤框时，得滤液量 *V* 0.810.810.02512.850.211*m*3

* *q*  *V* / *A*0.211/(20.810.81)0. 161*m*3/ *m*2
* (0.161)2  2  0.161 2.2110−3  8.2310−3 *τF*

*τF*  323.6 *s*

②洗涤时间：过滤终了时：

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |  |  |  | *K* |  |  |  | 8.2310−5 | | | |  |  |  |  |  | −4 | 3 |  |
| ( *dq*/ *dτ*) *E* | | | | | | |  | |  |  |  |  |  |  |  |  |  |  |  |  |  2.52 10 | | | |  | *m* |  |
| 2( *q* *qe*) | | | | |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | 2(0.161  0.00221) | | | | | |  |  |  |  |  |  |  |
|  | *dV* | |  |  |  |  |  | *dq* | | | |  |  |  |  |  |  | −4 |  | 2 |  |  |  |  | −4 | 3 |  |
| ( |  | | ) *E* | |  ( | |  |  |  | | ) *E* |  | *A*2.5210 | | | | |  |  2  0.81 | |  3.3110 | | | |  | *m* |  |
| *dτ* | |  | *dτ* | | |  |  |  |
|  | *dV* | |  |  | 1 | | |  |  | *dV* | |  |  |  |  |  | −4 |  |  |  |  | −5 | 3 |  |  |  |  |
| ( |  | | ) *w* | |  |  | | ( |  | | | ) *E* |  3.3110 | | | |  | / 4  8.28 10 | | | |  | *m* / | *s* |  |  |  |
| *dτ* | | 4 | | *dτ* | | |  |  |  |  |  |
| *V* 0.10.16120.8120.0211*m*3 | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |
|  | *w* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *τ* | | *w* | |  *V* | | | /( *dV* / *dτ*) | | | | | | | *w* |  0.0211/(8.28 10−5 )  255 *s* | | | | | | | | |  |  |  |  |
|  |  |  | *W* | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

/( *s m*2 )

* *s*

③生产率 *G*:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | *V* | | 0.161 2  0.812 |  | −4 3 |  |
| *G*  |  |  |  |  1.02 10 | *m* / *s* |  |
|  | 323.6  255  25  60 |  |
|  | *τF*  *τW*  *τD* | |  |  |  |

11）板框压滤机在 1.5at（表）下恒压过滤某种悬浮液 1.6 小时后得滤液 25m3，

不计，①如表压加倍，滤饼压缩指数为 0.3，则过滤 1.6 小时后得多少滤液？②设其它情况不变，将过滤时间缩短一半，可得多少滤液？③若在原表压下进行过滤 1.6 小时后，用 3m3 的水来洗涤，求所需洗涤时间？

解： ① V2=KA2τ

1.  2 *∆*pm 1−s



r0 φ μ、r0、Φ是滤饼结构参数，为常量

∴ K *∆*pm1−s 其中 A 与τ不变

* V2  *∆*pm 1−s

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | V′ | | 2 |  |  | ′ | | 1−s |  |  |  |
|  |  |  |  | *∆*pm | |  2 | 0.7 |  1624. |  |
|  |  | 2 | |  |  |  |  |  |
|  | V |  |  | *∆*pm | |  |  |  |  |
|  |  |  |  |  |  |  |  |
| ∴ | |  |  |  |  |  |  |  |  |  |  |

V′2  1624.  252  1015 m6

* + V′  3186. m3
* V2=KA2τ 其中 K、A 不变
  + V2 τ

V′2  V2τ′

* + τ



|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | V′  V | | |  | τ′ |  25  | | | 1 |  17.68 | |  |
|  |  |  |  |
|  |  |  |  |  | τ | |  |  | 2 |  | m3 |  |
| dV | | |  | KA 2 | | |  | V |  7.812 m | | 3 |  |
|  |  |  |  |  |  |  | h |  |
|  |  |  |  |  |  |
| ③ | dτ | | E |  | 2V | |  | 2τ |  |  |  |



|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| dV | | | 1 | | dV | |  | |  |
|  |  |  |  |  |  |  |  | |  |
|  |  |  |  |
|  | dτ W | | 4 | | dτ | |  | |  |
|  | τW  | |  | VW | | |  |  |  |
|  | dVdτW | | | |  |  |  |
| ∴ | | |  |  |  |  |  |  |  |



|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | | | KA 2 | | | |  1953.m3 |  |
|  |  |  |  | |  |
| E |  |  |  | 8V | | |  | h |  |
|  | 3 | | | |  |  |  1536. | |  |
|  |  | KA 2 | |  |  |  |
|  |  |  | 8V | | | |  | h |  |



12）用某板框过滤机进行过滤，采用先恒速后恒压过滤，恒速 1 分钟达恒压压差

便开始恒压过滤，已知过滤常数 ， ， 滤饼刚充满滤框时停止过滤，求：①过滤时间？②若用清水洗涤滤饼，水量为滤液量的 1/10 ，洗涤压差、温度均与恒压过滤时相同，求洗涤时间？③如装卸、整理时间为 25 分钟，求每只滤框的生产率？

[解] ①过滤时间：

恒速阶段： *q*12 *q*1 *q* ( *K*/ 2)*τ*1

* + *q*12 *q*10.00221(8.2310−5/ 2)60 *q*10.0486 *m*3/ *m*2

恒压阶段：(*q*2 − *q*12 )  2 *qe*( *q*− *q*1 )  *K*(*τ* − *τ*1 )

* : (0.1612 − 0.04862 )  2  0.00221 (0.161 − 0.0486）
* 8.2310−5 (*τ* − 60)

*τ*  352 *s*

则过滤时间 *τF*  60  352  412 *s*

②洗涤时间：

与第10题解法相同， *τw*  255 *s*

③生产率 *G*:

|  |  |  |  |
| --- | --- | --- | --- |
| *G*  | 0.161 2  0.812 |  9.75 10−5 *m*3 / *s* |  |
|  |  |
| 412  255  25  60 | |  |  |

13）某板框过滤机有 8 个滤框，滤框尺寸 810×810×25mm。浆料为 13.9%（质

量）的悬浮液，滤饼含水 40%（质量），固体颗粒密度 2100 。操作在 20

℃恒压条件下进行， ， ，求：①该板框过滤机每次过滤（滤饼充满滤框）所需时间？②若滤框厚度变为 15mm，问滤饼充满滤框所需时间？③若滤框数目加倍，滤饼充满滤框时所需时间？

解：①设滤饼空隙率为ε，设有 1Kg 滤饼，则含水 0.4kg

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0.4 | | | | 1000 | |  |  |  |
| ε  |  |  |  |  |  0.583 |  |
|  | 0.4 |  |  | 0.6 |  |  |
| 1000 | | |  |  |  |  |  |
|  | 2100 | |  |  |  |



设 1m3 滤饼得 xm3 滤液,对 1m3 滤饼作物料衡算:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 1 − ε ρp |  | 0139. |  |  |
| ε ρ水  ρ水 x | 0861. ∴x=4.84 m3 滤液/滤饼 | |  |
|  |  |

过滤面积 A=2×8×8102×10-6=10.498 m2

V 饼=8×0.812×0.025=0.131 m3 滤饼

∴V= V 饼·x =0.634 m3 滤液

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| q  | V |  | 0.634 |  0.0604 |  |
|  |  |  |
| ∴A | | 10.498 | | m3/m2 |  |

q2＋2qqe=Kτ

0.06042＋2×0.0604×2.21×10-3=1.8×10-5τ ∴τ=217.5 s

②滤框厚度减小为 15mm，设为δ＇

从上解可知，V 饼∝δ 即 V∝δ 也即 q∝δ

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| q ′  q | δ′ |  0.0604  | 15 |  |  0.0362 | |  |  |
|  | 25 | |  |  |
| ∴δ | | |  |  | m3/m2 |  |
| ∴τ＇= 81.7 s | | |  |  |  |  |  |  |
| ③框数加倍，也即 A＇= 2A | | | | | | V饼 | ′ |  |
|  | = 2V 饼 |  |

q=V/A 故 q 不变，也即τ不变

14）欲过滤料浆浓度为 ，经小试所得滤饼空隙率为 0.485，固

相密度 1820 ，在某恒压差条件下测得过滤常数 ， ，现用回转真空过滤机进行过滤，料浆浓度、温度及滤布

均与小试相同，唯过滤压差为小试时的 。由试验知，该物系滤饼压缩指数为0.36，回转真空过滤机鼓直径为 1.75m，长为 0.98m，但真正过滤面积为 5m2（考虑滤布固定装置）。浸没角度为 120°，转速 0.2r.p.m。设滤布阻力可略，试求：

①此过滤机的滤液生产能力及滤饼厚度？②若转速为 0.3r p m， 可略，其它操作条件不变，求生产能力滤饼厚度。

解：

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | n  | n′ |  | 0.2 |  0.0033 | | | |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
| ① | 60 60 | | | |  |  |  | s-1 |  |  |  |  |  |  |  |  |
|  |  |  |  | *∆*p′ | | | | 1−s |  |  | 1 0.64 | |  |  |  |  |
|  |  |  |  |  | −5 |  | −5 |  |  |
|  |  | K′  K | | | |  |  |  8.23  10 |  |  |  |  |  339.  10 |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  | | *∆*p | |  |  |  | 4 | |  | 2 | /s |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | m |  |



* G  nA2 K′ *Ψ*  9.70  10 −4 m3/s

已知ε，对 1m3 滤饼作物料衡算，设对应滤液 x m3

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | 1 | − ερp |  8108. |  |  |
|  |  |  |  |  |
| ∴ | ε  x | | | x=11.08 m3 滤液/m3 滤饼 |  |
| q F |  | K *Ψ* / n  0.0582 | | m3/m2 |  |



δ  q F  4.53

* + 1. mm
* G n0.5



|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| n′ | | | 0.5 |  | −4 |  | 0.3 | | 0.5 |  | −3 |  |
| G′  G |  |  |  |  9.70  10 |  |  |  |  |  |  119.  10 |  |  |
|  |  |  |  |  |  |  |
|  | n | |  |  |  |  | 0.2 | |  |  | m3/s |  |

* ∵ q F n−0.5

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| ′ |  |  | n | | 0.5 |  |
| q F |  q F |  |  |  |  0.0475 |  |
|  |  |
| ∴ |  | n′ | | | m3/m2 |  |

δ  q F  0.0475  0.0043m  4.3mm

* x 1108.



15）试进行光滑固体圆球颗粒的几种沉降问题计算：

① 球径 3mm、密度为 2600 颗粒在 20℃清水中的自由沉降速度



|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ② | 测得密度 2600 | | | 的颗粒在 20℃清水中的自由沉降速度为 12.6 | | | | | ， |  |
| 计算颗粒球径。 | | |  |  |  |  |  |  |  |  |
| ③ | ③ 测得球径为 0.5mm、密度 2670 | | | | | 颗粒在 | | 液体中的 | |  |
|  | 自由沉降速度为 0.016 | | | | ，计算液体的粘度。 | | |  |  |  |
| [解]①200 *C*水， *ρ*  1000 *kg*/ *m*3 , **  1*cP* | | | | | |  |  |  |  |  |
| Q *dp*[ | | *g*( *ρm* − *ρ*) *ρ* | 1/ 3 |  | 9.81(2600 −1000) 1000 1/ 3 | | |  |  |  |
|  | ] |  0.003[ |  |  | ] |  7.51 |  |  |
|  | 0.0012 |  |  |  |
|  | **2 | |  |  |  |  |  |  |  |



属于牛顿区

*ut*  1.74[ *g dp* ( *ρm* − *ρ*)]1/ 2

*ρ*



* 1.74[9.81 0.003(2600 −1000)]1/ 2  0.387 *m*/ *s* 1000



②设沉降属于斯托克斯区：

*g d*2*p* ( *ρm* − *ρ*)

*ut* 

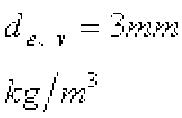


18 **

12.6 10−3  9.81 *d*2*p* (2600 −1000)（/18  0.001)

*d p* 1.2010−4 *m*

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *R* 1.2010−4 | | | | | 12.6 10−3 106 | | | | | |  1.512  2 | | |  | 16 ） 试 进 行 形 状 系 数 | |  |
| *ep* |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 的固体颗粒的沉 | |  |
| 即原设正确，计算有效。 | | | | | | | | | |  |  |  |  |  |  |
|  |  |  |  |  | 降问题计算： | |  |
| ③设沉降属于阿伦区： | | | | | | | | | |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  | *g d p* ( *ρm* | | | | − *ρ*) | | | 0.6 | 1 / 2 |  |  |  | ① 等 体 积 当 量 直 径 | |  |
| *u* 0.27[ | | |  |  |  |  |  |  *R* | |  | ] |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
| *t* |  |  |  |  |  | *ρ* |  |  | *ep* |  |  |  |  |  |  | ，密度为 2600 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 即： |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | 颗粒在 20℃清水中 | |  |
|  |  |  |  | 9.81 0.0005(2600 − 860) | | | | | | | |  | 0.6 ]1 / 2 | |  |
| 0.52  0.27 [ | | | |  *Rep* | 的自由沉降速度。 | |  |
|  | |  | | |  | | |  |
|  |  |  |  |  |  |  | 860 | | |  |  |  |  |  |  |  |  |
| *Rep* |  391.2属于阿伦区，即假设正确，计算有效。 ② ② 测得密度为 2600 | | | | | | | | | | | | | | | |  |
| Q *Rep* |  | *d p ut ρ* | | | | 即391.2  | | | 0.0005  0.52  860 | | | | |  |  | 颗粒在 20℃清 |  |
|  | | | |  | | | | |  |  |
|  |  | ** | |  |  |  |  |  |  |  | ** |  |  |  | 水中的自由沉降速度 | |  |
| **  5.72 10−3 | | | | | *Pa s* | | | | |  |  |  |  |  | 为 0.01 | ，计算颗 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |



粒的等体积当量直径。

[解]① *ζ* / *Rep*2  4 *g dp*( *ρs* − *ρ*) /(3 **2 )

* 4  9.81 (0.003)3 (2600 −1000) 1000 /(3 0.0012 )
* 5.65 105

查得 *Rep* 400

* *Rep*  *dp ut ρ*即4000.003 *ut* 103*ut* 0.133 *m*/ *s*

**0.001



* *ζ* / *Rep*  4 *g*( *ρs* − *ρ*) **/(3 *ρ*2 *u*3*t* )
* 4  9.81(2600 −1000)  0.001/(310002  0.013 )

查得 *Rep* 1.85

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *d* | *p* | *u ρ* | |  | *d* | *p* |  0.01103 |  |
| Q *Rep*  |  | *t* | | 即1.85  |  |  |  |
|  |  | ** |  |  |  | 0.001 |  |
|  |  |  |  |  |  |  |  |

*dp* 1.8510−4 *m*

17）以长 3m、宽 2m 的重力除尘室除烟道气所含的尘粒。烟气常压，250℃，处

理量为 4300 。已知尘粒密度为 2250 ，颗粒形状系数 ， 烟气的 与 可按空气计。设颗粒自由沉降。试计算：

① 可全部除去的最小粒径的 。

② ② 能除去 40%的颗粒的 。

[解]① Q4300 / 3600  *ut*  3 2 *ut* 0.199 *m*/ *s*

常压、2500 *C*空气 : *ρ*  0.674 *kg*/ *m*3 , **  2.74 10−5 *Pa s*

*ζ* / *Rep*  4 *g*( *ρs* − *ρ*) **/(3 *ρ*2 *u*3*t* )

* 4  9.81(2250 − 0.674)  2.74 10−5 /(3 0.6742  0.1993 )
* 225

查得 *Rep* 0.39,则：

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 0.39  | *dp* |  0.199  0.674 | *dp* 7.9710 | −5 | *m* |  |
|  | 2.74 10−5 |  |  |
|  |  |  |  |  |  |

②设除去40 0 0 的颗粒为 *d*40 ,其沉降速度为 *u*40 ,除去100 0 0 的颗粒沉降速度为 *u*100，并令停留时间为 *τ*，则：



|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *u*40 *τ* |  4.0  | *u*40 | *u* 0.400.1990.0796 *m*/ *s* |  |
|  |  |  |
| *u*100 *τ* | | 40 | |  |
| *u*100 | |  |

*ζ*  225( *u*100 )3  225  ( 1 )3  3515



|  |  |  |
| --- | --- | --- |
| *Rep* | *u*40 | 0.4 |

* *ζ* / *Rep*  4  9.81 (2250 − 0.674)  2.74 105 /(3 0.6742  0.07963 )
  + 3518

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 查得 *R* 0.105 | *d*400.07960.674 | | *d* 5..3610−5 | *m* |  |
|  | |  |
| *ep* | 2.74 10 | −5 | 40 |  |  |
|  |  |  |  |

18）仓库有内径 的标准型旋风分离器多台，拟用以烟气除尘。烟气常

压，300℃，需处理量为 4300 。已知尘粒密度为 2250 。烟气的 与 可按空气计。由于压降限制，只允许旋风分离器并联操作，不允许串联操作，问：共需几台旋风分离器？能除去 40%的颗粒粒径是多少？进口风速 20

。

[解] : ①分离器进风口面积 *Bh*  *D*2 / 8, *ui*  20 *m*/ *s*

每台分离器处理气量 *ui Bh*  *ui D*2/ 8200.42/ 80.4 *m*3/ *s* 需分离器台数  4300（/0.4  3600)  2.99 ≈ 3台

* *d*500.27{ *D*/[ *ui* ( *ρs* − *ρ*)]}1/ 2

4300 / 3600

*u*1  3 0.42 / 8  19.91*m*/ *s*



常压、3000 *C*空气： *ρ*  0.615 *kg*/ *m*3 , **  2.97 10−5 *Pa s*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *d* 0.27[ | |  | * D* | ]1/ 2 |  |  |
|  |  |  |
| 50 |  | *ui* | ( *ρs* − *ρ*) | | |  |
|  |  |  |
|  | 2.97 10−5  0.4 1/ 2 | | | | |  |
|  0.27[ |  |  |  | | ] |  |
|  |  |  | |  |
|  | 19.91 (2250 − 0.615) | | | | |  |

* 4.40 10−6 *m*

查图知， *ηpi*  40 0 0 时， *d*/ *d*50  0.82.故能除去40 0 0 颗粒的粒径是



0.82 *d*50  0.82  4.40 10−6  3.6110−6 *m*

19）流体通过圆直、等径管内的阻力 与管长 、管内径 、管壁绝对粗糙

* 、流体流速 及流体的粘度与密度 有关。试用因次分析法求出有关的数据。

[解]①物理量数为7，基本因次为 *L*、 *τ*、 *M*,共三个，故准数共4个。

②取 *d*、 *u*、 *ρ*为“初始变量”，则各准数为：

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *π*1 |  |  | *l* |  | , *π*2 | |  | | *ε* | |  |
|  | *d x*1 *u y*1 *ρ z*1 | | *d x*2 *u y*2 *ρ z*2 | |  |
|  |  |  |  |  |  |  |  |
|  | ** | | |  |  |  |  |  | *hf* | |  |
| *π*3 |  |  |  |  |  | , *π*4  | |  | |  |  |
|  | *d x*3 *uy*3 *ρ z*3 | |  | *d x*4 *uy*4 *ρ z*4 | | |  |
|  |  |  |  |  |  |  |

* + *π*1的求取（又因次和谐原则求取）。

Q[1]  [ *d*] *x*1[ *u*] *y*1[ *ρ*] *z*1

* *L*  *Lx*1[ *L τ*−1] *y*1[ *M L*−3] *z*1

*L*:1 *x*1 *y*1−3 *z*1

*τ* : 0  − *y*1

*M* : 0 *z*1

*x*11, *y*10, *z*10

*π*1 *l*/ *d*

* + *π*2的求取：
* [ *ε*]  [ *d*] *x*2 [ *u*] *y*2 [ *ρ*] *z*2

即 *L*  *Lx*2[ *L τ*−1] *y*2[ *M L*−3] *z*2

同理可得： *π*2  *ε* / *d*

* *π*3的求取：
* [ **]  [ *d*] *x*3 [ *u*] *y*3 [ *ρ*] *z*3
  + *M τ*−1 *L*−1 *LX*3[ *L τ*−1] *y*3[ *M L*−3] *Z*3

*M* :1 *z*3

*τ* : −1  − *y*3

*L*:−1 *x*3 *y*3−3 *z*3

*x*31, *y*31, *z*31,

*π*3  **/( *d u* *ρ*)一般取 *Re*  *d u* *ρ*/ **

* *π*4的求取：
* [ *hf* ]  [ *d*] *x*4 [ *u*] *y*4 [ *ρ*] *z*4

即L2 *τ*−2  *Lx*4 [ *l* *τ*−1 ] *y*4 [ *M L*−3 ] *z*4

*M* : 0 *z*4

*τ* : −2  − *y*4

*L*: 2 *x*4 *y*4−3 *z*4

*x*40, *y*42, *z*40 *π*4 *hf* /( *u*2)

⑦准数一般为： *hf* / *u*2 *f*( *Re*, *ε* / *d*, *l*/ *d*)

20）某粉磨车间空气的粉尘浓度较高，拟用两台相同规格的标准型旋风分离器串

联操作除尘。空气常压，温度为 20℃，粉尘的颗粒密度 2250 。拟处理量

为 600 。空气中粉尘的粒度分布如下：



|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 粒径 | <3 | 3～6 | 6～10 | 10～16 | 16～30 | >30 |
| 质量分率% | 3 | 12 | 18 | 34 | 25 | 8 |

欲使 15 的尘粒除去效率达 99.75%，试确定每台分离器的内径，计算总的收尘效率。

[解]查图知， *ηdDi*  0.95, *d*/ *d*50  4.1,因要求15微米颗粒 *ηDi*  0.95

*d*5015 / 4.13.66微米

常压、200 *C*空气： *ρ*  1.205 *kg*/ *m*3 , **  1.8110−5 *Pa s*

* *d*500.27{1.8110−5 *D*/[ *ui* ( *ρs* − *ρ*)]}1/ 2

即3.66 10−6  0.27{1.8110−5 *D*/[ *ui* (1500 −1.205)]}1/ 2

*D*/ *ui* 0.0152

又Q *V*  *ui* *BH*  *ui* *D*2 / 8即600 / 3600  ( *D*/ 0.0152) *D*2 / 8 *D* 0.273 *m*, *ui* 17.94 *m*/ *s*

两极分离器串联操作的粒径效率， *η*  1 −（1 − *ηDi* )2

∴总除尘分率= ∑ *xiηi* =0.00807+0.0935+0.173+0.337+0.250+0.08=0.942

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 粒径（微米） | <3 | 3-6 | 6-10 | 10-16 | 16-30 | >30 |  |
|  |  |  |  |  |  |  |  |
| 平均粒径（微 | 1.5 | 4.5 | 8 | 13 | 23 | 30 |  |
| 米） |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
| D/d50 | 0.410 | 1.23 | 2.19 | 3.55 | 6.28 | 8.20 |  |
|  |  |  |  |  |  |  |  |
| *ηpi* | 0.145 | 0.53 | 0.80 | 0.91 | 0.99 | 1.00 |  |
| *ηi* | 0.269 | 0.779 | 0.96 | 0.992 | 0.999 | 1.00 |  |
|  |  |  |  |  |  |  |  |
| 质量分率 xi | 0.03 | 0.12 | 0.18 | 0.34 | 0.25 | 0.08 |  |
|  |  |  |  |  |  |  |  |
| *Xiηi* | 0.00807 | 0.0935 | 0.173 | 0.337 | 0.250 | 0.080 |  |
|  |  |  |  |  |  |  |  |

21）试 计算某气、固系流化床的起始流化速度与带出速度。已知固体颗粒平

均粒径为 150 ，颗粒密度为 2100 ，起始流化床层的空隙率为 0.46，

流化气体为常压、35℃的空气。最小颗粒了粒径为 98 。

[解]常压、350 *C*空气： *ρ*  1.147 *kg*/ *m*3 , **  1.89 10−5 *Pa s* ①按“白井−李伐”法计算 *umf* :

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ' |  |  |  |  | −3 | [ *ρ*( *ρ* | | *s* | − *ρ*)]0.94 | | | 1.82 |  |  |  |
| *umf* |  8.024 10 | | | |  |  |  |  |  |  |  | *dp* |  |  |  |
|  |  | *ρ* | | | **0.88 |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  8.024 10−3 | | | | [1.147(2100 −1.147)]0.94 | | | | | | | | |  (750 10−5 )1.82 |  0.311*m*/ *s* |  |
| 1.147  (1.89 10−5 )0.88 | | | | | | | | |  |
|  |  |  |  |  |  |  |
| *R* |  |  | 750 10−5 | | |  0.3111.147 | | | | |  |  14.2  10查线得： *ϕ*  0.9 | | |  |
|  |  |  |  |  |  |  |  |  |  |  |
| *e*, *mf* | | 1.89 10 | | | | | | −5 | |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |

*um*, *f* 0.9 *u*'*m*, *f* 0.90.3110.28 *m*/ *s*

②求带出速度 *ut* ,按最小颗粒且按圆球形估算：

判断：

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *dp*[ | *g* ( *ρs* − *ρ*) *ρ* | 1/ 3 |  | −6 |  | 9.81(2100 −1.147) | 1.147 1/ 3 | |  |  |
|  | ] |  398 10 |  | [ |  |  | ] |  16.1属于阿伦区 |  |
|  |  | (1.89 10−5 ) |  |  |
| **2 | |  |  |  |  | 2 |  |  |  |

则：

*ut*  0.27[9.81 398 10−5 (2100 −1.147) *R*0*ep*.5 ]1/ 2  0.27  (7.144  *R*0*ep*.5 )1/ 2 − − − − − −(1) 1.147



|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *u* | ** | | |  | *R*  | 1.89 10 | | −5 |  *R* |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
| *t* |  | *dp* | *ρ* | | *ep* | 39810−5 | 1.147 | | *ep* |  |
|  |  |  |  |  |

* 0.0414 *Rep* − − − − − − − − − −(2)

解得： *Rep* 59.34, *ut* 2.46 *m*/ *s*

22)试证流化最大速度与最小速度之比 ut /umf , 对小颗粒为 91.6，对大颗粒为 8.61。

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 | | 的项可略， | | | | | | | 且（1 − *εmf* ) /(*ψ*2 *ε*3*mf* ) ≈ 11 | | | | | | | | |  |
| 对小颗粒，欧根公式中含 u | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |
| 对大颗粒，欧根公式中含 *u*2得项可略，且1（/ *ψ ε*3*mf* )≈14 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |
| 解：①对小颗粒，沉降可认为属 Stokes 区： | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |
| *u*  | | *g dp*2( *ρs* − *ρ*) | | | | | | | |  |  |  | *u* |  |  |  |  |  | *g dp*2( *ρs* − *ρ*) | | | | | | | | |  |  | *u* | |  |
|  |  |  |  |  |  |  |  |  |  |  | *mf* | |  | | |  |  |  |  |  |  |  |  |  |  | | *t* |  1650 /18  91.6 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *t* | | | | 18 ** | | |  |  |  |  |  |  |  |  |  |  |  | 1650 ** | | | | |  |  |  |  |  | *umf* | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ②对大颗粒，沉降可认为属 Newton 区： | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |
| ∆ *P* 1.75 | | | | | | (1 − *ε*) | | | | | |  | *ρ u*2 | | |  |  |  *L*(1− *ε*)(( *ρ* | | | | | | | | − *ρ*) *g* | | |  |  | 省去下标 mf |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *m* | | | |  |  |  |  | *ε*2 |  |  |  |  | *ψ de*, *v* | | | | | | |  |  |  |  |  | *s* |  |  |  |  |  |  |  |
|  |  | *g d* | | | .*ψ* ( *ρ* | | | | *s* | − *ρ*).*ε* | | | | 3 | |  | 1/ 2 | | |  | | *g d* | | | ( *ρ* | | | − *ρ*) | 1/ 2 | | |  |
| *umf*  | | |  | *p* |  |  |  |  |  |  |  |  | *mf* | |  |  | | | ≈ |  |  |  | *p* |  |  | *s* |  |  | | |  |
|  |  |  |  | 1.75 *ρ* | | | | | |  |  |  |  |  | 1.75 14 *ρ* | | | | | | |  |
|  |  |  | |  |  |  |  |  |  |  |  | | |  | |  | | |  |
|  |  |  | |  |  |  | *g dp* ( *ρs* − *ρ*) | | | | | | | |  |  |  | | |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 又： *u* 1.74[ | | | | | | | ]1/ 2 | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | *t* | |  |  |  |  |  |  |  |  | *ρ* | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | *u* | |  |  |  |  | *g d p* | | | | ( *ρs* − *ρ*) *ρ*1.75 14 | | | | | | | | | | | | |  |  |  |  |  |  |  |  |
|  | *t* | | |  1.74[ | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ]1/ 2 | |  1.74(1.75 14)1/ 2  8.61 | | | | | |  |
| *umf* | | |  |  |  |  | *g d p* ( *ρs* − *ρ*) *ρ* | | | | | | | | | |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

23）石灰、水悬浮液通过增稠器增稠，进料：4.5kg 水/kg 固。要求增稠到 1.8kg 水/kg 固 。

间歇实验数据如下。

温度 200C。

[解]悬浮液浓度以 Xkg 固/kg 水表示，则 xi=1/4.5kg 固/kg 水，xc=1/1.8kg 固/kg 水，进料中固体质量流量 w=6.5×(1/5.5)=1.18kg 固/s

* ① 增稠器横截面积 A:（由题给数据计算 Ai）

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *A*≥ | | | | *W* | | | ( | 1 | − | 1 | ) | |  | ( *m*2 ) | |  |
|  | |  |  |  |  |  |
|  |  |  |  |  | *ρ u*0 | |  | *X XC* | | | |  |  |  |  |  |
| ∵ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 则： *A* ≥ | | | | | |  | 1.18 | | | |  |  |  |  | (4.5 −1.8)  31.86 *m*2 |  |
|  |  |  |  |  |  |  |  |  |  |
|  | 1 | | | | 1000  0.10 10−3 | | | | | | | | |  |  |  |
|  |  |  |  |  |  |  |  |
| *A* ≥ |  |  |  |  |  |  | 1.18 | | |  |  |  | (4.0 −1.8)  36.06 *m*2 | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2 | 1000  0.072 10 | | | | | | | | | | | −3 |  |  |  |  |
|  |  |  |  |  |
| *A* ≥ |  |  |  |  |  |  | 1.18 | | |  |  |  | (3.2 −1.8)  36.71*m*2 | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 3 | 1000  0.045 10 | | | | | | | | | | | −3 |  |  |  |  |
|  |  |  |  |  |
| *A* ≥ |  |  |  |  |  |  | 1.18 | | |  |  |  | (2.6 −1.8)  28.61*m*2 | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 4 | 1000  0.03310 | | | | | | | | | | | −3 |  |  |  |  |
|  |  |  |  |  |

实际 *A*1.336.7147.72 *m*（2安全系数取1.3)

# 第4章 传热及换热器

1）用平板法测定材料的导热系数，其主要部件为被测材料构成的平板，其一侧用电热器加热，另一侧用冷水将热量移走，同时板的两侧用热电偶测量其表面温度。设平板的导热面积为 0.03m2，厚度为 0.01m。测量数据如下：

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | 电热器 | | 材料的表面温度 | | ℃ |
| 安培数 A |  | 伏特数 V | 高温面 |  | 低温面 |
| 2.8 |  | 140 | 300 |  | 100 |
| 2.3 |  | 115 | 200 |  | 50 |
|  |  |  |  |  |  |

试求：①该材料的平均导热系数。②如该材料导热系数与温度的关系为线性：

，则λ0 和 a 值为多少？

[解]1） *Q*  ( *t*1 − *t*2 ) *λS*/ *L*  *VI*

(300 − 200)  0.03 *λ*1 / 0.01  2.8 140

*λ*1  0.6533 *w*/( *m* 0 *C*)

(200 − 50)  0.03 *λ*2 / 0.01  2.3115 *λ*2  0.5878 *w*/( *m* 0 *C*)

*λm*  ( *λ*1  *λ*2 ) / 2  0.6206 *w*/( *m* 0 *C*)

0.6533  *λ*0 [1  *a*(300 100) / 2] 0.5878  *λ*0 [1  *a*(200  50) / 2] 得 *λ*0  0.4786 *w*/( *m* 0 *C*)

*a* 0.001825

2）通过三层平壁热传导中，若测得各面的温度 t1、t2、t3 和 t4 分别为 500 ℃、400℃、200℃和 100℃，试求合平壁层热阻之比，假定各层壁面间接触良好 。

[解]*Q*  ( *T*1 − *T*2 ) / *R*1  ( *T*2 − *T*3 ) / *R*2  ( *T*3 − *T*4 ) / *R*3 *R*1： *R*2(500−400）：（400−200）1：2 *R*2： *R*3(400−200)：(200−100)2：1

*R*1： *R*2： *R*31：2：1

3）某燃烧炉的平壁由耐火砖、绝热砖和普通砖三种砌成，它们的导热系数分别为 1.2W/(m·℃)，0.16 W/(m·℃)和 0。92 W/(m·℃)，耐火砖和绝热转厚度都是 0.5m，普通砖厚度为 0.25m。已知炉内壁温为 1000℃，外壁温度为 55℃，设各层砖间接触良好，求每平方米炉壁散热速率。

[解] *Q*/ *S*  ( *t*1 − *t*2）/∑（ *bi* / *λi* )

* (1000 − 55) /[（0.5 /112)  (0.5 / 0.16)  (0.25 / 0.92)]
* 247.81 *w*/ *m*2

4）在外径 100mm 的蒸汽管道外包绝热层。绝热层的导热系数为 0.08 W/(m·℃)，已知蒸汽管外壁 150℃，要求绝热层外壁温度在 50℃以下，且每米管长的热损失不应超过 150W/m，试求绝热层厚度。

[解]*Q*/ *L*  2*πλ*( *t*1 − *t*2 ) / *Ln*( *r*2 / *r*1 )

* + 0.16*π*(150 − 50) *Ln*( *r*2 / 50)  150 *r*269.9 *mm*

壁厚为： *r*2− *r*169.9−5019.9 *mm*

5）Φ38×2.5mm 的钢管用作蒸汽管。为了减少热损失，在管外保温。 50 第一层是 mm 厚的氧化锌粉，其平均导热系数为 0.07 W/(m·℃)；第二层是 10mm

厚的石棉层，其平均导热系数为 0.15 W/(m·℃)。若管内壁温度为 180℃，石棉层外表面温度为 35℃，试求每米管长的热损失及两保温层界面处的温度？

解：①r0 = 16.5mm = 0.0165m ，r1 =19mm = 0.019 m r2 = r1＋δ1 = 0.019＋0.05 = 0.069 m

r3 = r2＋δ2 = 0.069＋0.01 = 0.079 m

λ0 = 45 W/(m·℃)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Q |  |  |  |  |  |  |  |  |  | 2π(t 0 | | | | | − t 3 ) | | | | | |  |  |  |  | |  |  |  |  |  |  |  | 2  314.  (180 − 35) | | | | | | | | | |  |  |  |  471. |  |  |
|  | L | 1 | |  |  |  | r1 | |  |  | 1 | |  |  |  |  | r2 | | 1 | |  | r3 |  | 1 | |  |  |  | 19 | | |  |  |  | 1 |  | 69 | 1 | |  | 79 | | |  |  |
|  |  |  |  |  |  | ln | |  |  |  | |  |  | ln | | | |  |  |  |  | ln |  |  |  |  |  |  | ln | | |  |  |  |  | | |  | ln |  |  |  |  | ln |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| m | |  |  | λ0 | | | | r0 | |  |  | λ1 | | | |  |  | r1 | |  | λ2 |  | r2 | 45 | | | | | |  |  | 165. | | | |  |  | 0.07 |  | 19 | 015. | | | 69 | |  |  | W/ |  |
|  |  |  | Q | | |  | 2π(t 2 − t 3 ) | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  | 2π(t | | | |  |  | − 35) | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  | | |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 47.1  | | | | 2 | |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  | |  |  | 1 | |  |  |  | r3 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | L | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | ln | |  |  |  |  |  |  |  |  | 1 | | | | |  |  | ln | | | 79 | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | λ2 |  | r2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | ② | | | | | |  |  |  |  |  |  |  |  |  |  |  | 即 |  |  | 015. | | | | | | | | 69 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

* t2 = 41.8 ℃

6）通过空心球壁导热的热流量 Q 的计算式为：，其中

，A1、A2 分别为球壁的内、外表面积，试推导此式。

解： *dQ*  *λdS*( *dt*/ *dn*)4*πλr*2 *dt*/ *dr*

积分限为： *r*  *r*1, *t*  *t*1; *r*  *r*2, *t*  *t*2.积分得：

*Q* 4*πλr*1 *r*2∆ *t*/( *r*2− *r*1)

*A*14*πr*1, *A*24*πr*2

*Am* 4*πr*1 *r*2 *Q*  *λAm*∆ *t*/ *b*

7）有一外径为 150mm 的钢管，为减少热损失，今在管外包以两层绝热层。

已知两种绝热材料的导热系数之比1，两层绝热层厚度相等皆为 30mm。试问应把哪一种材料包在里层时，管壁热损失小。设两种情况下两绝热层的总温差不变。

解：若小的 *λ*包在里层时：

*Q* 2 *πL*∆ *t*/{ *Ln*( *r*2/ *r*1) / *λ*1 *Ln*( *r*3/ *r*2) / *λ*2}

*r*175 *mm*, *r*27530105 *mm*, *r*3135 *mm*

* *λ*1  1, *λ*2  2

*Ln*( *r*2/ *r*1) / *λ*1 *Ln*( *r*3/ *r*2) / *λ*20.462

若大的包在里层是：

*Ln*( *r*2/ *r*1) / *λ*2 *Ln*( *r*3/ *r*2) / *λ*10.420

小的包在里层时，热损失小。

8）试用因次分析法推导壁面和流体间强制对流给热系数α的准数关联式。

已知α为下列变量的函数：。式中λ、CP、ρ、μ分别为流体的导热系数、等压热容、密度、粘度，u 为流体流速，l 为传热设备定型尺寸。

|  |  |  |  |
| --- | --- | --- | --- |
| 解： *α*  *Kλ*  *Cpb ρc d U e l f* | |  |  |
| 物理量 *λCP* | *ρ* | *u* | *lα* |
| 因次 *ML*/ *Tθ*3 *L*2/ *Tθ*2 | *M* / *L*3 *M* / *Lθ L*/ *θ* | | *L M* / *Tθ*3 |

根据因次一次性原则，建立方程

*M* / *Tθ*3  *M* *a* *c* *d* *La*2 *b*−3 *c*− *d* *e* *f* *θ*−3 *a*−2 *b*− *d*− *e* *T*− *a*− *b*

*a*2 *b*−3 *c*− *d*  *e* *f* 0

*a* *b* 1

*a* *c* *d* 1

3 *a* 2 *b* *d*  *e* 3

设已知 *c*、 *b*、 *d*

* + *a* 1− *b e*  *b*− *d*

*f* 3 *c*2 *d* −2 *b*−1

*αL*/ *λ*  *K*( *Luρ*/ **) *c* ( *CP */ *λ*) *b*

9）水流过φ60×3.5mm 的钢管，由 20℃被加热至 60℃。已知，水流速为 1.8m/s，试求水对管内壁的给热系数。

* : *t*  (20  60）/2  400 *C*查水的物性数据得：

*ρ*  992.2 *Kg*/ *m*3 , *CP*  4.174 *kJ* / *kg* 0 *C*, *λ*  0.6338*W* / *m* 0 *C*

*  0.6560 10−3 *Pa s*, *Pr*  4.32

*Re*  *di uρ*/ ** 0.0531.8992.2 /(0.65010−3)144292.5

*αi*  0.023 *λRe*0.8 *Pr*0.4 / *di*

* + 0.023 0.6338 144292.50.8  4.320.4
  + 6622 *w*/( *m*2 0 *C*)

10）空气流过φ36×2mm 的蛇管，流速为 15m/s，从 120℃降至 20℃，空气

压强 4×105Pa（绝压）。已知蛇管的曲率半径为 400mm，，试求空气对管壁的给热系数。空气的密度可按理想气体计算，其余物性可按常压处理。

* *t* (12020) / 2700 *C*

查空气物性得： *Pr* 0.694, ** 2.0610−5 *Pa s*, *λ* 0.0297 *w*/ *m* 0 *C*

*ρ*  *PM* /( *RT*)410529 /(8.314103343)4.07 *kg*/ *m*3

* *Re*  *duρ*/ **得 *Re* 9.48104

*α*  0.023 *λRe*0.8 *Pr*0.3 / *di*  183.3 *w*/( *m*2 0 *C*) *α*'  *α*(1 1.77  32 / 400)  209.6 *w*/( *m*2 0 *C*)

11）苯流过一套管换热器的环隙，自 20℃升至 80℃，该换热器的内管规格为φ19×2.5mm，外管规格为φ38×3mm。苯的流量为 1800kg/h。试求苯对内管壁的给热系数。

解： *t* (2080) / 2500 *C* 查苯的物性得：

*ρ*  860 *kg*/ *m*3 *CP* 1.8 *J* / *kg* 0 *C*

* +  0.45 *CPa* *λ*  0.14 *w*/( *m* 0 *C*) *de* 0.013 *m*

*Vs* 1800 /(3600860)0.00058 *m*3/ *s u* 4*VS* / *π*( *d*2− *d*1)1.11*m*/ *s*

*Pr* 1.81030.4510−3/ 0.145.79

*Re* 0.0131.11860 / 0.4510−32.78104

*α*  0.023 *λR*0*e*.8 *Pr*0.4 / *de*  1794 *w*/( *m*2 0 *C*)

12）冷冻盐水（25%的氯化钙溶液）从φ25×2.5mm、长度为 3m 的管内流过，流速为 0.3m/s，温度自-5℃升至 15℃。假设管壁平均温度为 20℃，试计算管壁与流体之间的平均对流给热系数。已知定性温度下冷冻盐水的物性数据如下：密度为 1230kg/m3，粘度为 4×10-3Pa·s，导热系数为 0.57 W/(m·℃)，比热为2.85kJ/(kg·℃)。壁温下的粘度为 2.5×10-3Pa·s。

解：d = 0.025－0.0025×2 = 0.02 m

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | L |  | |  | 3 | |  |  150 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  | |  |  50 | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ∴ d 0.02 | | | | | | | | |  |  |  | duρ | | |  |  | 0.02  0.3  1230 | | | | | | | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  | Re  | | | | | | |  | |  1845 | |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  | |  | |  | |  |  | | | |  |  |  |
| ∵ u = 0.3m/s | | | | | | | | | | ∴ | | |  |  |  |  |  | | |  |  |  |  |  |  |  | 4  10−3 | | | |  |  | ＜ 2000 | | ∴层流 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  | Cp | |  | | | |  | 2.85  103  4  10−3 | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |
| Pr  | | |  | |  |  |  | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  20 | | | |  |  |  |  |  |  |  |
|  | |  |  |  |  |  |  |  | 057. | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  | λ | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Re Pr di | | | | | L |  1845  20  0.020 | | | | | | | | | | | | | | | |  |  246 | | | | | | ＞100 | |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 3 | | |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | 1 | | |  | 1 | d | | | i |  |  | 13 | | |  0.14 | | | | | |  | λ | |  |  |  |  |  |  |  |  |
| α  186. Re 3 | | | | | | | | | Pr 3 | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  | d | |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  | L | | | | | |  | w | | | | |  |  |  |  |  |  |  |  |  |  |  |  |
|  186.  1845 | | | | | | | | | 1 | 3  20 | | | 1 | 3 |  0.020 | | | | | | | |  | 13 | | 4 | | | | 0.14 |  0.57 | | 0.02 |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 3 | | | |  |  |  |  |  | 2.5 | |  |  |  |  |  |



= 354.7 W/(m2 ℃)

13）室内分别水平放置两根长度相同，表面温度相同的蒸汽管，由于自然对

流两管都向周围散失热量，已知小管的，大管直径为小管的 8 倍 ，试求两管散失热量的比值为多少？

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 解：∵小管 Gr Pr = 108 | | | | | | |  | ∴b = 1/3 | | | | |  | 又因 Gr∝d0 | | 3，故大管 Gr Pr ＞108 | | | |  |
|  | Q | 大 |  | α | 大 | *∆*tπd | 大 | L | | α | 大 | d | 大 |  | Gr大 Pr大 13 d 大 | |  | d 2 | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  | 大 |  82  64 |  |
|  |  |  |  |  |  |  |  |  |  |  |  | Gr小Pr小 |  |  |  |
|  | Q | 小 | | α 小 *∆*tπd | | | 小 L | | | α 小 d 小 | | | |  | 13 d 小 |  | d 2小 | |  |
| 则 | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |



14）某烘房用水蒸汽通过管内对外散热以烘干湿纱布。已知水蒸汽绝压为

476.24kPa，设管外壁温度等于蒸汽温度现室温及湿纱布温度均为 20℃，试作如下计算：①使用一根 2m 长、外径 50mm 水煤气管，管子竖直放于水平放置单位时间散热量为多少？②若管子水平放置，试对比直径 25mm 和 50mm 水煤气管的单位时间单位面积散热之比。（管外只考虑自然对流给热）。

|  |  |  |
| --- | --- | --- |
| 解1)定性温度 *t*  (20 150) / 2 |  850 *C* |  |
| 查空气物性数据： *λ*  3.09 10−2 /( *m* 0 | | *C*) *ρ* 0.986 *kg*/ *m*3 |
| **  2.13 | 10−5 *Pa s* | *P* 0.691 |
|  |  | *r* |

*β*  1/ *T*  1/(273  85)  1/ 358(1/ *K*) ∆ *t* 150−201300 *C*

|  |  |  |
| --- | --- | --- |
| *v*  **/ *ρ* 2.1310−5/ 0.9862.1610−5 *m*2/ *s* | | |
| *G*  *βgL*3∆ *t*/ *v*2 |  |  |
| *r* |  |  |
| 水平管 *G* 954301.9 | *G P* 6.59105 *b* 1/ 4， *A*0.54 | |
| *r* | *r* | *r* |
| 垂直管 *G* '6.111010 | *G* | ' *P* 4.221010b1/ 3, *A*0.135 |
| *r* | *r* | *r* |

*α*  *λA*( *Gr Pr* ) *b* / *L*

*α*  3.09 10−2  0.54  (661400.66）1/ 4 / 0.05  9.51 *w*/( *m* 0 *C*) *α*'  3.09 10−2  0.135  (4.231010 )1/ 3 / 2  7.26 *w*/( *m* 0 *C*)

*Q*  *απdL*( *t*− *tw*)9.511300.052 *π* 388.2 *w Q*' *α*' *πdL*( *t*− *tw*)7.261300.052 *π* 296.4 *w*

2)若管子水平放置

*Q*25/ *Q*50 *α*25∆ *t*/ *α*50∆ *t*

* [( *Gr* *Pr* )125/4 / *d*25 ] /[( *Gr* *Pr* )150/4 / *d*50 ]
* ( *d*50 / *d*25 )( *d*25 / *d*50 )3 / 4
* ( *d*50 / *d*25 )1/ 4
* 1.189

15）油罐中装有水平蒸汽管以加热管内重油，重油温度为 20℃，蒸汽管外壁温为 120℃，在定性温度下重油物性数据如下：密度为 900kg/m3，比热 1.88 ×103J/(kg·℃)，导热系数为 0.175W/(m·℃)，运动粘度为 2×10-6m2/s，体积膨胀系数为 3×10-4 l/℃，管外径为 68mm，试计算蒸汽对重油的传热速度 W/m2。

* *Gr*  *β gL*3∆ *t*/ *v*2
* 310−4  9.81 0.0683 100 /(2 10−6 )2  2.313107 *Pr*  *CP */ *λ* 1.88103900210−6/ 0.17519.34

*Gr Pr* 4.474108 *A*0.135 *B* 1/ 3

*α*  *λA*( *Gr Pr* ) *b* / *L* 265.7 *w*/( *m* 0 *C*)

*Q*/ *S*  *α*∆ *t* 265.7(120−20)26570 *w*/ *m*2

16）有一双程列管换热器，煤油走壳程，其温度由 230℃降至 120℃，流量

* 25000kg/h，内有φ25×2.5mm 的钢管 70 根，每根管长 6m，管中心距为 32mm，

正方形排列。用圆缺型挡板（切去高度为直径的 25%），试求煤油的给热系数。

已知定性温度下煤油的物性数据为：比热为 2.6×103J/(kg·℃)，密度为 710 kg/m3，粘度为 3.2×10-4Pa·s，导热系数为 0.131 W/(m·℃)。挡板间距 ，壳体内径。

* *A* *hD*(1− *d*0/ *t*)0.240.48(1−25 / 32)0.0252 *m*2

*u*  *Vs* / *A*0.0388 *m*/ *s*

*de*

 4( *t*2

− *πd*2

/ 4) /

*πd* 

0.027 *m*

*Re*



*de uρ*/

**

2325

*Pr*



*CP */

*λ* 

6.35

*ϕ*  0.95

*α*  0.36 *λRe*0.55 *Pr*1/ 3  0.95 / *de*

* 0.36  0.131 23250.55  6.351/ 3  0.95 / 0.027
* 218.3 *w*/( *m* 0 *C*)

17）饱和温度为 100℃的水蒸汽在长为 2.5m，外径为 38mm 的竖直圆管外冷凝。管外壁温度为 92℃。试求每小时蒸汽冷凝量。又若将管子水平放置每小时蒸汽冷凝量又为多少。

解 : *ts*  1000 *C*时 *r*  2258 *kJ* / *kg*

定性温度 *t* 960 *C*

水的物性： *λ*  0.6816*W* /( *m* 0 *C*) *ρ* 961.16 *kg*/ *m*3

* + -  0.2969 10−3 *Pa s*

假定为滞流

*α*  1.13[ *gρ*2 *λ*3 *r*/( *L*∆ *t*)]1/ 4

* 1.13[9.81 961.162  0.68163  2258 / 2.5  0.2969  8]1/ 4
* 6496.17*W* /( *m* 0 *C*)

*Q*  *αS*( *ts* − *tw*)6496.17 *π* 0.0382.58

* 15510.32 *w*

*W*  *Q*/ *r* 0.006869 *kg*/ *s* 24.73 *kg*/ *h*

核算流型 *M*  *W* /( *πd*)0.006869 / 0.038*π* 0.0575 *kg*/ *m s Re* 4 *M* / ** 774.671800(符合假设）

管子水平放置： *α*’ *α* 0.725  ( *L*/ *d*)0.25 /1.13

* 11870*W* /( *m* 0 *C*)

*Q*' *αS*( *ts* − *tw*)11870 *π* 0.0382.58

* 28340.94 *w*

*W*'0.01255 *kg*/ *s* 45.18 *kg*/ *h*

核算流型 *Re*'1.827 *Re* 1415.51800(符合假设）

18）由 φ25×2.5mm、225 根长 2 米的管子按正方形直列组成的换热器，用 1.5 ×105Pa 的饱和蒸汽加热某液体，换热器水平放置。管外壁温度为 88℃，试求蒸汽冷凝量。

解 : 查得 *P*  1.5 105 *Pa ts*  111.10 *C r*  2228.74 *kJ* / *kg* 定性温度 *t* (111.188) / 299.550 *C*

*λ*  0.6820 *w*/( *m* 0 *C*) *ρ*  958.7 *kg*/ *m*3 **  0.2838 10−3 *Pa s* *α*  0.725 [ *gρ*2 *λ*3 *r*/( *n*2 / 3 *d*∆ *t*)]1/ 4

* 6486.2 *w*/( *m* 0 *C*)

*Q*  *α S*( *t*− *tw*)6486.2 *π* 0.025223.1225 *W*  *Q*/ *r* 2.375 *kg*/ *s*

19）设有 A、B 两平行固体平面，温度分别为 TA 和 TB（TA>TB）。为减少辐射散热，在这两平面间设置 n 片很薄的平行遮热板，设 A 所有平面的表面积相同，黑度相等，平板间距很小，试证明设置遮热板后 A 平面的散热速率为不装遮热板

时的倍。

证明： *C*1−2 *C*0/(1/∑11/∑2−1

Q∑ , *δ*不变 *C*1−2不变设 *C*  *C*1−2

放置前 *QA*− *B*  *CS*[( *TA* /100)4−( *TB* /100)4]

放置后 *QA*−1 *CS*[( *TA* /100)4−( *T*1/100）4]

*Q*1−2 *CS*[( *T*1/100)4−( *T*2/100）4]

M

*QA*− *B*  *CS*[( *TA* /100)4−( *TB* /100）4]

*QA*−1 *Q*1−2 *Q*2−3LL *Qn*− *B Q*  *QA*− *B*

当传热稳定时：

*QA*−1 *Q*1−2 *Q*2−3LL *Qn*− *B*

*Q*' *Q*/(1 *n*)

20）用热电偶测量管内空气温度，测得热电偶温度为 420℃，热电偶黑度为0.6，空气对热电偶的给热系数为 35 W/(m·℃)，管内壁温度为 300℃，试求空气温度。

解： *Q*  *αS*( *t*− *tw*) *C*1−2 *S*[( *T*1/100)4−( *T*2/100)4]35( *t*− 420)  5.67  0.6  (6.934 − 5.734 )

*t* 539.40 *C*

21）外径为 60mm 的管子，其外包有 20mm 厚的绝热层，绝热层材料导热系数

* 0.1 W/(m·℃)，管外壁温度为 350℃，外界温度为 15℃，试计算绝热层外壁温度。若欲使绝热层外壁温度再下降 5℃，绝热层厚度再增加多少。
* :1)*αT*  9.4  0.052( *tw* −15)

*αT* ( *tw* −15)  2 *πr*2 *L*  2 *πλL*(350 − *tw*) *Lnr*2 / *r*1

9.4( *tw* −15)  0.052( *tw* −15)2  0.1(350 − *tw*) /(0.05 *Ln*50 / 30)

试差得： *tw* 910 *C*

1. *αT* (86 −15) *r*2'  *λ*(350 − 86) / *Lnr*2' / *r*1

试差得： *r*250.6 *mm*

固绝热层厚度在增加0.6 *mm*

22）设计一燃烧炉，拟用三层砖，即耐火砖、绝热砖和普通砖。耐火砖和普通砖的厚度为 0.5m 和 0.25m。三种砖的系数分别为 1.02 W/(m·℃)、0.14 W/(m·℃)和 0.92 W/(m·℃)，已知耐火砖内侧为 1000℃，外壁温度为 35℃。试问绝热砖厚度至少为多少才能保证绝热砖温度不超过 940℃，普通砖不超过138℃。

解：（1000 − 34) /(0.5 /1.02  *b*2 / 0.14  0.25 / 0.92)  (1000 − *t*2 ) /(0.5 /1.02)

* *t*29400 *C* 解得 *b*20.997 *m*

(1000 − 35) /(0.5 /1.02  *b*2 /1.04  0.25 / 0.92)  ( *t*1 − 35) /(0.25 / 0.92)

* *t*11380 *C* 解得 *b*20.250 *m*

经核算 *t*2814.40 *C* 9400 *C*

以题意应选择 *b*2为0.250 *m*

23）为保证原油管道的输送，在管外设置蒸汽夹。对一段管路来说，设原油的给热系数为 420 W/(m·℃)，水蒸气冷凝给热系数为 104 W/(m·℃)。管子规格为φ35×2mm 钢管。试分别计算 Ki 和 K0，并计算各项热阻占总热阻的分率。

* : *dm*  0.035 0.031/ *Ln*(35 / 31)  0.033 *m*

1/ *K*0  1/104  0.002 0.035 /(45 0.033)  0.035 / 420 0.031

* 0.002835 *l*/[ *w*/( *m*2 0 *C*)]

*K*0398.3*W* /( *m*2 0 *C*)

1/ *Ki*  1/ *αi*  *bdi* / *λdm*  *di* / *α*0 *d*0

* 31/(35104 )  0.002 31/(45 33) 1/ 420
* 0.002511 *l*/[ *w*/( *m*2 0 *C*)]

*Ki* 398.3*W* /( *m*2 0 *C*)

计入污垢热阻 *Re*00.859810−4

*d*0 *Rei* / *di* 1.719710−435 / 311.9410−4

污垢热阻占：(0.8598 1.94) 10−4 /[0.002835  (0.8595 1.94) 10−4 ]

* 8.9 0 0



原油侧热阻占：0.035 /(420 0.031) / 0 002835  94.8 0 0



蒸汽侧热组占：1/10000 / 0.002835  3.5 0 0



管壁导热热阻占：0.002 0.035 /(45 0.033) / 0.002835  1.7 0 0



24）某列管换热器，用饱和水蒸汽加热某溶液，溶液在管内呈湍流。已知蒸汽冷凝给热系数为 104 W/(m·℃)，单管程溶液给热系数为 400W/(m·℃)，管壁导热及污垢热阻忽略不计，试求传热系数。若把单管程改为双管程，其它条件不变，此时总传热系数又为多少？

解：1）单管程

1/ *K*0  1/ *αi*  1/ *α*0  1/104 1/ 400  0.0026 *l*/[ *w*( *m*2  *C*)] *K*0384.6 *w*( *m*2 *C*)

2)改为双管层

管内流速提高一倍，则：

1/ *K*0  1/(20.8  *αi* ) 1/ *α*0  1/104 1/(400  20.8 )

*K*0651.1*w*/( *m*2 *C*)

25）一列管换热器，管子规格为φ25×2.5mm，管内流体的对流给热系数为100 W/(m·℃)，管外流体的对流给热系数为 2000 W/(m·℃)，已知两流体均为湍流流动，管内外两侧污垢热阻均为 0.0018 m·℃/W。试求：①传热系数 K 及各部分热阻的分配；②若管内流体流量提高一倍，传热系数有何变化？③若管外流体流量提高一倍，传热系数有何变化？

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 解：①Ri = R0 = 0.00118m2 ℃/W | | | | | | | | | | | | | | | | | | | |  |  | 钢管 λ = 45W/(m ℃) | |  |
|  |  | d m  | | | | d 0 − d i | | | | | | |  | | 0.025 − 0.020 | | | | | | |  0.022 | |  |
|  | |  | |  |  | |  |  | |  | | |  |  |
|  |  |  |  |  |  |  | ln | | d 0 | | |  |  |  |  | ln | 25 | |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | d i | | | 20 | | | | | |  |  |  |  | m |  |
|  | 1 |  | 1 | |  | | | bd0 | | |  | | | d0 | |  Ri  R0 | | | | | | |  |  |
|  |  |  |  |  | |  |  | |  |  |
|  | K0 | | α0 | | | |  | λd m | | | | |  | αi di | | | | | |  |  |  |  |  |
|  | | |  | 1 | |  |  | | | 0.0025  0.025 | | | | | | | |  | |  | 0.025 | |  2  0.00118 |  |
| 2000 | | | |  | | | | | | | | 100  0.02 | | |  |
|  |  |  | 45  0.022 | | | | | | | | | |  |  |  |  |  |

* 0.01542 1/(W/m2℃) K0 = 64.84 W/(m2 ℃)

热阻分配：

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  | R0  Ri | | | | | | | | |  | | | |  | 2  0.00118 | | | | | | | | | | | | | | |  0153.  153%. | | | | | | | |  |  |  |
|  |  |  |  |  |  | 1 | | |  |  |  |  |  |  |  |  |  | |  | | |  | | |  | |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 0.01542 | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 污垢： | | |  |  |  |  | K0 | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | 1 | | |  |  |  |  |  |  | 1 | | | 2000 | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | α0 | | |  |  |  |  |  |  |  |  324%. | | | | | | | | |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | 1 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | 0.01542 | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 管外： | | |  |  |  |  | K0 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | d 0 | | | | |  |  |  |  |  |  |  |  |  |  |  |  | 0.025 | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | αi d i | | | | | | |  | | | 100  0.02 | | | | | | | | | | | | |  |  |  811%. | | | | | | | |  |  |  |  |  |
|  |  |  |  |  |  | 1 | | |  |  |  |  |  |  |  |  |  |  |  | 0.01542 | | | | | | |  |  | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 管内： | | |  |  |  |  | K0 | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | bd 0 | | | | |  |  |  |  |  |  |  |  |  |  |  |  | 0.0025  0.025 | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | λd m | | | | | | |  |  |  | | |  |  |  |  |  | 45  0.022 | | | | | | | | | | |  |  |  |  |  0.41% | |  |  |  |  |
|  |  |  |  |  |  | 1 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 0.01542 | | | | | | | | | |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 管壁： | | |  |  |  |  | K | | | 0 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ② | W ′  2W | | | | | | | | | | ， | | | | | | |  |  |  |  |  |  | u | i | ′  2u | | | | | i | | | | | ， | | | | α | ′  20.8 | α | i | |  |
| i | | |  |  |  |  | i | | |  |  |  |  |  |  |  |  |  |  |  |  |  | i |  |  |
|  |  | 1 |  |  | | | | 1 |  | | | bd0 | | | | | | | | | | | |  | |  |  | d 0 | |  |  |  Ri  R0 | | | | | | | | |  |  |  |  |  |
|  |  | ′ | |  |  | | | |  | | | | | | | |  |  |  | |  |  |  |  |  |  |
|  |  |  |  |  |  | α0 | | |  |  | λd m | | | | | | | | | |  |  |  |  |  | ′ | d i | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | ∴ K0 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | αi | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | | | | |  | 1 | |  |  |  | | | | | 0.0025  0.025 | | | | | | | | | | | | | | | | | |  | | |  |  |  | 0.025 | |  |  |  2  0.00118 |  |
|  | 2000 | | | | |  | | | | | | | | | | | | | | | | | |  |  |  | 0.8  100  0.02 | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  | 45  0.022 | | | | | | | | | | | | |  |  |  |  |  | 2 | | | |  |  |



* 0.01010 m2℃/W K0 ′  98.99 W/( m2℃)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ③ W0 | | ′  2W0 | | | | |  | ， | α0 | | | ′  20.8 α0 | | | | |  |  |  |  |
|  |  | 1 |  |  | | 1 |  |  | bd 0 | |  | | | d 0 |  Ri  R0 | |  |  |  |  |
|  |  | ′ |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | α0 | ′ | | λd m | | |  |  | αi d i | | |  |  |  |  |
| ∴ K0 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  | |  |  | 1 | |  |  | | | 0.0025  0.025 | | |  |  | 0.025 |  2  0.00118 |  |
|  |  |  |  |  |  2000 | | |  | | | 100  0.02 | |  |
|  |  |  | 20.8 | | | |  |  | 45  0.022 | | | |  |  |  |

* 0.01521 m2℃/W K0 ′  65.74 W/( m2℃)

26)在列管换热器。用热水加热冷水，热水流量为4.5 103 *kg*/ *h*, 温度从950 *C*冷却到550 *C*,冷水温度从200 *C*升到500 *C*,总传热系数为2.8 103 *W* /( *m*2 0 *C*).试求：①冷水流量。

②两种流体做逆流时的平均温度差和所需要的换热面积。③两种流体做并流时的平均温度差和所需要的换热面积。④根据计算结果，对逆流和并流做一比较，可得到那些结论。解1）Q *Qh*  *QC*

*Wh Cph*∆ *T*  *WC Cpc*∆ *t*

*Cph* 4.181*kJ* / *kg*0 *C* *Cpc* 4.174 *kJ* / *kg*0 *C*

*WC* 6010 *kg*/ *h*

2)∆ *t*  (45 − 35) / *Ln*(45 / 35)  39.80 *C*

* *KS*∆ *tm*  *Wh Cph*∆ *T*
  1.  4.5 103  40  4.181103 /(3600  2.8 103  39.8)
* 1.89 *m*2

3)∆ *tm*  (75 − 5) / *Ln*(75 / 5)  25.850 *C*

同理 *S* 2.89 *m*2

4)略

27)有一台新的套管换热器，用水冷却油。水走内管，油与水逆流，内管为 *φ*19  3 *mm*，外管为 *φ*32  3 *mm*的钢管。水与油的流速分别为1.5 *m*/ *s*、0.8 *m*/ *s*,油的密度、比热、导热系数及粘度分别为860 *kg*/ *m*3、1.90 103 *J* /( *kg* 0 *C*)、0.15 *w*/( *m* 0 *C*)及1.8 10−3 *Pa s*.水的进出口温度为100 *C*和300 *C*,油的进口1000 *C*, 热损失忽略不计，试计算所需要的管长。

若管长增加20 0 0 ，其他条件不变，则油的出口温度为多少？设油的物性数据不变。若该换热器长期使用后，水侧及油侧的污垢热阻分别为3.5 10−4 *m*2 0 *C*/ *W*和 1.52 10−3 *m*2 0 *C*/ *W*,其他条件不变，则油的出口温度又为多少？



解：1） *t*  (30 10) / 2  200 *C*

查表得水的物性数据： *ρ*  998.2 *kg*/ *m*3 *CP*  4.183 *kJ* / *kg* 0 *C* *λ*  0.6 *w*/( *m* 0 *C*) **  110−3 *Pa s*

*WC*  *πρ*(19−6)210−61.5 / 40.199 *kg*/ *s Wh*  *πρ*(262−192)10−60.8 / 40.170 *kg*/ *s*

* 无热损失故 *Qh*  *Qc*

*Qh* 1.90.170(100− *T*2)

*Qc* 4.1830.99(30−10)16.648 *kJ* / *s*

*T*248.460 *C*

*Re* 0.0131.5998.2 / 0.00119464.910000

*Pr*  *Cp */ *λ* 7.02

*αi*  0.023 *λRe*0.8 *Pr*0.4 / *di*

* 6249.9 *w*/( *m* 0 *C*)

*de* (26−19)7 *mm*

*Re* 0.0070.8860 /(1.810−3)2675.610000111 *Pr*  *Cp */ *λ* 22.8

*φ*  1 − 6 105 / *Re*1.8  0.594

*α*0  0.023 0.914 *λR*0*e*.8 *Pr*0.3 / *de*

* 412.9 *w*/( *m* 0 *C*)

*λ*  45 *w*/( *m* 0 *C*) *dm*  (19 −13) *Ln*(19 /13)  15.8 *mm* 1/ *K*0  1/ *α*0  *bd*0 / *λdm*  *d*0 / *αi* *di*

* 0.0027361/[ *w*/( *m*2 0 *C*)]

∆ *tm* (70−38.46) / *Ln*(70 / 38.46)52.670 *C*

*S*  *Q*/ *K*∆ *tm* 16648 /(365.552.7)0.865 *m*2

*L*  *S*/ *πd* 0.865 / 0.019*π* 14.5 *m*

2)管长增加20 0 0 *S*'  1.2 *S*  0.4296 *m*



* 0.17 1.9 1000  323.0 *w*/ 0 *C*

*WC CPC* 0.1994.1831000832.4 *W* /0 *C*

*R*1 *Wh Cph* / *Wc Cpc* 323.0 / 832.40.388

*NTU*1 *KS*/(*Wh CPh* )365.51.20.865 / 323.01.175 *ε*1  1 − exp[ *NTU*1 (1 − *R*1 )]/{ *R*1 − exp[ *NTU*1 (1 − *R*1 )]}

* {1 − exp[1.175(1 − 0.388)]}/{0.388 − exp[1.175(1 − 0.388)]}
* 0.6323

*ε*1  ( *T*1 − *T*2' ) /( *T*1 − *t*1 )

*T*2' *T*1−0.6323( *T*1− *t*1)100−0.6323(100−10)43.10 *C*

即油的出口温度为43.10 *C*

此时冷却水温度为:

*t*2' *Wh Cph*(100−43.1) / *Wc Cpc* 100.388(100−43.1)1032.10 *C* 3)1/ *K*0'  0.002736  0.00035  0.00152  0.004604 *K*0'217.1*W* /( *m*2 0 *C*)

*NTU*1' *K*' *S*/(*Wh Cph*)217.10.865 // 323.00.5814 *R*1' *R*10.388

同理 *ε*1  ( *T*1 − *T*2' ) /( *T*1 − *t*1 )

*T*2' *T*1−0.4112( *T*1− *t*1)100−0.4112(100−10)63.00 *C* 即油的出口温度为63.00 *C*

28)在逆流换热器中，管子规格为 *φ*38  3 *mm*，用初温为150 *C*.的水将2.5 *kg*/ *s*的甲

苯由 800 *C*冷却到300 *C*,水走管程，水侧和甲苯侧的给热系数分别为2500W/( *m*2 0 *C*), 900*W* /( *m*2 0 *C*),污垢热阻忽略不计。若水的出口温度不能高于450 *C*,试求该换热器的传热面积。

解： *t* (8030) / 2550 *C*

查得甲苯的物性数据： *CP* 1.8 *kJ* / *kg*0 *C*

*Q* 2.51.8501032.25105 *J* / *s*

*dm* (38−32） *Ln*(38 / 32)35 *mm*

1/ *K*0  1/ *α*0  *bd*0 / *λ*  *d*0 / *αi* *di*

* 38 /(2500  32)  0.003 38 /(45  35) 1/ 900
* 0.001611/[*W* /( *m*2 0 *C*)]

*K*0603*W* /( *m*2 0 *C*)

∆ *tm* (35−15) / *Ln*(35 /15)23.60 *C*

*S* ≤225103/(60323.6)15.8 *m*2

29)两种流体在一列管换热器中逆流流动，热流体进出口温度为1000 *C*，出口温度为

600 *C*冷流体从200 *C*加热到500 *C*, 试求下列情况下的平均温差：

①换热器为单壳程，四管程。

②换热器为双管程，四管程。

解：1）∆ *tm*  (50 − 40) *Ln*(50 / 40)  44.80 *C*

*P*(50−20) /(100−20)0.375

*R*(100−60)（/50−20）1.33

查表得： *ϕ*∆ *t*1  0.91

∆ *tm*1 *ϕ*∆ *t*1∆ *tm* 40.80 *C* 2）查表得： *ϕ*∆ *t*2  0.97

∆ *tm*2 *ϕ*∆ *t*2∆ *tm* 43.50 *C*

30)在逆流换热器中，用水冷却某液体，水的进出口温度分别为150 *C*和 800 *C*，液

体的进出口温度分别为1500 *C*和750 *C*。现因生产任务要求液体进出口温度降至700 *C*，假设水和液体的进出口温度，流量及物性均不发生变化，换热器的损失忽略不计，试问此换热器管长增为原来的多少倍才能满足生产要求？

* :Q *Qh*  *QC*

*Wh Cph*∆ *T*  *Wc Cpc*∆ *t*

* *Wh Cph*(150−75) *Wc Cpc*(80−15) *Wh Cph*(150−70) *Wc Cpc*( *t*2'−15)

*t*2'84.30 *C*

∆ *tm* (70−60) *Ln*(70 / 60)64.90 *C*

∆ *t*'*m* (65.7−55) *Ln*(65.7 / 55)60.20 *C*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 又 *Q*  *KS*∆ *tm* | | | *Q*' *KS*'∆ *t*'*m* |  |
| 75*Wh* *Cph* | |  64.9 *KS* | |  |
| 80*W C* | *ph* |  60.2 *KS*' | |  |
| *h* |  |  |  |
| *S*'/ *S* 1.149 | | | 即 : *L*' / *L*  1.149 |  |

1. 120℃饱和水蒸汽将空气从 20℃加热至 80℃，空气流量 1.20×104kg/h。现有单程列管换热器，φ25×2.5mm 钢管 300 根，管长 3m，α0 = 104W/(m2℃)，污垢及管壁热阻不计。问此换热器能否满足要求。

t  20  80  50



解： 2 ℃

50℃空气，ρ = 1.093kg/m3，Cp = 1.005kJ/(kg ℃)，λ = 0.02824W/(m ℃)

* = 1.96×10-5 Pa s ，Pr = 0.698

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  | V | | | | | 120.  104 | | | | | |  |  |  |  |
| u  |  |  | |  | |  |  | |  |  |  |  |  |  |  |  32.4 | |  |
|  |  | |  | |  |  |  |  |  |  |  |  |  |
|  | n | |  | π | d 2 | | | | 3600  1093.  | | | π |  0.022 | |  300 |  |  |  |
|  | 4 |  | m/s |  |
|  |  |  |  |  |  |  |  | 4 | | | |  |  |  |  |  |
| Re  | | duρ | | | |  | | 0.020  32.4  1093. | | | | | |  361.  104 | | |  |  |
|  | | | |  | |  |  | | |  |
|  |  |  |  |  | |  |  |  |  | 196.  10−5 | | | | |  | ＞10000 | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *αi* | | | |  0.023 | | | | | | *λ* | Re0.8 Pr 0.4  0.023  | | | | 0.02824 | |  3.61104 0.8  0.6980.4 |  |
|  | 0.020 | |  |
| ∴ | | | |  |  |  |  |  |  | *d* | | | | |  |  |
|  |  |  |  |  |  | *i* | | | | |  |  |  |  |

* 154.5 W/(m2℃)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ∵α0＞＞αi | | | |  | ∴Ki = αi = 124.5 W/(m2℃) | |  |  |
|  |  |  |  | 120.  104 | |  |  |  |
|  |  |  |  |  |  |  | |  |
| Q = WcCpc∆t = | | | |  | 3600 ×1.005×60 = 201 kJ/s | | |  |
| 100 − 40 | | | |  655. | |  |  |  |
|  | ln | 100 |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |
| ∆tm =40 | | | |  | ℃ | |  |  |
| Q = KiAi∆tm 即 201×103 = 124.5Ai×65.5 | | | | | | | ∴Ai = 24.6 m2 |  |
| 又，Ai = nπdiL | | | |  | 即 24.6 = 300π×0.020L | | ∴ L = 1.31 m＜3 m |  |
| ∴ 满足要求 | | | |  |  |  |  |  |

32）某单壳程单管程列管换热器，用 1.8×105Pa 饱和水蒸汽加热空气，水蒸汽走壳程，其给热系数为 105 W/(m·℃)，空气走管内，进口温度 20℃，要求出口温度达 110℃，空气在管内流速为 10m/s。管子规格为φ25×2.5mm 的钢管，管数共 269 根。试求换热器的管长。

若将该换热器改为单壳程双管程，总管数减至 254 根。水蒸汽温度不变，空气的质量流量及进口温度不变，设各物性数据不变，换热器的管长亦不变，试求空气

的出口温度。

* : *t*  (20 110) / 2  650 *C*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 查空气物性数据： *CP* 1.007 *kJ* / *kg*0 *C* | | | | | *λ*  0.0294 *w*/ *m*0 *C* |
|  |  |  | *P* 0.695 ** 2.0410−5 *Pa s ρ* 1.045 *kg*/ *m*3 | | |
|  |  |  | *r* |  |  |
| 1.8 105 *Pa*的饱和水蒸气： *T*  116.60 *C* | | | | | *I* 2214.3 *KJ* / *kg* |
| 1) *Re*  10245.1  10000 | | | |  |  |
| *α* |  0.023 *λR* | 0.8 *P*0.4 | / *d* |  47.23 *w*/ *m*0 *C* |  |
| *i* | *e* | *r* | *i* |  |  |
| 每根管内: *W* | |  *πd*2 *uρ*/ 4 *π* 0.022101.0450.03283 *kg*/ *s* | | | |
|  | *C* |  |  |  |  |

|  |  |  |  |
| --- | --- | --- | --- |
| *Q*  *W C* | *PC* | ∆ *t* 0.0032831.007103900.29753 *kg*/ *s* |  |
| *C* |  |  |
| Q *α*0  *αi* | | *Ki*  *αi* |  |

∆ *tm* (96.6−6.6) / *Ln*(96.6 / 6.6)33.540 *C*

*Q*  *Ki Si*∆ *tm* *Si* 0.1878 *m*2

*Si*  *πdi L* *L* 3 *m*

2)质量流量不变 *u*'26910 / 254 / 221.18 *m*/ *s*

*α*'*i*  (21.18 /10)0.8  47.23  86.10 *w*/( *m* 0 *C*)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ' | ' | 2 | 0 | *C*) |  |
| *Ki* | *αi* |  83.00 *w*/( *m* |  |  |
| *W*' |  *π*( *n*/ 2) *d*2 *u*' *ρ*/ 4  0.8826 *kg*/ *s* | | | |  |
| *C* |  |  |  |  |  |
| Q *R*  0 | | *ϕ*∆ *t*  1 |  |  |  |

∆ *t*'*m* ( *t*2'−20) / *Ln*96.6 /(116.6− *t*2')

*Si*' *nπdi L* 2543.140.02347.85 *m*2

由方程： *Q*  *WC*' *CPC*∆ *t*

*Q*  *Ki*' *Si*'∆ *t*'*m*

解得 *t*2'115.70 *C*

33）一套管换热器，用热柴油加热原油，热柴油与原油进口温度分别为 155 ℃和 20℃。已知逆流操作时，柴油出口温度 50℃，原油出口 60℃，若采用并流

操作，两种油的流量、物性数据、初温和传热系数皆与逆流时相同，试问并流时柴油可冷却到多少温度？

解：逆流时： *Qh*  *Qc*

*Wh Cph*∆ *T*  *Wc Cpc*∆ *t*

* *Wh Cph*(150−50) *Wc Cpc*(60−20)

∆ *tm* (95−30) ln(95 / 30)56.40 *C*

|  |  |
| --- | --- |
| *Q*  *KS*∆ *tm* |  |
| *KS* 1.862*Wh Cph* | (1) |
| 并流时： *Qh*  *Qc* |  |
| *Wh Cph*∆ *T*  *Wc Cpc*∆ *t* |  |

* *Wh Cph*(155− *T*2') *Wc Cpc* ( *t*2'−20)∆ *t*'*m* [135−( *T*2'− *t*2')]/ ln135 /( *T*2'− *t*2')

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *Q*  *KS*∆ *t*'*m* | (2) |  |  |  |  |
| 联立方程（1）（2）解得： *T*'  64.70 | | | *C* | *t*' |  54.40 *C* |
|  |  | 2 |  | 2 |  |
| 即并流时柴油冷却到64.7 | | 0 *C* |  |  |  |

34）一套管换热器，冷、热流体的进口温度分别为 55℃和 115℃。并流操作时，冷、热流体的出口温度分别为 75℃和 95℃。试问逆流操作时，冷、热流体的出口温度分别为多少？假定流体物性数据与传热系数均为常量。

解：并流时： *Qh*  *Qc*

*Wh Cph*∆ *T*  *WC CpC*∆ *t*

则 *W C*（115−95） *W C* （75−55）

*h ph* *C pC*

∆ *tm* (60−20) / ln 60 / 2036.410 *C*

*Q*  *KS*∆ *tm*

*KS* 0.55*Wh Cph*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 逆流时： *W C*（115− *T*'） *W* | | | | | | *C* （ *t*' | − 55） |
|  |  | *h* | *ph* | 2 | *C* | *pC* 2 |  |
| 115 − *T*' | |  *t*' | − 55 | |  |  |  |
|  | 2 | 2 |  |  |  |  |  |
| Q∆ *t* |  *T*'−55 | |  | ∆ *t* 115− *T*' | |  |  |
| 1 | 2 |  |  | 2 | 2 |  |  |

∆ *t*1∆ *t*2

∆ *t*'*m* (∆ *t*1∆ *t*2) / 230( *T*2'− *t*2') / 2

115 − *T*2'  0.55[30  ( *T*2'− *t*2' ) / 2]

115 − *T*2'  *t*2' − 55

|  |  |  |  |
| --- | --- | --- | --- |
| 解得 *T*'93.70 | *C* | *t*' |  76.30 *C* |
| 2 |  | 2 |  |

35）一列管换热器，管外用 2.0×105Pa 的饱和水蒸汽加热空气，使空气温度从 20℃加热到 80℃，流量为 20000kg/h，现因生产任务变化，如空气流量增

* 50%，进、出口温度仍维持不变，问在原换热器中采用什么方法可完成新的生产任务？

解：200 *kPa*饱和水蒸气温度为： *T*  120.20 *C*

∆ *tm* (120.2−20)−(120.2−80) / ln(120.2−20) /(120.2−80)65.70 *C*

|  |  |  |  |
| --- | --- | --- | --- |
| 《 | *α*气 | *K*  *α*空 |  |
| Q *α*空 |  |

*Q*  *KS*∆ *tm* 65.7 *ks*

*Q*' *K*' *S*∆ *tm*'

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *K* | ' | ‘ |  1.5 | 0.8 | *α*空  1.38 *K* |  |
|  | *α*空 |  |  |
| *Q*' | |  1.38 *KS*∆ *t*'*m* | | | *Q*'1.5 *Q* ∆ *t*'*m* 71.40 *C* |  |

Q空气的进出口温度不变

∆ *t*'*m* 60 / ln( *T*'−20) /( *T*'−80) *T*'125.570 *C*

查的饱和水蒸气压力为234.3 *kPa*,

所以可通过调节饱和蒸汽压力至234.3 *kPa*完成新任务。’

36）在一单管程列管式换热器中，将 2000kg/h 的空气从 20℃加热到 80℃，空气在钢质列管内作湍流流动，管外用饱和水蒸汽加热。列管总数为 200 根，长度为 6m，管子规格为φ38×3mm。现因生产要求需要设计一台新换热器，其空气处理量保持不变，但管数改为 400 根，管子规格改为φ19×1.5mm，操作条件不变，试求此新换热器的管子长度为多少米？

解：Q据题意 *Q*  *Q*'

*Q*  *KS*总∆ *tm*

|  |  |  |  |
| --- | --- | --- | --- |
| Q *α*0  *αi* | |  | *Ki*  *αi* |
| *u*' | / *u*  *nd*2 | | /( *nd*'2 ) |
| *i* | *i* | *i* | *i* |

*αi u*0*i*.8 *d*0*i*.2

*α*'*i* / *αi*  ( *u*'*i* / *ui* )0.8 ( *di* / *di*' )0.2

*α*'*i* / *αi*  (200  322 /(400 162 )0.8  (32 /16)0.2  2

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Q *α*'*i* / *αi*  2 *K*'*i*  2 *Ki* | | | | |  |  |  |
| *S*总 *nLπdi* | | | ‘ | ' ' |  | ' |  |
| *S*总 | *n Lπdi* | | |  |
| ' | ' | ‘ | ' | ' | ' | ∆ *tm* |  |
| *Q* |  *Ki* | *S*总∆ *tm* |  2 *Ki* *n Lπdi* | |  |  |

*Q*  *Ki S*总∆ *tm*  *Ki nLπdi*∆ *tm*

*L*'1/ 2( *n*/ *n*')( *di* / *di*') *L* 3 *m*

37）在单程列管换热器内，用 120℃的饱和水蒸汽将列管内的水从 30℃加热

* 60℃，水流经换热器允许的压降为 3.5Pa。列管直径为φ25×2.5mm，长为 6m，换热器的热负荷为 2500kW。试计算：①列管换热器的列管数；②基于管子外表面积的传热系数 K。

假设：列管为光滑管，摩擦系数可按柏拉修斯方程计算，。

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| t  | | | 30  60 | | | | | | | | |  45 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  | |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 解：(1) | |  |  |  |  |  | 2 |  |  |  |  |  |  | ℃ | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 45℃时水：ρ = 990kg/m3 ,Cp = 4.174×103 J/(kg℃)，λ = 64.03×10-2W/(m℃) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |
|  = 60.12×10-5Pa s | | | | | | | | | | | | | | | | | | ，Pr = 3.925 | | | | | | | | | |  |  |  |  |  |  |  |  |  |
| *∆*p  λ | L |  | | | ρu | | 2 |  |  | |  |  |  | 0.3164 | | |  |  |  | L |  |  | ρu | 2 |  | |  | 0.3164  6  990 | |  |  |  u | 1.75 |  35.  10 | 3 |  |
| d |  |  |  |  |  | duρ 0.25 | | | | | | | d | |  |  |  | 0.020  990 0.25 | | | |  |  |  |
|  | 2 | | | | |  |  |  |  |  |  | 2 | |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  | |  | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  | |  | | | |  |  |  |  |  |  |  |  |  | 2  0.020  | | | −5 | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 6012.  10 | |  |  |  |  |  |  |  |
| ∴ u = 1.00m/s | | | | | | | | |  | 60 − 30 | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *∆*t m  | | | | | | | |  |  |  |  |  73.99 | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | ln | | | 120 − 30 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | 120 − 60 | | | | |  |  |  |  |  | ℃ | | | | |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 设管壁及污垢热阻可略 | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ∵α0＞＞αi | | | | | | | | | | | | | | ∴Ki = αi | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 对一根管， | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Q′  | | | | π | | d 2 | | | u | | |  |  | ρ C | (t | | |  | − t | | | )  | | π | |  0.022 | |  100.  990  4174  (60 − 30) | | | | | |  |  |  |
|  | |  |  |  | 4 | |  |  |  |
|  |  | 4 | | | |  | i | |  |  |  | i | | p |  |  |  | 2 | 1 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |



* + 3.895×104 W
* *Q*′ *Ko πdo L* ∆ *tm* ，即3.895104= 5.231030.02673.99
* *Ko* = 1.117×103W/(m2℃)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| (2) |  | ′ |  |  |  |
| *Q*总 *nQ* | |  |  |  |
|  | 2500  103 | | |  |  |
|  | n  |  |  |  64.2 |  |
|  |  | 4 |  |
| ∴ | 3895.  10 | | 取 n 为 64 根。 |  |

38）有一立式单管程列管换热器，其规格如下：管径φ25×2.5mm，管长 3m，管数 30 根。现用该换热器冷凝冷却 CS2 饱和蒸汽，从饱和温度 46℃冷却到 10℃。 CS2 走管外，其流量为 250kg/h，冷凝潜热为 356kJ/kg，液体 CS2 的比热为

1.05kJ/(kg·℃ )。水走管内与 CS2 呈逆流流动，冷却谁进出温度分别为 5℃和 30 ℃。已知 CS2 冷凝和冷却时传热系数（以外表面积计）分别为

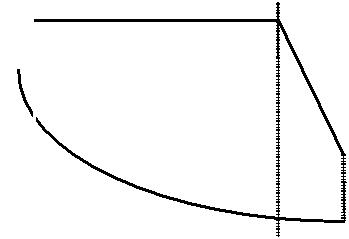
和。问此换热器是否合用？

250

解： Q  Wh r  Cp Ts − T2   3600 356  105.  46 − 10  27.35 kJ/s



设换热器上部为蒸汽冷凝段,以下标“1”表示,下部为冷却段,以“2”表示



|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Q | 1 | 250 |  356  24.72 |  |  |  |  |
| 则 |  |  | 3600 | kJ/s | T1=46 |  |  |  |
|  |  | ℃ |  |
|  |  |  |  |  |  |  |  |  |



|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Q2  250 | | | |  105.  36  2.63 | | | | | | | | | | kJ/s |  |  |  | t2=30℃ | | |  | Q1 | Q2 T2=10℃ |  |
|  | 3600 | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 设冷水 Cp 为常量，则上下两段分界处 t3： | | | | | | | | | | | | | | | | | |  |  |  |  |  | t3 t1=5℃ |  |
| Q1 | t 2 − t 3  | | | | | − t1  | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Q  |  |  |  | t 2 | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 24.72 | 27.35  | | | 30 − t 3  | | | | | 30 − 5 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 即 |  |  |  |  |  |  |  | ∴t3 = 7.4℃ | | | | | | |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| A | 1  | | Q1 | | |  |  |  | 24.72  103 | | | | | |  |  |  |  4.14 | | |  |  |  |  |
| K1 *∆*t m,1 | | |  |  |  |  |  | 30 − 7.4 | | |  |  |  |  |  |  |  |
|  |  |  | 232.6  | | | | |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | 46 − 7.4 | | |  | | |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  | ln | |  |  |  | | |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 于是： |  |  |  |  |  |  |  |  |  |  |  | 46 − 30 | | |  | | |  | 2 | |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | m |  |  |  |  |
| A 2 |  |  | Q | 2 |  |  |  |  | 2.63  103 | | | | | |  |  |  |  |  |  137. |  |  |  |  |
| K2 *∆*t m,2 | | | |  |  |  | 46 − 7.4 − 10 − 5 | | | | | | | | |  |  |  |  |  |
|  |  | 1168.  | | | |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | 46 − 7.4 | | | | |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  | ln | |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  | 10 − 5 | | | | |  |  |  | m | 2 |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |



∴A = A1＋A2 = 4.14＋1.37 = 5.51m2(以外表面积计)

现有换热器 A＇= nπd0L = 300.0253 = 7.07 m2＞ A 故能适用。

39）现有两台规格完全一样的列管换热器，其中一台每小时可以将一定量气体自 80℃冷却到 60℃，冷却水温度自 20℃升到 30℃，气体在管内与冷却水呈逆流流动，已知总传热系数（以内表面积为基准）Ki 为 40 W/(m·℃)。现将两台换热器并联使用，忽略管壁热阻、垢层热阻、热损失及因空气出口温度变化所引起的物性变化。试求：①并联使用时总传热系数；②并联使用时每个换热器的气体出口温度；③若两换热器串联使用，其气体出口温度又为多少（冷却水进出每个换热器的温度不变）？

解：**单台**：Wh Cph(T1－T2) = Wc Cpc(t2－t1)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Wh Cph |  | t | 2 | | − t | 1 | |  | | 30 − 20 | |  |  0.5 | |  |  |  |  |  |
| ∴ Wc Cpc | |  |  | |  |  | |  |  |  |  |  |  |  |  |
|  | T1 − T2 | | | | |  |  |  | 80 − 60 | | |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | *∆*t m  | | 50 − 40 | | |  44.8 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ln | 50 |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Wh Cph(T1－T2) = Ki Ai ∆tm， | | | | | | | | | | | | | | 40 | | | |  | ℃ |  |
|  | Wh Cph |  | K | | i | *∆*t | | m | |  | 40  44.8 | | | |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | |  | |  |  89.6 | |  |  |  |  |
| ∴A i | |  |  |  |  |  |  | |  | |  |  |  |  |  |
|  | T1 − T2 | | | | | | | |  | 80 − 60 | | | | | | |  |  |

**二台并联**： Ki ′ ≈ αi ′  0.50.8 αi  0.50.8  40  22.97 W/(m2 ℃)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Wh | | Cph | |  | (T − T ′ )  | | | (T − t | ′ ) − (T | | | | ′ | − t | 1 | ) | |  |  |  |  |  |  |  |
|  |  |  |  |  |  | 1 | 2 |  |  | 2 | |  |  |  |  |  |  |  |  |  |  |
|  |  | ′ |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |
|  | K | 2A |  | 1 | | 2 |  |  |  | T − t | |  | ′ |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |
|  |  | i |  | i |  |  |  |  | ln | | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | T ′ | − t | | 1 |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | 2 | |  |  |  |  |  |  |  | ′ ) − (T2 | | ′ − 20) | |  |  |
|  |  | 89.6 | |  |  |  (T | − T | ′ )  195.  (80 − T | | | | | | | ′ )  | | | (80 − t 2 | |  |  |
|  |  |  |  |  |  |  | |  | | ′ | |  |  |
| 2  22.97 | | | | | 1 | | 2 | |  |  |  |  |  | 2 | |  |  |  |  |  | 80 − t 2 |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | ln |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 即 | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | T ′ − 20 | | | ……① |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 | |  |  |  |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  | Wh | |  | Cph |  05.  | | | | | t | ′ | − 20 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  | Wc Cpc | | | |  |  |  | ′ | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 又 | | | | | |  |  |  |  |  |  |  | 80 − T2…………………………………………② | | | | | | | | | | | | | | | | | |  |
| 由①、②式联立，解得 | | | | | | | | | | | | | | |  | T2′= 57.6℃，t2′= 31.2℃ | | | | | | | | | | | |  |  |  |  |
|  |  |  |  | Wh | |  | Cph |  | (T − T ′ )  | | | | | | | (T − t | | 2 | ′ ) − (T | | | ′ | − t | ) | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | 1 |  | 2 | | | | 1 |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  | |  | |  |  |  |  |  |  |  |  |  |
|  |  |  |  | Ki | | 2A i | |  |  | 1 | | 2 |  |  |  |  |  |  |  | T1 − t 2 | | ′ |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  | ln | | |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **二台串联**： | | | | | |  |  |  |  |  |  |  |  |  |  |  | T ′ − t | | 1 |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  | 2 | |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | |  | |  |  |  | | | | | | | |  |  | (80 − t 2 | | | | ′ ) − (T2 | | | ′ − 20) | |  |  |
|  | 89.6 | | | |  (80 − T | | | | | ′ )  112.  (80 − T | | | | | | | | |  | ′ )  |  |  |
|  |  |  | | |  |  | | | |  | | | ′ | |  |  |
| 2  40 | | | | |  |  |  | 2 | |  |  |  |  |  |  |  |  | 2 | | |  |  |  |  |  | 80 − t 2 | |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ln | |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 即: | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | T ′ − 20 | | | | ………③ |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | ′ − 20 | | |  |  |  |  |  |  |  |  |  |  | 2 | | |  |  |  |
|  |  | Wh Cph | | | |  |  05.  | | |  | t |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | Wc Cpc | | | |  |  |  |  |  | ′ |  | ……………………………………………④ | | | | | | | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| 又： | | | | | |  |  |  |  |  | 80 − T2 | | | |  |  |

③、④式联立，解得：T2′=48.2℃ ， t2′ = 35.9℃

40）拟设计一台列管换热器，20kg/s 的某油品走壳程，温度自 160℃降至 115 ℃，热量用于加热 28kg/s 的原油。原油进口温度为 25℃，两种油的密度均为870kg/m3。其他物性数据如下：

|  |  |  |  |
| --- | --- | --- | --- |
| 名称 | CP kJ/(kg·℃) | μ Pa·s | λ W/(m·℃) |
| 原油 | 1.99 | 2.9×10-3 | 0.136 |
| 油品 | 2.20 | 5.2×10-3 | 0.119 |
| 解：(略) |  |  |  |

# 第6章 气体吸收

1）1）总压 100 ，温度 25℃的空气与水长时间接触，水中的 的浓度为多少？分别用摩尔浓度和摩尔分率表示。空气中 的体积百分率为 0.79。

解：将空气看作理想气体：y=0.79

p\*=yp=79kPa

查表得 E=8.76×105 kPa

*x*  *p*\* / *E* 10−6

H= *ρ*/( *EMS*)  1000 /(8.76 105 18)  6.342 10−6 *kmoL*/( *kN*. *m*)

C=p\*.H=79×6.342×10-5=5.01×10-4kmol/m3

2）2）已知常压、25℃下某体系的平衡关系符合亨利定律，亨利系数 E 为 大气压，溶质 A 的分压为 0.54 大气压的混合气体分别与三种溶液

接触： ① 溶质 A 浓度为  的水溶液； ② 溶质 A 浓度为

的水溶液；③溶质 A 浓度为 的水溶液。试求上述三种情况下溶质 A 在二相间的转移方向。

解： E=0.15×104atm，p=0.054atm，P=1atm，y=p/P=0.054 m  E  015.  104



* P

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| x1  |  | 0.02 | | |  |  |  |  3.6  10−5 | |  |  |  |
| 1  103 | | | | 18 | |  |  |  |
|  |  |  |  |  |  |  |
| ∴ y1\* |  |  |  |  |  |  | ∴ *∆*y  y − y1\* |  |  |  |
|  |  |  |  mx1  0.054 | | | | |  0 | ∴平衡 |  |
| x2  |  | | | 0.001 | |  |  |  18.  10−5 | |  |  |  |
| 1  103 | | | | 18 | | |  |  |  |
| ② |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
| ∴ y\*2  mx2 | | | | | |  0.027 | | | ∴ *∆*y  y − y\*2 f 0 | | ∴气相转移至液相 |  |
| x3  |  | | 0.003 | | |  |  |  5.4  10−5 | |  |  |  |
| 1  103 | | | | 18 | | |  |  |  |
| ③ |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
| ∴ y\*3 |  |  |  |  mx3  0.081 | | | | | ∴ *∆*y  y − y\*3 p 0 | | ∴液相转移至气相 |  |
| ④ P=3atm | | | | | y=0.054 | | | | E=0.15×104atm | |  |  |
| ∴m=E/P=0.05×104 | | | | | | | | | |  |  |  |
| x4=x3=5.4×10-5 | | | | | | | | |  |  |  |  |
| ∴ y\*4 |  |  |  |  mx4 |  0.027 | | | | ∴ *∆*y  y − y\*4 | f 0 | ∴气相转移至液相 |  |



3）3）某气、液逆流的吸收塔，以清水吸收空气～硫化氢混合气中的硫化氢。总



压为 1 大气压。已知塔底气相中含 1.5%（摩尔分率），水中含

的浓度为 （摩尔分率）。试求塔底 温度分别为 5℃及 30℃时的吸收过程推动力。

解：查表得（50C） E1=3.19×104kpa m1=E1/P=315

p\*1=Ex=0.319105 1.8 10−5  0.5724 *KPa*

*y*\*1 *p*\*1/ *P* 0.5742 /101.330.0057

*y*.10.015

气相推动力：∆ *y*1 *y*1− *y*\*10.0093

液相推动力：∆ *x*1 *x*\*1− *x*1 *y*1/ *m*− *x*12.9610−5

查表得（300 *C*）： *E*2  6.17 104 *KPa*, *m*2  *E*2 / *p*  609 *p*\*2 *E*2 *x* 6.171041.810−51.1106 *kpa*

*y*\*2 *p*\*2/ *P* 1.1106 /101.330.011

气相推动力：∆ *y*2 *y*2− *y*\*20.0040

液相推动力：∆ *x*2 *x*\*2− *x*2 *y*2/ *m*2− *x*26.6310−6

4）4）总压为 100 ，温度为 15℃时 的亨利系数 E 为 。

试计算：①H、m 的值（对稀水溶液密度为 ）；②若空气中

的分压为 50 ，试求与其相平衡的水溶液浓度，分别以摩尔分率和摩尔浓度表示。

解：1） *H*  *EMs*/ *ρg*  1.22 105  18 /(103 )  2196 *kN*. *m*/ *KmoL* *m* *E*/ *P* 1.22105/1001220

1. *p*  *Ex*
2.  1.22 105 *x* *x* 4.1010−4

*p*  *HC*

50  2196 *C*

*C* 0.023k *mo*l / *m*3

5）5）在总压为 100 、水温为 30℃鼓泡吸收器中，通入纯 ，经充分接

触后测得水中 的平衡溶解度为 溶液，溶液的密度可

近似取为 ，试求亨利系数。

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 解： p\*=100KPa | | | |  |  |  |
| H  | C |  | 2.857  10−2 |  2.857  10 | −4 |  |
| p\* | 100 | (mol/L)/kPa |  |
|  |  |  |  |
|  |  |  |  |  |  |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | ρ | 103 | |  |  | 5 |  |  |
| E  |  |  |  |  |  1945.  10 |  |  |  |
| HMs |  | −4  18 |  |  |  |
|  | 2.857  10 | |  | kPa |  |  |
| 6）6）组分 A 通过另一停滞组分 B 进行扩散，若总压为 | | | | | | | ，扩散两端组 |  |



* A 的分压分别为 23.2  和 6.5  。实验测得的传质系数  为 。若在相同的操作条件和组分浓度下，组分 A 和 B

进行等分子扩散，试分别求传质系数 和传质速率 。

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 解：pA1=23.2KPa | | | | | pA2=6.5KPa | | | | pB1=P－pA1=78.1KPa | | pB2=94.8KPa |  |
|  |  | D |  | |  | D |  |  | P |  |  |  |
| k G |  |  | P |  |  |  |  141.  10 | −5 mol / (m2 s Pa) |  |
|  |  | RTδ | pB1 − pB2  | |  |
|  |  | RTδ pBm | | |  |  |  |  |  |



ln pB2



pB1

* 1.  12.  10−5 mol / (m2 s Pa)
* RTδ



|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| k | ′ |  | D |  12.  10−5 mol / (m2 s Pa) |  |
| G |  |  |
| ∴ |  | RTδ | |  |

∴ *NA*′ *kG*′ *pA*1− *pA*22.010−4 *kmol*/( *m*2 *s*)

7）7）已知：柏油路面积水 ，水温 20℃，空气总压 100 ，空气中水

汽分压 1.5 ，设路面积水上方始终有 厚的静止空气层。问柏油路面积水吹干需多长时间？

解：该过程可看作一组分通过另一停滞组分的扩散过程

查表得

200C 时 水的饱和蒸汽压为 P=1.5kPa

依题意

*pA*1=2.3346kPa

*pA*2=1.5kPa

*pB*1100−2.334697.6654 *kPa*

*pB*2100−1.598.5 *kPa*

*pBm* ( *pB*1− *pB*2) / *Ln*( *pB*1/ *pB*2)98.08 *kPa*

由表得：

00 *C*水的扩散系数 *D*  0.22 10−4 *m*2 / *s*

200 *C*水的扩散系数 *D*  0.248 10−4 *m*2 / *s*

*NA*  *Dp*( *pA*1− *pA*2) /( *RTZPBm* )

* 0.24810−4 100  (2.2346 −1.5) /(8.314  293 0.2510−3  98.08)
* 3.46 10−5 *KmoL*/( *m*2  *s*)

以为扩散为稳定扩散，所以

*NA*  *ρ h*/( *M Aθ*)K*θ*  *ρh*/( *M A NA*)

*θ*  1000  310−3 /(18  3.46 10−5 )  4.808 103 *s*

8）8）试分别计算 0℃及 101.3 下 、 在空气中的扩散系数，并与实验值进行比较分析。

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 解：(1) |  |  | A：CO2，B：空气，MA=44，MB=29 | | | | | | | | | | | | | | | | | | | | | |  |  |
| VB=29.9，VA=34.0，P=101.3KPa，t = 273.2K | | | | | | | | | | | | | | | | | | | | | | | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  | 1 | | | |  |  |  |  |  |  | | 1 |  |  |  |
|  |  |  |  |  |  |  | −5 | |  | 1.5 | | 1 | | | |  | 2 |  |  |  |
|  | 4.36  10 | | | | | |  |  | T |  |  |  |  |  |  |  | |  |  |  |  | |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| D  | | | |  |  |  |  |  |  |  |  | MA | | | |  |  | M B | | | | |  |  1155.  10−5 m2 | |  |
|  | PVA 13  VB 13 2 | | | | | | | | | | | | | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | s |  |
| (2)A：SO2，B：空气，MA=64，MB=29 | | | | | | | | | | | | | | | | | | | | | | | | |  |  |
| VB=29.9，VA=44.8，P=101.3KPa，t = 273.2K | | | | | | | | | | | | | | | | | | | | | | | | |  |  |
|  |  |  |  |  |  |  |  | 1.5 | | | |  |  |  |  |  | 1 | | | 1 |  |  |  |  |  |  |
|  | 4.36  10 | | | | −5 | T | | 1 | |  |  |  | 2 | |  |  |  |  |  |
|  |  |  |  | |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |
| D  | | |  | |  |  |  |  | MA | | | | | | |  | M B | | |  |  |  |  9.822  10−6 m2 | | |  |
|  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  | PVA 13  VB 13 2 | | | | | | | | | | | | | | | |  |  |  |  |  | s |  |
| 9）9）试计算 | | | | |  | 在 35℃水中的扩散系数，并与实验值进行比较分析。 | | | | | | | | | | | | | | | | | | | |  |
| 解： A：HCl，B：H2O，MB=18，α=2.6 | | | | | | | | | | | | | | | | | | | | | | | | |  |  |
| VA=3.7+21.6=25.3，T=308.2K，μ=0.7225cp | | | | | | | | | | | | | | | | | | | | | | | | |  |  |
| D  |  | 7.4  10−8 αM B 0.5 T | | | | | | | | | | | |  311.  10 | | | | | | | | | −5 cm2 | |  |  |
|  |  | | | | | | | | | | | |  |  |
|  |  |  |  |  | 0.6 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | s |  |  |
|  |  |  |  | VA | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 10） | 10） | | | | 某传质过程的总压为 300 | | | | | | | | | | | | | | | | | | | | ，吸收过程传质系数分别为 |  |
|  |  |  |  |  |  |  |  |  |  |  |  | 、 | | | |  |  |  |  |  |  |  |  |  | ，气液相平衡关系符合亨利定 |  |



律，亨利系数 E 为 ，试求：①吸收过程传质总系数 和 ；②液相中的传质阻力为气相的多少倍。

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | m  | | E |  3557. |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 解：10. (1)E = 10.67×103kPa，P = 300kPa， | | | | | | | | | | | | | | | | | | | | |  | P | |  |
|  | 1 |  | | 1 |  |  | | m | |  | |  | 1 | |  | 3557. |  |  |  |  |  |  |  |  |
|  | Ky | k y | |  |  | 107. | | |  |  |  |  |  |  |  |  |
|  |  |  |  |  | k x | | | | 22 | |  |  | ∴Ky = 0.3919 | | | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 | |  |  | 1 | |  |  | | 1 | |  |  | |  | 1 | |  |  | 1 |  |  |  |  |  |
|  | Kx |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |
|  |  |  | mk y k x | | | | | | | | 3557.  107. | | | | | | 22 | | ∴Kx | = 13.94 | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | m |  | 1 |  |  |
|  | k x |  | k x | 173. |  |
|  | 1 | 1 |  |
|  |  |  |  |
| (2) | k y |  | mk y |  |  |
|  |  |  |  |  |



11）在填料塔内以水吸收空气～氨混合气中的氨。已知：总压 P 为 1 大气压，温

度 t 为 20 ℃ ，亨利系数 E 为  ，气相体积传质分系数  为

，液相体积传质分系数 为 。气相中含氨 5.4%（体积），液相中含氨 0.062（摩尔分率），液相可按稀溶液处理。试求气、液界面处平衡的浓度以及气相传质阻力占总阻力的分率。

解：m=E/P=76.6/101.33=0.756

∴ y=0.054 x=0.062 c=1000/18=55.56kmoL/m 3

*kym*  *p* *kam* 101.334.2510−40.0431*kmoL*/( *m*3 *s*)

在界面处： *y*1 *mx*1

*kym* ( *y*− *y*1) *kxm* ( *x*1− *x*2)

*y*10.756 *x*1

4.3110−2 (0.054 − *y*1 )  0.323( *x*1 − 0.062)

|  |  |
| --- | --- |
| 得： *x*10.0629 | *y*10.0475 |

1/ *kym*  1/ *kym*  *m*/ *kxm*  1/ 0.0431  0.756 / 0.323  25.54

气相阻力占总阻力分率为： *η* 1/(0.043125.54)90.800



12)若某组分在气相中的摩尔分率保持不变，将其总压增大一倍，但其质量流速

不变，试分析 和 的变化情况？

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | *D* | | |  |  |  |  |  |  |  |  |  | ln | | *pB*2 | |  | |  |  |
|  |  | *P* | |  | *DP* | | |  |  | *p* | *B*1 | |  |  |  |
|  |  |  |  |  |  |  |  |  |
| *kg*  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *RTδ* | | | *p* | |  *RTδ p* | | | | | | |  | − *p* | | | |  |  |
|  |  |  |  |  |
| 解： |  |  |  |  | *Bm* | |  |  |  |  |  |  |  | *B*2 | |  |  | *B*1 | |  |  |
| D | | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| P | |  | ∵P↑, DP 不变，(pB2－pB1)’=2(pB2－pB1) | | | | | | | | | | | | | | | |  |
|  |  |  |  |
|  |  |  |  |  | k | |  | ′  | | 1 | k |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | g |  | g | | |  |  |  |  |  |  |  |
|  |  |  |  |  | ∴ | | 2 | | |  |  |  |  |  |  |  |  |
|  |  |  |  |  | ∵ky=Pkg | | | | | | |  | ∴ | | k | ′ |  k | | |  |  |
|  |  |  |  |  |  |  | y |  |  |  | y |  |

NA=ky(y1－y2) ∴ N A ′  N A

13)用填料塔进行逆流吸收操作，在操作条件下，气相、液相传质系数分别为 和 。试分别计算相平衡常数 为 0.1 和 100

时，吸收传质过程的传质阻力分配情况。若气相传质分系数 ，当气相流量 G 增加一倍时，试分别计算上述两种情况下总传质系数增大的倍数。

解：①ky = 0.013 kmol/(m2 s)， kx = 0.026 kmol/(m2 s)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |  |  | 1 | |  76.92 | | ｍ | |  3846. | | | |  |  |
| m = 0.1 时， | | | | | | | | | | |  | k y |  | k |  |  |
|  |  |  | , |  |  | x |  |  |  |  |  |
|  | 1 |  |  | |  | 1 |  |  |  | *m* | |  80.769 *Ky*  0.01238 | | | | | |  |  |  |  |  |
|  |  | *ky* | |  |  |  |  |  |  |  |
|  | *Ky* | | |  |  |  |  | *kx* |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 | | *ky* | | : 1 | | |  |  0.9524  95.24% | | | | | | |  |  | *m* | : | | 1 |  4.76% |  |
|  |  |  |  |  |  | *Ky* | | |  |  |  |  |  |  | *kx* |  |  | *Ky* |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  0.769 | |  | 1 | *k* |  |  38.462 | |  |
|  | m = 100 时， | | | | | | | | | | | | *mk* | , |  |  |  |
|  |  | *y* |  |  |  | *x* |  |  |  |
| 1 | | | |  |  | | 1 | |  | | 1 | |  39.231 *Ky* | | |  0.02549 | | | | |  |  |
|  |  |  |  |  |  | |  | *mky* |  |  |
|  |  | *Kx* | | | | | | *kx* | | |  |  |  |  |  |  |  |  |  |  |  |
| 1 | | | | : | | |  | 1 |  |  |  0.9804  98.04% | | | | |  | 1 |  |  | : 1 |  1.96% |  |
|  |  |  |  | *kx* | | | | *Kx* | | |  |  |  |  |  |  |  | *mky* | | | *Kx* |  |



* G′= 2G，ky′= 20.8ky=0.02263



|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | 1 | |  |  |  |  | 1 | | |  |  |  | *m* | | |  |  |  | *Ky* ' |  |  |  |
|  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  48.027 *Ky* '  0.02082 | | | |  | *Ky* |  1.784 |  |
| m = 0.1 时， | | *K*' | |  |  |  | *k*' |  |  | *k* |  |  |  |
| *y* | | | |  | *y* | | | | *x* | |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | 1 | | |  |  |  | 1 | | |  | |  |  | 1 | |  |  38.904 | *Kx* '0.0257 | *Kx* | ' |  1.008 |  |
| m = 100 时， | |  | *K*' | |  | |  | *k* |  |  | *mk*' | | |  |  | *Kx* |  |
|  | *x* | | |  | *x* | | | | *y* | |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |



1. 对低浓度气体吸收，当平衡关系为直线时，试证明：



式中 分别为塔底与塔顶两端面上的气相吸收推动力。

证明： *NOG* ( *y*1− *y*2) /∆ *ym*

* ( *y*1 − *y*2 )( *Ln*∆ *y*1 / ∆ *y*2 ) /[( *y*1 − *mx*2 ) − ( *y*2 − *mx*2 )]
* ( *Ln*∆ *y*1 / ∆ *y*2 ) /[1 − *m*( *x*1 − *x*2 ) /( *y*1− *y*2 )]
* *Ln*(∆ *y*1/∆ *y*2) /(1− *mG*/ *L*)

15）用纯溶剂对低浓度气体作逆流吸收，可溶组分的回收率为 ，实际液气比

为最小液气比的 倍。物系平衡关系服从亨利定律。试以 两个参数列出

计算 的计算式。

解：令进塔气体浓度为 y1，则出塔气体浓度为 *y*2  *y*1(1− *η* ) *x*20

*L*/ *G*  *β*( *L*/ *G*)min *β*( *y*1− *y*2) / *x*\*1 *βηm*

* *L*/ *G* ( *y*1− *y*2) /( *x*1− *x*2)

*βη m* [( *y*1− *y*1(1− *η*)]/ *x*1 *x*1 *y*1/ *mβ*

由上题证明的结果： *NOG* ( *Ln*∆ *y*1/∆ *y*2) /(1− *mG*/ *L*)

又∆ *y*1 *y*1− *mx*1 *y*1− *y*1/ *β*

∆ *y*2 *y*2−0 *y*1(1− *η*)

∆ *y*1/∆ *y*2( *β* −1) /[ *β*(1− *η*)]

*NOG*  *β η Ln*[( *β* −1) / *β*(1− *η*)]/( *β η* −1)

16 ）在一逆流吸收塔中，用清水吸收混合气体中的  ，气相流量为 （标准状况），进塔气体中含 6.0%（体积），要求条件下的平

衡关系 ，操作液气比为最小液气比的 1.6 倍。试求：⑴吸收剂用量和出塔液体组成；⑵写出操作线方程；⑶气相总传质单元数。

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Vy2 | | Lx2 | | 解： | x2 = 0，y1 | | | = 0.06，y2 = 0.06(1－0.95) = 0.003 | | | | |  |
|  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | PV | |  |  |
|  |  |  |  |  |  |  |  |  | n  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | V = 300m | 3 | /h = 12.27kmol/h， | |  | RT | | , m = 1200 |  |
|  |  |  |  |  |  |  |  |  |  |



|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  | L | |  | |  | y | 1 | | − y | 2 |  |  |  | y | 1 | − y | | 2 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | |  |  |  |  |  | y1 | | |  |  |
|  |  |  |  |  | V min | | | | |  | y1 | | \* − x2 | | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | m |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Vy1 | | Lx1 | | L | |  |  | L | |  |  |  |  |  |  |  | y1 − y 2 | | | | | |  |  |
|  |  |  |  |  |  16. | | |  |  |  |  |  |  |  16. | |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  | y1 | |  |  |  |  |  |
|  |  |  |  | V | |  |  | V | | min | |  |  |  |  |  |  |  |  |  |  |  |
|  |  | ∴L = 22380.48 kmol/h | | | | | |  |  |  |  |  |  |  |  |  |  |  | m | |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |



V(y1－y2) = L(x1－x2) = Lx1

* x1 = 3.125×10-5

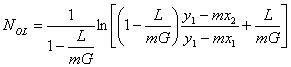
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | L | | | |  |  |  |  |  |  |  |  | L | |  | |  |  | L | |  |  |  |  |  |  |  |  |
| y  | |  |  | x  | | y | | | |  | − | | |  | x |  | |  | |  |  | x  y | |  |  |  1824x  0.003 | | |  |
|  |  |  | V | |  |  |  |
| (2) |  | V | | | |  |  |  |  | 2 |  |  |  | V | | 2 | |  |  |  |  | 2 | |  |  |  |  |
|  |  |  |  |  |  |  |  | L | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  | A  | | | |  |  |  |  |  152. | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |
| (3) (3) | |  | mV | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | 1 | | | |  |  |  |  |  |  | | | | | 1 y | | | | 1 | − mx | | 2 |  |  |  | 1 | |  |
| N | oG |  |  |  |  |  |  |  |  | ln | | | 1 − | | |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | 1 | |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  | 1 − | |  |  |  |  |  | | | | | A y | | | | 2 − mx2 | | | | | |  | A | |  |
|  |  |  |  |  |  |  |  |  |  |  |

A

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | | |  |  | 1 | | y | 1 |  | 1 |  |  |  |
|  |  |  |  | ln 1 − |  |  |  |  |  |  |  589. |  |
|  |  |  |  |  |  |  |  |
|  |  | 1 |  |  |  |  |  |  |  |  |  |  |
| 1 − | |  |  | A y 2 | | | |  | A | |  |  |
|  |  |  |  |

A

17）试按吸收因数法推导出以液相浓度差为推动力的吸收过程传质单元数计算



式：

证明： *NOL* ∫ *x*1 *dx*/( *x*\*− *x*)

*x*2

*y*  *y*1/ *m*− *L*( *x*1− *x*) / *G*

*x*\* *y*1/ *m*− *L*( *x*1− *x*) / *G*

*x*1

*NOG* ∫*x*2 *dx*/[( *y*1/ *m*− *L*( *x*1− *x* ) / *Gm*− *x*]

 { *Ln*[(1 − *L*/ *mG*) *x*2  ( *L*/ *mG*) / *x*1 − *y*1 / *m* ( *L*/ *mG*) *y*1 −

( *L*/ *mG*) *y*1 ] /[(1 − *L*/ *mG*) *x*1  ( *L*/ *mG*) *x*1 − *y*1 / *m*]}/[1 − *L*/( *mG*)]  { *Ln*[(1 − *L*/ *mG*)( *y*1 / *m*− *x*2 )  ( *L*/ *mG*)( *y*1 / *m*− *x*1 )]/ ( *y*1 / *m*− *x*1 )}/(1 − *L*/ *mG*)

* { *Ln*[(1 − *L*/ *mG*)( *y*1 − *mx*2 ) /( *y*1 − *mx*1 )  *L*/ *mG*]}/(1  *L*/ *mG*)

18）以清水在填料塔内逆流吸收空气～氨混合气中的氨，进塔气中含氨 4.0%（体

积），要求回收率 为 0.96，气相流率 G 为 。采用的液气比为

最小液气比的 1.6 倍，平衡关系为



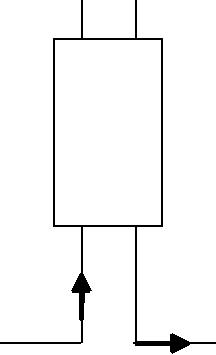
。试求：①塔底液相浓度

，总传质系数 ；②所需填料层高度

。

为

y2  x2 解：



y11

x1

1. *y*2 *y*1(1− *η*)0.040.040.0016

*L*/ *G* 1.6( *L*/ *G*)min1.6( *y*1− *y*2) /( *y*1/ *m*− *x*2)1.413

*Mm* 0.04170.962928.52 *kg*/ *kmoL*

*G* 0.35 / 28.520.01227 *kmol*/( *m*2 *s*)

*L* 1.413*G* 0.017338 *kmol*/( *m*2 *s*)

*L*/ *G* ( *y*1− *y*2) / *x*1

*x*10.0272

1. *HOG*  *G*/ *Kym* 0.01227 / 0.0430.2853 *m*

*NOG* ( *y*1− *y*2) /∆ *ym*

∆ *ym* [( *y*1− *mx*1)− *y*2] / *Ln*[( *y*1− *mx*1) / *y*2]

* + - * (0.04 − 0.92  0.0272 − 0.0016) / *Ln*[(0.04 − 0.92  0.0272) / 0.0016
    - 0.00598

*NOG*6.41

*H*  *HOG*  *NOG* 0.28536.411.83 *m*

19）接上题，若气、液相接触改为并流操作，气、液流量及进口浓度都不变，填料层高度为上题算出的 ，操作温度、压强亦不变，问回收率 为多少？

解： *x*10 且汽流量不变

* *y*1− *y*2) / *x*2 *L*/ *G* 1.413

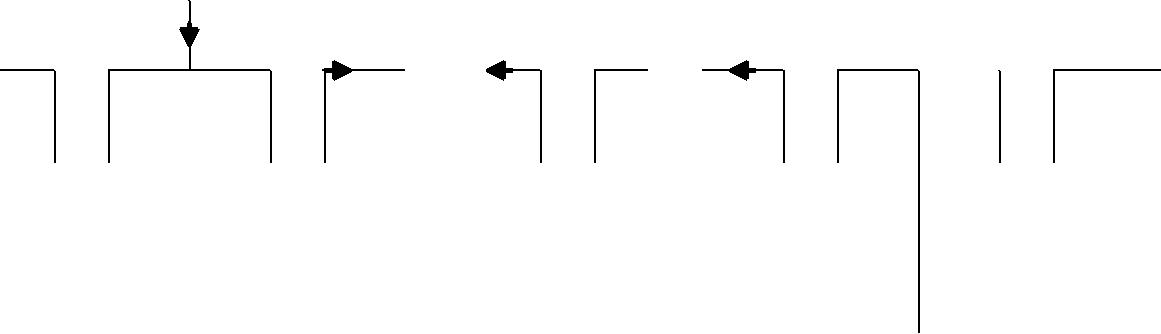
因 *H*及操作温度，压强不变 *NOG* 6.41

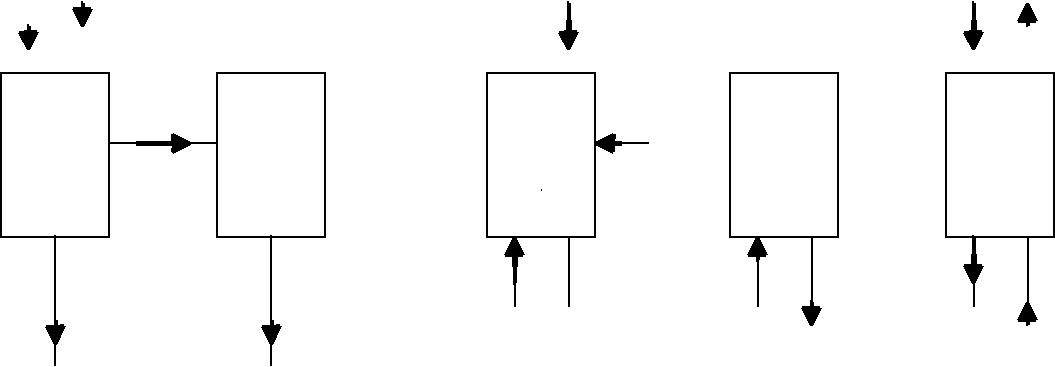
∆ *ym* [ *y*1−( *y*2− *mx*2)]/ *Ln*[ *y*1/( *y*2− *mx*2)] *y*1− *y*21.413 *x*2

( *y*1 − *y*2 ) / ∆ *ym*  6.41

联立上面三式 得：

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *y* 0.01584 *η* '1− *y* / *y* 1−0.01584 / 0.0460.6 | | | | 0 |  |
| 2 | 2 | 1 |  | 0 |  |
| 20）试在“y～x”图中定性画出下列各吸收流程的操作线与平衡线 | | | | |  |
| G,y1 | L | x2 | y3y2 | L1,x2 y2 | x3 |
| L,x2 | y4 |  |  |  |  |





L2x3

y2

L2=L1/2



L/2,x1 L/2,x3 G,y1 L3,x1 G1,x3 x1 G1=G2

G2,y3

21）在一逆流接触的填料吸收塔中，用纯水吸收空气～氨混合气中的氨，入塔气

体中含 9%，要求吸收率为 95%，吸收剂用量为最小用量的 1.2 倍，操作条

件下的平衡关系为 。传质单元高度为 0.8m。试求：①填料层高度 ；

②若改用含 0.05%（摩尔分率）的稀氨水作吸收剂， 及其它条件均不变 ，吸收率为多少？

解：1）

*y*10.09 *x*20 *y*2(1−0.95)0.090.0045

*L*/ *G* 1.2( *L*/ *G*)min1.2(0.09−0.0045) /(0.09 /1.2)1.368

*x*1 *G*( *y*1− *y*2) / *L* (0.09−0.0045) /1 3680.0625

∆ *y*10.09−0.06251.20.015∆ *y*20.0045

∆ *ym* (0.015−0.0045) / *Ln*(0.015 / 0.0045)0.00872

*NOG* (0.09−0.0045) / 0.008729.8

*H* 9.80.87.84 *m*

2) *y*10.09 *x*10.0625 *x*20.0005

* *L*/ *G*不变

（ *y*1− *y*2) /( *x*1− *x*2)1.368

解得： *y*20.0052

*η*  1 − *y*2 / *y*`  1 − (0.0052 / 0.09)  94.24 0 0



22）以清水在填料塔内逆流吸收空气～二氧化硫混合气中的 ，总压为 1 ，温度为 20℃，填料层高为 4m。混合气流量为 1.68 ，其中含 为 0.05（摩尔分率），要求回收率 90%，塔底流出液体浓度为 。

试求：①总体积传质系数 ；②若要求回收率提高至 95%，操作条件不变，要求的填料层高度为多少？

解：1） *Mm*  64  0.05  29  0.95  30.75

*G* 1.68 / 30.750.055 *kmol*/( *m*2 *s*)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 查表(200 *C*) |  | *E* 0.355 | | 104 *kPa* |
|  | *m*  *E*/ *P* 35 | | |  |
| 由 *G*( *y* − *y* ) *L*( *x* − *x* ) | | | | *L* 2.475 *kmol*( *m*2 *s*) |
| 1 | 2 | 1 | 2 |  |

∆ *y*1 *y*1− *mx*10.05−350.0010.015∆ *y*20.005

∆ *ym* (0.015−0.005) / *Ln*30.0091

*NOG* (0.05−0.005) / 0.00914.94

|  |  |
| --- | --- |
| *H*  *NOG*  *HOG*  *G* *NOG* / *Kym* |  |
| *Kym* 0.068 *kmol*/( *m*2 *s*) | *HOG* 0.81*m* |
| 2） *y*2  0.05(1 − 0.95)  0.0025 |  |
| 由 *G*( *y*1− *y*2) *L*( *x*1− *x*2) | *x*10.001056 |

∆ *y*1 *y*1− *mx*10.05−350.0010560.01304∆ *y*2 *y*20.0025

∆ *ym* (0.01304−0.0025) / *Ln*(130.4 / 25)0.00638

1.  0.81 7.45  6.04 *m*

23 ） 接 上 题 ， 若 液 体 流 量 增 大 15% ， 其 它 操 作 条 件 不 变 。 已 知 ， 。式中： 的

单位是 。问回收率 为多少？

解： *L*0 *G*( *y*− *y*) / *x*0.0546(0.05−0.005)10002.457 *kmol*/( *m*2 *s*)

*L*1.15 *L*02.83 *kmol*/( *m*2 *s*)

*kya* 1.570.05460.72.830.250.266 *kmol*/( *m*3 *s*)

*kxa* 1.622.830.823.797 *kmol*/( *s m*3)

1/ *Kya*  *m*/ *kxa*  1/ *kya*  35 / 3.797  1/ 0.266  12.98 *Kya* 0.077 *kmol*/( *s m*3)

*HOG*  *G*/ *Kya* 0.0546 / 0.0770.71*m*

* *NOG*  *H* / *HOG* 4 / 0.715.65

∆ *ym* (0.05−35 *x*1− *y*2) / *Ln*[(0.05−35 *x*1) / *y*2] *NOG* (0.05− *y*2) /∆ *ym*

又 ( *y*1 − *y*2 ) / *x*1 

可得 *y*20.0029

*L*/ *G*

即得 (0.05 −

*x*10.00091

*y*2) / *x*1

51.75

*η* ' *y*2/ *y*10.942

24）一逆流操作的吸收塔中，如果 为 0.75，相平衡关系为 ，吸收

剂进塔浓度 为 0 .0 0 1（摩尔分率，下同）进气浓度为 0.05 时，其回收率为 90%，试求进气浓度为 0.04 时，其回收率为多少？若吸收剂进口浓度为零，其它条件不变，则其回收率又如何？

解：依题意： *NOG*不变

*NOG* { *Ln*[(1− *mG*/ *L*)( *y*1− *mx*2) /( *y*2− *mx*2) *mG*/ *L*]] /(1− *mG*/ *L*)

*mG*/ *L*不变，故 （ *y*1− *mx*2) /( *y*2− *mx*2)保持不变

( *y*1 − *mx*2 ) /( *y*2 − *mx*2 )  (0.05 − 2  0.001) /(0.005 − 2  0.001)  16

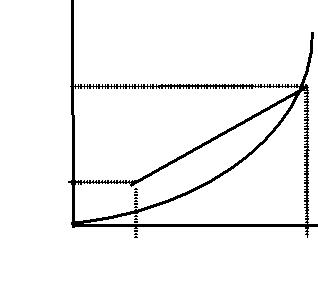
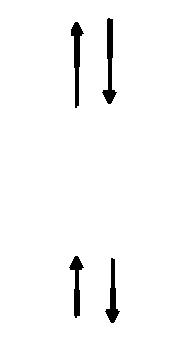
|  |  |  |  |
| --- | --- | --- | --- |
| 1) | 由 (0.04 − 2  0.001) | | /[0.04(1 − *η* ) − 2  0.001]  16 |
|  | 可推出 | *η*  89.1 | 0 0 |
| 2) | *y*1/(1− *η* ) *y*1 |  16 |  |
|  | 可推出 | *η*  93.75 0 0 | |



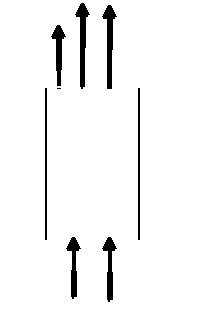
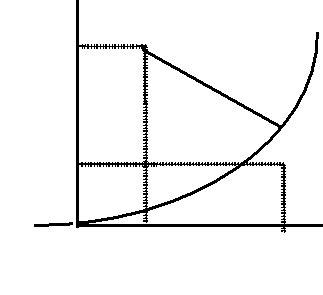
25）某混合气体中含溶质 5 %（体积），要求回收率为 85%。吸收剂进塔浓度为 0.001



|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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| （摩尔分率），在 20℃，101.3 | | | | | |  |  | 下相平衡关系为 | | | | | | | 。试求逆流操作和 | | | | | | | |  |
| 并流操作的最小液气比各为多少？由此可得到什么结论？ | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |
| 解： |  |  | | Lx2 | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Gy2 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | 逆流：y1 = 0.05，y2 = 0.05(1－0.85) = 0.0075， | | | | | | | | | | | | | | | | |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  | m = 40，x2 = 0.001 | | | | | | | | | |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | L | |  |  | y | 1 | − y | 2 |  170 |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | y1 | |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | V min | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | − x2 | | |  |  | y1 |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | m | |  |  |  | |  | |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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|  |  | Gy1 | | Lx1 | |  |  |  |  |  |  |  |  |  |  | y2 | |  |  |  |  |  |  |
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|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | x2 | | x1\* |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |



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|  |  |  |  |  | 并流：y1 = 0.05，y2 = 0.0075， | | | | | | | | | | | | | | | |  |
|  |  |  |  |  |  | m = 40，x1=0.001 | | | | | | | | | |  |  |  |  |  |  |
|  |  |  | Lx2 | |  |  |  |  |  |  |  |
| Gy2 | |  |  |  |  |  |  |  |  |
|  |  | L | |  | y |  | − y |  |  |  | y |  | − y |  |  |  |  |
|  |  |  |  |  | − |  |  |  |  | 1 |  | 2 |  |  |  | 1 |  | 2 |  −52.3 |  |  |
|  |  |  |  |  |  |  |  |  |  |  | y 2 | |  |  |  |  |
|  |  |  |  |  | V min | | |  | x\*2 | | − x1 | | | | − x1 | |  | y1 |  |
|  |  |  |  |  |  | m | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |



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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  | L | |  52.3 | y2 | |  |  |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  | V min | |  |  |  |  |  |
| Gy1 | | Lx1 | | ∴ |  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |

26） 用纯溶剂吸收某混合气体中的可溶组分。进塔气体浓度为 0. x1 （摩 x2\* 尔分率），要求回收率 为 92%。取液气比为最小液气比的 1.6 倍。气液逆流，

平衡关系 ，气相总传质单元高度为 0.62 米。试求填料层高 。

又，为增大填料润湿率，采用吸收剂再循环流程，气体流量及进、出塔的浓度不变，补充的纯溶剂流量和传质单元高度均不变，循环液流量与补充液流量之比为 0.10。试求此操作所需的填料层高度 。

解：1） *y*1

 0.048

*y*2

*y*1(1− *η* )0.00384 *x*20

*L*/ *G* 1.6( *L*/ *G*)min1.6(0.048−0.00384) / 0.01923.63

*L*/ *G* ( *y*1− *y*2) / *x*1 *x*10.012

∆ *ym* (0.048−2.50.012−0.00384) / *Ln*[(0.048−2.50.012) / 0.00384]

* + 0.009166

*NOG* ( *y*1− *y*2) /∆ *ym* (0.048−0.00384) / 0.0091664.82 *H*  *HOG NOG* 4.820.622.99 *m*

2）对虚线框进行物料衡算

Q *L*, *G*不变 *y*1, *y*2不变 *x*1不变

*x*20.1 *x*1/1.10.0011

∆ *ym* [0.048−2.50.012−(0.00384−2.50.0011)]/ *Ln*[(0.048− 2.5  0.012) /(0.00384 − 2.5  0.0011)]

* + 0.00603

*NOG* 7.32

*H* 0.627.324.54 *m*

27）在填料塔中，用纯油吸收空气中的苯，入塔混合气量为 ，其中含苯 6%（体积），要求出塔气体中含苯不高于 0.5%（体积），操作条件下的

平衡关系 ，实际液气比取最小液气比的 1.5 倍。试求：①吸收剂用量

及出塔液相浓度；②全塔对数平均推动力 ；③若采用吸收剂循环流程，在保证原吸收率不变的条件下，入塔液体浓度和循环液量最大应为多少？④画出两种情况下操作线示意图。

解：1） *G* 1200 / 22.4  53.57 *kmol*/ *h*

*y*10.06 *y*20.005 *x*20

*L*/ *G*1.5( *L*/ *G*)min1.5(0.06−0.005) /(0.06 / 0.2)0.275 *L*0.27553.5714.73 *kmol*/ *h*

*x*1 *G*( *y*1− *y*2) / *L* *x*2(0.06−0.005) / 0.2750.22)∆ *y*1  *y*1 − *mx*1  0.06 − 0.2  0.2  0.02

∆ *y*2 *y*20.005

∆ *ym* (0.02−0.005) / *Ln*(0.02 / 0.005)0.0108

3)由题意 *x*0与 *y*2呈平衡 即: *y*2  *mx*0

*x*0 *y*2/ *m*0.005 / 0.20.025

*x*0( *x*1 *θ*  *x*2) /(1 *θ* ) *x*1 *θ* /(1 *θ* )

*θ*  *x*0/( *x*1− *x*0)0.025 /(0.2−0.025)0.143 *θ L*0.14314.732.106 *kmol*/ *h*

4)略

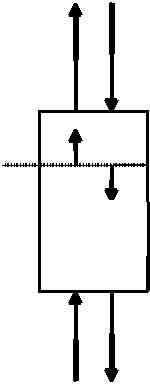
28）空气～四氯化碳化合气体中含四氯化碳 5%（体积，下同），气相流量 G 为

，要求回收率 90%。吸收剂分两股，第一股含四氯化碳为 0.002，从塔顶进入塔内；第二股含四氯化碳 0.010，从塔中部某处进入塔内。两股吸收

剂用量相同，均为 。已知操作条件下体系的相平衡关系为

，试计算：①出塔液体浓度为多少？②若全塔传质单元高度为 0.8 米 ，则第二股吸收剂加入的最适宜位置（加入口至塔底的高度）应在何处。

解：Gy2 Lx2



y



Lx2’

2Lx2’

Gy1 2Lx1 (2)

(1) y1 = 0.05，y2 = 0.05×(1－0.9) = 0.005，

G = 0.042kmol/(m2 s)，x2 = 0.002，x2’ = 0.01，m = 0.5 L1 = L2 = 0.021kmol/(m2 s)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |  x2 | | ′ |  2Lx1 |  |
|  | Gy1 − y 2   −L x2 | | | | | | | |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ∴x1 = 0.051 | | | | |  |  | ′ | |  |  |  |  |  |
|  |  |  |  |  |  | − x2 |  |  |  |  |  |
| Gy1 − y  2L x1 | | | | | |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  | 2L | |  | ′ |  | |  |  |  |  |  |
|  |  |  |  |  | − x2 | |  | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
| ∴ y  y1 − G x1 | | | | |  | |  0.009 | | |  |  |
| A  | 2L |  2 | |  |  | 1 − | | 1 | |  0.5 | |  |  |
| mG |  |  |  | |  |  |
|  |  |  | ， |  |  |  | A | | |  |  |  |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 1 | |  |  | 1 | | *y* − *mx* | | ′ |  | 1 |  |  |
| *NOG* |  |  |  | ln 1 − |  |  | 1 | 2 |  |  |  |  3.625 |  |
|  |  |  |  | ′ | |  |  |
|  | 1 − 1 | | |  | *A y*− *mx* | | |  | *A* | |  |
|  |  | *A* | |  |  |  | 2 | |  |  |  |  |  |



* + H = HOG·NOG = 0.8×3.625 = 2.9 m

1. 29) 矿石焙烧炉气中含 SO24.5%(体积)，其余惰性气体按空气计。炉气冷

却后在填料塔中以清水逆流吸收炉气中的 SO2。操作压强为 1atm，操作温度为 30℃。塔径为 0.8m，填料层高为 10m，要求回收率为 95%，进塔炉气流量为 1150m3/h(标准状态)。已知 *k*G *a*为 5×10-4kmol/(s·m3·kPa)， *k*L *a*=5 ×10-21/s。试求：① 塔底液体浓度为多少?② 若将炉气进一步降温后再吸

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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|  |  |  |  | 收，其操作温度降至 20℃时，其回收率为多少?设其它操作条件不变， *k*G *a* | | | | | | | | | | | | | | | | | | | | | | |  |
|  |  |  |  | 和 *k*L *a*的值均不变。 | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |
| 解：1） 由题意 : *y*1  0.045 | | | | | | | | | | | | | | | | | | | *y*2 |  0.00225 | | | | *x*20 |  |  |  |
|  |  |  |  |  |  | *G* 1150 /(22.436003.140.82/ 4）0.0284 *kmol*（/ *s*. *m*2) | | | | | | | | | | | | | | | | | | | |  |  |
|  |  |  |  |  | 30 *C*时， *E*  0.485104 k *P*a | | | | | | | | | | | | | | | | |  |  |  |  |  |  |
|  |  |  |  |  | m＝ *E*/ *P*  48.02 | | | | | | | | | | |  |  |  | *C*  *ρ*/ *Ms* | | |  1000 /18  55.56 *kmol*/ *m*3 | | | |  |  |
|  |  |  |  |  |  |  |  | 1 |  |  | 1 |  | | *m* | *Kya* 0.027 *kmol*（/ | | | | | | | | | *s*. *m*3) |  |  |  |
|  |  |  |  |  |  | *Kya* | | | | *kya* |  |  |  |  |
|  |  |  |  |  |  |  |  |  | *kxa* | |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *HOG*  *G*/ *Kya* 1.05 *m* | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *NOG*  *H* / *HOG* 9.53 | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |
| 由 *N* | | |  |  |  ( *y* − *y* ) / ∆ *y*  ( *y* − *y* ) / ( *y* − *mx* ) − ( *y* − *mx* )/ ln | | | | | | | | | | | | | | | | | | | | *y*1− *mx*2 |  |  |
| *OG* | |  |  |  |
|  |  |  |  |  |  | 1 | | 2 | |  |  | *m* | | 1 | | | 2 | 1 | | 1 | | 22 | *y*− *mx*2 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |
| 经试差得：x1＝0.000775（塔底出液浓度） | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |
| 20 *C*时， *E*  0.355 104 k *P*a | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | m＝ *E*/ *P*  35.03 | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | *Kya*' | | | |  0.0309 *kmol*（/ *s*. *m*3 ) | | | | | | | | | |  |  |  |  |  |  |  |  |
|  | *HOG* ' *G*/ *Kya* '0.918 *m* | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *NOG* ' *H* / *HOG* '10.9 | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |
| 由： *N* | | | | |  |  |  |  |  | 1 | |  |  |  | |  | 1 | | *y* − *mx* | | | 1 | |  |  |  |  |
| *OG* | | |  |  |  |  |  | ln 1 − | | |  |  |  | 1 | 2 |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |
|  | 1 |  |  | m *G* | | |  | 1 − 1 *A* | | | | | | | |  | *A* | | *y*2'− *mx*2 | | | *A* | |  |  |  |  |
|  | ＝ | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *A L* | | | | | | |  |  |  |  |  |  |  |  | *η*'  1 − y2 ' / *y*1  99.3% | | | | | | | | |  |  |  |
| 得：y2 ' 0.0003095 | | | | | | | | | | | | | | | |  |  |  |



30）一正在操作的逆流吸收塔，进口气体中含溶质浓度为 0 .0 5（摩尔分率，下同 ），

吸收剂进口浓度为 0.001，实际液气比为 4，操作条件下平衡关系为 ， 此时出口气相中含溶质为 0.005。若实际液气比下降为 2.5，其它条件不变，计算时忽略传质单元高度的变化，试求此时出塔气体浓度及出塔液体浓度各为多少？

解： *x*1 *G*/ *L*( *y*− *y*) *x* (0.05−0.005) / 40.0010.01225

∆ *y*10.05−20.012250.0255∆ *y*20.005−20.0010.003

∆ *ym* (0.0255−0.003) / *Ln*(255 / 30)0.01051

*NOG* (0.05−0.005) /∆ *ym* 4.28

*N*' *OG* { *Ln*[(1− *s*)( *y*1− *mx*2) /( *y*2'− *mx*2) *s*]}/(1− *s*)

* { *Ln*[0.2(0.05 − 0.002) /( *y*2 ' − 0.002)  0.8]}/ 0.2

据题意 *NOG*  *N*' *OG*

*y*2'0.0082

*x*1' *G*(0.05− *y*2') / *L*0.0010.01772

31）在一吸收塔内用洗油逆流吸收煤气中含苯蒸汽。苯的初始浓度为 0.02（摩尔

分率，下同），吸收时平衡关系为 ，液气比为 0.18，洗油进塔浓度为 0.006，煤气中苯出塔浓度降至 0.002。由吸收塔排出的液体升温后在解吸塔内

用过热蒸汽逆流解吸。解吸塔内气液比为 0.4，相平衡关系为 。在吸收塔内为气相控制，在解吸塔为液相控制。若现将液体循环量增加一倍，煤气及

过热蒸汽流量等其它操作条件都不变。已知解吸塔中， 。问此时吸收塔出塔煤气中含苯多少？题中流量皆为摩尔流量。

解： *x*1 *G*( *y*1− *y*2) / *L* *x*2(0.02−0.002) / 0.180 0060.106

*y*1' *L*( *x*1'− *x*2') / *G* *y*2'(0.106−0.006) / 0.40.25

吸收塔 ∆ *y*1 *y*1− *mx*10.02−0.1050.1060.00675

∆ *y*2 *y*2− *mx*20.002−0.1250 0060.00125

∆ *ym* (0.00675−0.00125) / *Ln*(675 /125)0.003621 *NOG* (0.02−0.002) /∆ *ym* 5.52

∆ *x*1' *x*1'− *y*1'/ *m*0.106−0.25 / 3.160.02689

∆ *x*2' *x*2'− *y*2'/ *m*0.006

∆ *xm* (0.02689−0.006) / *Ln*(0.02689 / 0.006)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 解吸塔 | *N* | *OL* |  ( *x* ' | − *x* | ' ) / ∆ *x*  7.18 |  |
|  | 1 | 2 | *m* |  |

|  |  |  |
| --- | --- | --- |
|  | 当 L 增加一倍时 | *L*/ *G*10.36− *L*/ *G*20.2 |
| 吸收塔 | *NOG*不变 |  |
| 解吸塔 | *HOL*  *L*/ *Kxm* | *H*' *OL* 2 *HOL* / 20.66 |

*N*' *OL*  *HOL* / 20.340.797.185.67

* *N*' *OG* { *Ln*[(1− *mG*/ *L*)( *y*1− *mx*2) /( *y*2− *mx*2) *mG*/ *L*]}/(1− *mG*/ *L*)5.52 *N*' *OL* { *Ln*[(1− *A*)( *y*2'− *mx*1') /( *y*2'− *mx*2') *A*]}/(1− *A*)5.67

# 第7章 液体蒸馏

|  |  |  |
| --- | --- | --- |
| 1） | 1） | 苯酚（C6H5OH）（A）和对甲酚（C6H4（CH3）OH）（B）的饱 |
|  | 和蒸汽压数据为： | |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 温度 | 苯酚蒸汽压 | | 对甲酚蒸汽压 | | 温度 | 苯酚蒸汽压 | | 对甲酚蒸汽 |  |
| *t* ℃ | *p*A0 | kPa | *p*B0 | kPa | *t* ℃ | *p*A0 | kPa | 压 *p*B0 |  |
|  |  |  |
|  |  |  |  |  |  |  |  | kPa |  |
| 113.7 | 10.0 | |  | 7.70 | 117.8 | 11.99 | | 9.06 |  |
| 114.6 | 10.4 | |  | 7.94 | 118.6 | 12.43 | | 9.39 |  |
| 115.4 | 10.8 | |  | 8.2 | 119.4 | 12.85 | | 9.70 |  |
| 116.3 | 11.19 | |  | 8.5 | 120.0 | 13.26 | | 10.0 |  |
| 117.0 | 11.58 | |  | 8.76 |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |

试按总压 P=75mmHg（绝压）计算该物系的“t—x—y”数据。此物系为理想物系 。

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 解： *xA* |  | | *P*− *p* 0 |  |  |  | *yA* |  | *p* 0 | *x* |  | （ *x*， *y*— *mol*分率） | | |  |
| *B* |  |  |  | *A* |  | *A* |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  | *pA*0− *pB* | 0 |  |  |  |  | *P* | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | | |  |  |  |  |  |
|  |  |  | t0C |  |  | pA0kPa |  | pB0kPa | | |  |  | xA | xB |  |
|  |  |  | 113.7 |  | 10.0 | |  | 7.70 | |  |  |  | 1.0 | 1.0 |  |
|  |  |  |  |  |  | |  |  | |  |  |  |  |  |  |
|  |  |  | 114.6 |  | 10.4 | |  | 7.94 | |  |  |  | 0.837 | 0.871 |  |
|  |  |  |  |  |  | |  |  | |  |  |  |  |  |  |
|  |  |  | 115.4 |  | 10.8 | |  | 8.2 | |  |  |  | 0.692 | 0.748 |  |
|  |  |  |  |  |  | |  |  | |  |  |  |  |  |  |
|  |  |  | 116.3 |  | 11.19 | |  | 8.5 | |  |  |  | 0.558 | 0.624 |  |
|  |  |  |  |  |  | |  |  | |  |  |  |  |  |  |
|  |  |  | 117.0 |  | 11.58 | |  | 8.76 | |  |  |  | 0.440 | 0.509 |  |
|  |  |  |  |  |  | |  |  | |  |  |  |  |  |  |
|  |  |  | 117.8 |  | 11.99 | |  | 9.06 | |  |  |  | 0.321 | 0.385 |  |
|  |  |  |  |  |  | |  |  | |  |  |  |  |  |  |
|  |  |  | 118.6 |  | 12.43 | |  | 9.39 | |  |  |  | 0.201 | 0.249 |  |
|  |  |  |  |  |  | |  |  | |  |  |  |  |  |  |
|  |  |  | 119.4 |  | 12.85 | |  | 9.70 | |  |  |  | 0.0952 | 0.122 |  |
|  |  |  |  |  |  | |  |  | |  |  |  |  |  |  |
|  |  |  | 120.0 |  | 13.26 | |  | 10.0 | |  |  |  | 0.000 | 0.000 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

2）承第 1 题，利用各组数据，计算

①在 x=0 至 x=1 范围内各点的相对挥发度αi，取各αi 的算术平均值α，算出α对αi 的最大相对误差。

②以平均α作为常数代入平衡方程式算出各点的“y—xi”关系，算出由此法得出各组 yi 值的最大相对误差。

解：① *α i*（ *p*0 *B* / *p*0 *A*）*i*，计算结果如下：

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 113.7 | 114.6 | 115.4 | 116.3 | 117.0 | 117.8 | 118.6 | 119.4 | 120.0 |
| t0C |  |  |  |  |  |  |  |  |  |
| *α i* | 1.299 | 1.310 | 1.317 | 1.316 | 1.322 | 1.323 | 1.324 | 1.325 | 1.326 |

*α* ∑ *α i* 1.318最大误差  1.318 −1.299  1.46%



|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  | *n* | 1.299 |  |
| 2） *yi* |  | *α xi* |  |  |
|  |  |  |
|  | 1 （ *α* −1） *xi* | |  |  |

*α* 按1.318计，结果如下：

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| t0C | 113.7 | 114.6 | 115.4 | 116.3 | 117.0 | 117.8 | 118.6 | 119.4 | 120.0 |
| xi | 1.0 | 0.837 | 0.692 | 0.558 | 0.440 | 0.321 | 0.201 | 0.0952 | 0 |
|  |  |  |  |  |  |  |  |  |  |
| yi | 1.0 | 0.871 | 0.748 | 0.625 | 0.509 | 0.384 | 0.249 | 0.122 | 0 |
|  |  |  |  |  |  |  |  |  |  |

0.384 − 0.385  −2.60 10−3



最大误差= 0.385

3）已知乙苯（A）与苯乙烯（B）的饱和蒸汽压与温度的关系可按下式算得：



式中 p0 的单位是 mmHg，T 的单位是 K。

问：总压为 60mmHg（绝压）时，A 与 B 的沸点各为多少℃？在上述总压和 65℃ 时，该物系可视为理想物系。此物系的平衡汽、液相浓度各为多少摩尔分率？

解：1)令 *p*0 *A*  *p*，算得的 *t*为 *A*的沸点

*Ln*6016.0195−3279.47（/ *T* −59.95）

*TA* 334.95 *K* 61.80 *C*

* + *p*0 *B*  *p*，算得的 *t*为 *B*的沸点

*Ln*6016.0193−3328.57（/ *T* −63.72）

*T B*342.85 *K* 69.70 *C*

2） *p*  60 *mmHg*， *t*  650 *C*  338.15 *K*

*Lnp*0 *A* 16.0195−3279.47（/338.15−59.95）

*p*0 *A* 68.81*mmHg*

*Lnp*0 *B* 16.0193−3328.57（/338.15−63.72）

*p*0 *B* 48.92 *mmHg*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *xA* |  | 60 − 48.92 |  0.557 | *yA* |  | 68.81 0.557 |  0.639 |  |
|  |  |  |
|  |  | 68.81− 48.92 | |  | 60 | |  |  |

4）苯（A）和甲苯（B）混合液可作为理想溶液，其各纯组分的蒸汽压计算

式为



式中 p0 的单位是 mmHg，t 的单位是℃。

试计算总压为 850mmHg（绝压）下含苯 25%（摩尔百分率）的该物系混合液的泡点。

解：设 *t* 104.150 *C*

*Lgp*0 *A* 6.906−1211（/104.15220.8）

*p*0 *A* 1511*mmHg*

*Lgp*0 *B* 6.955−1345（/104.15219.5）

*p*0 *B* 629.9 *mmHg*

*xA* 850−629.90.25 所设正确，泡点为104.150 *C* 1511 − 629.9



5）试计算总压为 760mmHg（绝压）下，含苯 0.37、甲苯 0.63（摩尔分率）

的混合蒸汽的露点。若令该二元物系降温至露点以下 3℃，求平衡的汽、液相摩

尔之比。

解：1）设露点为102.250 *C*

*LgP*0 *A* 6.906−1211（/102.25220.8）

*P*0 *A* 1436.7 *mmHg*

*LgP*0 *B* 6.955−1345（/102.25219.5）

*P*0 *B* 595.3 *mmHg*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *xA* |  | 760 − 595.3 |  0.1957 | *yB* |  | 1436.7  0.1957 |  0.37 |  |
|  |  |  |
|  | 1436.7 − 595.3 | | |  | 760 | |  |  |

即所设正确，露点为102.250 *C*

2） *P*  760 *mmHg* *t* 102.25−399.250 *C LgP*0 *A* 6.906−1211（/99.25220.8）

*P*0 *A* 1325 *mmHg*

*LgP*0 *B* 6.955−1345（/99.25219.5）

*P*0 *B* 543.7 *mmHg*

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *xA*  | 760 − 543.7 | |  |  0.2768 | *yA* |  | 1325  0.2768 |  0.4826 |  |
|  |  |  |  |  |
| 1325 − 543.7 | | |  |  |  | 760 | |  |  |
| 汽相的摩尔数 | |  | 0.37 − 0.2768 | |  0.828 | | |  |  |
|  | |  | |  |  |
| 液相的摩尔数 | | | 0.4826 − 0.37 | |  |  |  |  |  |

6）有一苯（A）、甲苯（B）、空气（C）的混合气体，其中空气占 2%，苯与甲苯浓度相等（均指摩尔百分数），气体压强为 760mmHg（绝压）。若维持压强不变，令此三元物系降温至 95℃，求所得平衡汽相的组成。A、B 组分均服从

拉乌尔定律。已知 95℃时，。

解：设原来混合气量为1*kmol*，汽液平衡时汽相为 *Vkmol*，液相为 *Lkmol*。

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 空气 | | 0.02  *yC* *V* | |  | （1） |  |  |
| 苯 | | 0.49  *yA* *V* （1 − *V*） *xA* （2） | | | | | |
| 苯 | | 760 *yA*  1163 *xA* | | | （3） | | |
| 甲苯 | | 760（1 − *yA* − *yC*） 475（1 − *xA*） （4） | | | | | |
| 由四个独立方程可解出 *xA*， *yA*， *yC*， *V*四个未知量 | | | | | | | |
|  |  |  |  |  |  |  | ‘ |
| 试差方法：设 *xA*经（3）→ *yA*经（4）→ *yC*经（1）→ *V*经（2）→ *x A* →重设 *xA* | | | | | | | |
| 试差过程数据示例： | | | |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  | 设 XA |  | 0.38 | 0.378 | 0.377 | 0.376 |  |
|  |  | |  |  |  |  |  |
|  | 算得的 X‘A | | 0.324 | 0.352 | 0.363 | 0.373 |  |

解得： *xA* 0.376， *yA* 0.575， *yC* 0.0346， *V* 0.578 *kmol*

7）常压下将含苯（A）60%，甲苯（B）40%（均指摩尔百分数）的混合液闪蒸（即平衡蒸馏），得平衡汽、液相，汽相摩尔数占总摩尔数的分率——汽化率（1-q）为 0.30。物系相对挥发度α=2.47，试求：闪蒸所得平衡汽、液相的浓度。

若改用简单蒸馏，令残液浓度与闪蒸的液相浓度相同，问：馏出物中苯的平均浓度为多少？

提示：若原料液、平衡液、汽相中 A 的摩尔分率分别以 xf、x、y 表示，则存在

如下关系：。

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 解：1）闪蒸 | |  |  |  |  |  |  |  |  |  |  |
| *y*  |  | *q* | |  | *x*− | *xf* |  | （ *y*， *x*为平衡汽，液相的摩尔分率） | | |  |
| *q*−1 | | | | *q*−1 | |  |
|  |  |  |  |  |  |
| *y* −0.70 *x*/ 0.300.60 / 0.30−2.33 *x*2.0 | | | | | | | | | |  |  |
| *y*  | |  |  |  | 2.47 *x* | | |  |  |  |  |
|  | 1 （2.47 −1） *x* | | | | | |  |  |  |
| 解得 | |  |  |  | *x* 0.539 | | |  | *y* 0.742 |  |  |
| 2）简单蒸馏 | | | | | | | |  |  |  |  |
| *Ln*（ *w*1/ *w*2）{ *Ln*（ *x*1/ *x*2） *α Ln*（[1− *x*2）（/1− *x*1）]}（/ | | | | | | | | | | *α* −1） |  |

* + { *Ln*（[0.60 / 0.539） 2.47 *Ln*（[1 − 0.539）（/1 − 0.60）]}（/2.47 −1）
  + 0.311

*w*1/ *w*21.365

*y*（平均）

*x*  *w*（ *x* − *x* ）（/ *w* − *w*）

1 2 1 2 1 2

* 0.60 （0.60 − 0.539）（/1.365 −1）
* 0.767

8）某二元物系，原料液浓度 xf=0.42，连续精馏分离得塔顶产品浓度 xD=0.95。已知塔顶产品中易挥发组分回收率η=0.92，求塔底产品浓度 xw。以上浓度皆指易挥发组分的摩尔分率。

解： *η*  *DxD* （/ *Fxf*） 即0.92  0.95 *D*/ 0.42 *F*

*D*/ *F* 0.4067

* + *W* / *F* 1− *D*/ *F* 1−0.40670.5933

物料衡算式： *Fxf*  *DxD*  *WxW* 即 *xf* （ *D*/ *F*） *xD* （ *W* / *F*） *xW*

代入数据：0.42  0.4067  0.95  0.5933 *xW*

*xW* 0.0567

9）某二元混合液含易挥发组分 0.35，泡点进料，经连续精馏塔分离，塔顶产品浓度 xD=0.96，塔底产品浓度 xw=0.025（均为易挥发组分的摩尔分率），设满足恒摩尔流假设。试计算塔顶产品的采出率 D/F。

若回流比 R=3.2，泡点回流，写出精馏段与提馏段操作线方程。

解：1）按杠杆规则

*D*/ *F* （ *x*− *x*）（/ *x*− *x*）

（0.35 − 0.025）（/0.96 − 0.025）

* 0.3476

2）精馏段操作线方程：

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *y*  | *R* | *x* | *xD* |  |
|  |  |  |

*R*1 *R*1

* 3.2 *x*（/3.2 1） 0.96（/3.2 1）
  + 0.762 *x* 0.229

提馏段操作线方程： *y* （ *L*’/*V*’） *x*−（ *W* / *V*’） *xW*

‘ （ ）

*L*  *L* *qF*  *RD* *qF* [ *R D*/ *F*  *q*] *F*

*V*’ *V* −（1− *q*） *F*  *V* −（ *R*1）（ *D*/ *F*） *F*

*W* （1− *D*/ *F*） *F*

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *y*  |  | *R*（ *D*/ *F*） *q* | | *x*− | |  | 1 − *D*/ *F* | *x* | |  |
|  |  | |  |  |  |
| （ *R*1）（ *D*/ *F*） （ *R*1）（ *D*/ *F*） *W* | | | | | | | | | |  |
|  | | 3.2 |  0.3476 1 | | *x*− | | 1 − 0.3476 |  |  |  |
|  | 1） 0.3476 | |  |  |  |  |
| （3.2 | | | （3.2 1） 0.3476 | | | | |  |

* 1.447 *x*− 0.0112

10）某二元混合物含易挥发组分 0.24，以热状态参数 q=0.45 的汽、液混合物状态进入连续精馏塔进行分离。进料量为 14.5kmol/h，塔顶产品浓度 xD=0.95，塔底产品浓度 xw=0.03。若回流比 R=2.8，泡点回流，提馏段 L’/V’为多少？试计算塔顶全凝器的蒸汽冷凝量及蒸馏釜的蒸发量。以上浓度皆指易挥发组分的摩尔分率。

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 解： *D*/ *F* （ *zf* | | | | | | | | | − *xw*）（/ | | | | | | *xD* − *xW*）（0.24−0.03）（/0.95−0.03）0.2283 | | | | | | | | | | |  |  |
| ′ | |  |  |  |  |  |  | （ | | |  |  |  | ） | |  |  |  |  | （ | | ） |  |  |  |  |  |
| *L*  | | | | *L* *qF*  *R D*/ | | | | | | | | |  | *F F* ·*qF* [ *R D*/ | | | | | | | | *F*  *q*] *F* |  |  |  |  |  |
| ′ | |  | | *V* |  | （ ） （ | | | | | | | |  | ）（ | | *D*/ |  | ） （ ） （ | | | | ）（ |  | ）（ ） | |  |
| *V* | | − 1 − *q F* | | | | | | |  |  | *R*1 | |  | *F F* −1− *q F* [ | | | | | *R*1 | *D*/ *F* −1− *q* | | ] *F* |  |
|  |  | ′ | |  |  |  |  | （ | | | *D*/ | |  | ） | |  |  |  |  |  |  | 2.8  0.2283  0.45 | |  |  |  |  |
|  | *L* | | |  |  |  | [ *R* | |  |  | *F* | |  *q*] *F* |  |  |  |  |  |  |  |  3.43 |  |  |
|  | | | （ | | ）（ | | | | |  |  | ）（ | |  | ） |  |  |  | ） | （ |  |  |  |
|  |  | *V* | ′ |  | *D*/ |  |  |  |  | （ | | ） | |  |  |
|  |  |  |  | [ | | *R*1 |  |  |  |  |  | *F* | − 1 − *q* ] *F* | | | | |  | 2.8 1  0.2283 − 1 − 0.45 | | | | |  |  |
| 全凝器内蒸汽冷凝量： *V* （ *R*1） *D* （2.81）0.228314.512.58 *kmol*/ *h* | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |
| 釜的蒸发量： | | | | | | | |  | ′ |  |  | （ |  |  | ）（ | *D*/ | | ）（ | | | | ） |  |  |  |  |  |
|  |  |  |  |  |  |  |  | *V* | |  [ | | | *R*1 | | | *F* | | − 1 − *q* ] *F* | | |  |  |  |  |  |

（[2.8 1） 0.2283 −（1 − 0.45）]14.5

* 4.604 *kmol*/ *h*

11）用常压精馏塔连续分离苯和甲苯混合液。进料中苯的摩尔分率为 0.30。操作条件下苯的汽化潜热为 355kJ/kg。试求以下各种情况下的 q 值：①进料温度为 25℃；②98.6℃的液体进料；③98.6℃的蒸汽进料。

苯～甲苯体系在常压下的部分汽液平衡数据如下：

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 温度 t，℃ | 110.6 | 102.2 | 98.6 | 95.2 |
| 液相组成，x | 0.000 | 0.200 | 0.300 | 0.397 |
| 汽相组成，y | 0.000 | 0.370 | 0.500 | 0.618 |
|  |  |  |  |  |

解：①原料液的汽化潜热

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  | 0.7  |  | 355kJ | |  |  |
|  |  |  |  |  |  |  | 1kg |  | |  |
|  |  |  |  |  |  |  |  |  |
| rm= 0.30380kJ/(1kg/78kg/mol)＋ | | | | | |  |  | 92kg / mol | | |  |
|  |  |  |  |  |  |
| = 8892＋22862 = 31754 kJ/mol | | | | | |  |  |  |  |  |  |
| 由附表可知 xf = 0.30 时，液体的泡点为 98.6℃，则 | | | | | | | | | | |  |
| t |  |  | 25  98.6 |  618. |  |  |  |  |  |  |  |
| m |  | ℃= 334.95 K | | | | | |  |
| 平均温度 | 2 | |  |  |

查教材附录得 61.8℃下苯和甲苯的比热为 1.84kJ/(kg K)，故原料液的比热为：Cp = 1.840.378＋1.840.792

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  | = 161.552 kJ/(kmol K) | |  |
|  | Cp | *∆*t1 |  rm |  | 161552.  98.6 − 25  31754 | | |  |
| q1  |  |  |  |  |  |  |  1374. |  |
|  | rm |  | 31754 | |  |
| ∴ | |  |  |  |  |

②属饱和液体进料 q2 = 1

③属饱和蒸汽进料 q3 = 0。

12）已知某精馏塔操作以饱和蒸汽进料，操作线方程分别如下：

精馏线

提馏线

试求该塔操作的回流比、进料组成及塔顶、塔底产品中轻组分的摩尔分率。

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  | R |  |  |  0.7143 | |  |  |  |  |
| 解：由精馏线得： R  1 | | | | | | | | |  |  |
|  | ，R = 2.500 | | |  |  |
|  |  |  | x D | |  0.2714 | | | | | |  |  |  |  |
|  |  |  |  |  |  |  |
| 由提馏线得： R  1 | | | | | | |  |  |  | ，xD = 0.9499≈0.950 | | | |  |
|  | L ′ | |  |  |  | L  qF | | | | | | |  |  |
|  |  | |  |  | | | | | |  |  125. | |  |  |
| 提馏线斜率 | V′ | | R  1D − 1 − qF | | | | | | |  |  |
|  |  |  |  |  |  |  |  |  |  |  | ，得 F = 1.5D | |  |
|  | W | |  |  |  |  |  |  |  | F − D | | |  |  |
|  | xW  0.01 | | | |  |  |  |  |  | xW  0.01 |  |  |
|  |  |  | ， | | | R  1D − F | |  |  |
| 提馏线截距 V′ | | | ，得 xW = 0.04 |  |

* FxF = DxD＋WxW 得：

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Dx | | | D |  (F − D)x | | | | | W |  |  |  | D | | |  |  |  | | D | |  |  |  |  |  |
| x |  |  |  |  |  |  |  |  |  |  |  |  | |  | | x |  |  1 − | | |  | x |  |  |  |  |  |
|  |  |  |  |  |  |  | F |  |  |  |  | |  |  |  |  |  |  |  |
|  | f |  |  |  |  |  |  |  |  |  |  |  |  |  | F | | | D |  |  | | F | | W | | |  |  |
|  |  |  |  | D | | |  |  |  |  |  | D | |  |  |  |  |  |  | 0.95 | | |  | |  | 1 | |  |  |
|  |  |  |  |  |  |  | x |  |  1 − |  |  |  |  |  | x | |  |  |  |  |  |  1 − | | |  |  |  |  0.01 |  |
|  |  |  |  | D | |  |  |  |  |  |  |  |  | 15. | |  |  |
|  |  | 15. | | |  | D |  | 15. D | | | | | |  | W | |  |  |  | | 15. | | |  |  |

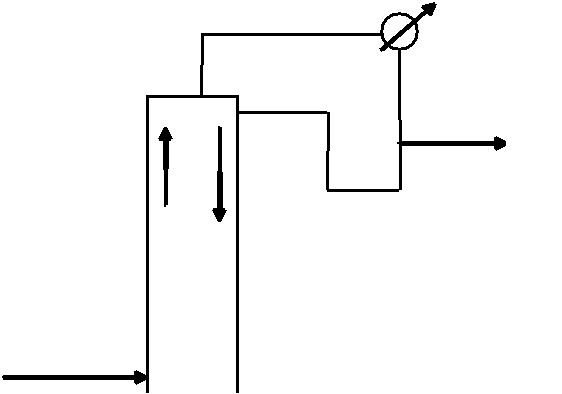
= 0.647

13）用一连续精馏塔分离甲醇和水的混合物，进料量为 100kmol/h，进料中甲醇的摩尔分率为 0.10，以饱和蒸汽形式连续进入塔底。要求塔顶产品中甲醇

含量为 0.90，塔釜产品中甲醇含量为 0.05。试求：①该精馏塔操作回流比及塔内的液汽比；②塔顶全凝器的蒸汽冷凝量。

解：①Fxf = DxD＋(F－D)xW

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| D  F | x f − xw |  |  100 | 01. | − 0.05 | | |  5882. | |  |  |
|  |  |  |  |  |  |
|  | x D − x w | | 0.9 | | − 0.05 | | | |  | kmol/h |  |
| V = F = 100 kmol/h | | | | |  | V |  |  | 100 |  |  |
|  |  |  |  | R  | | − 1  | | − 1 ≈ 16 |  |
| 由 V = (R+1)D | | |  |  | 5882. |  |
| 得 | |  | D | | |  |  |



|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| L  | RD |  | 16  0.941 |  |  |  |
| V | (R  1)D |  | 16  1 | V |  |  |
| ②塔顶全凝器蒸汽冷凝量 | | | | xD |  |
|  |  |
| V = 100 kmol/h | | |  |  |  |  |
|  |  |  |  | L |  |  |



F

xf q=0

xw

14）以连续精馏分离正庚烷（A）与正辛烷（B）。已知相对挥发度α=2.16，原料液浓度 Zf=0.35（正庚烷的摩尔分率，下同），塔顶产品浓度 xD=0.94，加料热状态 q=1.05，馏出产品的采出率 D/F=0 34。在确定回流比时，取

。设泡点回流。试写出精馏段与提馏段操作线方程。

解：1）计算 *R*min 和 *R*

平衡线方程； *y*\* *α x*/[1（ *α* −1） *x*]2.16 *x*（/11.16 *x*）

*q*线方程： *y*  *qx*（/ *q*−1）− *z f* （/ *q*−1）1.05 *x*/ 0.05−0.35 / 0.05

* 21 *x*− 7

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 二线交点： *xe* 0.3594 | | | | *ye* 0.5476 | |  |
| *R*  | *xD* − *ye* |  | 0.94 − 0.5476 | |  2.085 |  |
|  |  | |  |
| min | *ye* − *xe* | | 0.5476 − 0.3594 | | |  |
|  |  |

*R* 1.40 *R*min1.402.0852.92

2）精馏段操作线方程：

*L*′ *L* *qF*  *R*（ *D*/ *F*） *F*  *qF* （[ *R*（ *D*/ *F*） *q*] *F*

*V*′ *V* −（1− *q*） *F* （ *R*1）（ *D*/ *F*） *F* −（1− *q*） *F*

（[ *R*1）（ *D*/ *F*）−（1 − *q*）]*F*

又 *FZ f*  *Dx*0 *WxW* 即 *Z* *f* （ *D*/ *F*） *xD* （ *W* / *F*） *xW*

*WxW* 0.0304 *F*

提馏段操作线方程：

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| （ ′ | | | | | / *V* | ′） | | （ |  | ′） | *xW* | | |  |  |  |  |  |
| *y*  | |  |  | *L* |  |  | *x*− *W* / *V* | |  |  |  |  |  |  |
|  |  |  |  |  | [ *R*（ *D*/ *F*） *q*] *F* | | | | | | | | | 0.0304 | |  |  |  |
|  | | |  |  |  |  |  |  |  |  |  |  |  | *x*− |  |  |  |  |
| （[ *R*1）（ *D*/ *F*）−（1 − *q*）]*F* | | | | | | | | | | |  |  |  |
|  |  |  | （ *R*1）（ *D*/ *F*）−（1− *q*） | | | |  |
|  |  |  |  |  | 2.92 | |  0.34 | |  1.05 | |  | *x*− | | 0.0304 | |  |  |  |
|  | (2.92  1) | | | | |  0.34 | |  |  |  | (2.92  1)  0.34 − (1 −1.05) | | | |  |
|  |  | − (1 −1.05) | | | | |  |

* 1.477 *x*− 0.0220
* *xW* 0.0304（ *F*/ *W*）0.0304（/1− *D*/ *F*）0.0304（/1−0.34）0.046

15）承第 14 题，按最佳加料板位置加料，试用作图法求总理论板数，并指明加料板的序号。

解：又作图知，总理论板数为 13.4 块，第 7 块为加料板。（图略）

16）承第 14 题，试用逐板计算法计算离开塔顶第 2 块塔板的液体浓度 x2。

解：

精馏段操作线方程： *y* 0.745 *x*0.240LLL（1）

平衡线方程： *x*\* *y* /[ *α* −（ *α* −1） *y*]LL（2）

计算顺序： 已知 *y*1经（2）→ *x*1经（1）→ *y*2经（2）→ *x*2

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *y*1 |  0.94 | | |  |  |  |
| *x*1 |  | 0.94 | |  |  0.8788 |  |
|  |  |  |  |
| *y*2 |  | 2.16 −（2.16 −1） 0.94 | | | |  |
|  0.745  0.8788  0.240  0.8947 | | | | |  |
| *x*2 |  | 0.8947 | |  0.7973 | |  |
|  |  |  |
|  |  |  | 2.16 −1.16  0.8947 | | |  |

17）承第 14 题，试用快速估算法计算总理论板数和确定加料板序号。

解：（1）总理论板数

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  | *Lg*[( | | | | |  | *xD* | | |  | )( | 1 − *xW* | | | | | | | )] | | | |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | 1 − *xD* | | | |  |  |  |  |  | |  |  |  |  |  |  |
|  |  | *N*min  | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  | *xW* | | | |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | *Lgα* | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | *Lg*[( | | | | | | 0.94 | | | | | | )( | | | 1 − 0.046 | | | | | | | | | )] | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | | | | 0.046 | | | | | | |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 − 0.94 | | | | | | | | | |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | *Lg*2.16 | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  7.51 | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | *R*− *R*min | | | | | | | |  | | | 2.92 − 2.085 | | | | | | | | | | | | |  0.213 | | | | | | | |  |  |  |  |  |  |
|  |  |  | |  |  | | |  | |  | | |  |  | | | | |  |  | |  |  |  |  |  |
|  |  |  | *R*1 | | | | | | | | | | |  | 2.92 1 | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 查吉利蓝图，得 | | | | | | | | | | | | | | | | *N* − *N*min | | | | | | | | | | |  |  0.45 即 | | | | | | | | *N* −7.51 |  0.45 |  |
|  | | | | |  |  | |  | | |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | *N* 1 | | | | | | |  |  |  |  |  |  |  |  |  | *N* 1 | |  |
|  | 解得 | | | | |  |  |  |  |  |  |  |  |  | *N* 14.47（包括蒸馏釜） | | | | | | | | | | | | | | | | | | | | | | | |  |
| （2）精馏段理论板数 | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | *Lg*（[ | | | | |  |  |  | *x* | | | |  |  |  | 1 − *xf* | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | |  | *D* | ）（ | | | | | |  |  |  |  |  |  |  | ）] | | | | | | |  |  |  |  |
|  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | ′ | |  |  |  |  |  |  |  | 1 − *xD* | | | | | | | |  |  |  |  |  |  |  | *xf* | | |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *N*min | |  |  |  |  |  |  |  |  |  |  |  | *Lgα* | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | *Lg*（[ | | | | | |  | | 0.94 | | |  | ）（ | | | | | | | 1 − 0.35 | | | | | | | ）] | | | |  |  |  |  |
|  |  |  |  |  |  |  | |  |  |  |  |  | | | | | | |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  | 1 − 0.94 | | | | | | |  |  |  |  |  |  | 0 35 | | | | | | |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | *Lg*2.16 | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  4.376 | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | ′ | | ′ | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ′ | |  |  |  |  |  |  |  |  |  |  |  |  |
|  | *N* − | | *N* | | |  |  |  0.45 | | | | | | | | | |  |  |  |  |  |  | *N* −4.736 | | | | | | | | | | | |  0.45 | |  |  |
|  |  |  | min | | | | |  | 即 | | | |  |  |  |  |  | | | | | | |  | |  |  |
|  |  | ′ |  | | | | |  |  |  |  |  | ′ | | | | | | |  |  |
|  |  | *N* 1 | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  | *N* | | 1 | | | |  |  |  |  |  |  |  |  |
| 解得 | | |  |  |  |  |  |  |  |  |  |  | ′ | |  8.77 | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  | *N* | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

18）以常压操作的连续精馏塔分离“乙醇～水”溶液。原料液含乙醇 0.10 （摩尔分率，下同），进料热状态 q=1.10，塔顶产品浓度 0.80，釜液浓度 0.001。塔顶用全凝器，泡点回流，塔底用蒸馏釜，间接加热，操作回流比为最小回流比

* 2.0 倍。试用作图法求总理论板数和确定加料板序号。解：根据教材附录数据作“y-x”图

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *q*线方程： *y*  | *q* | | *x*− | *xf* | | 1.10 | |  | *x*− | 0.10 | |  11 *x*−1 |  |
|  |  |  |  |  |  |  |  |  |  |
| *q*−1 | | *q*−1 | |  |  |  |
|  |  | 1.10 −1 | | |  | 1.10 −1 | | |  |

由（0.1，0.1）及（0.15，0.65）两点连直线即为 *q*线

由（0.80，0.80）点出发作 *R*min的精馏段操作线，取决于平衡线与操作线相切点。 *R*min的精馏段操作线的截距为0.36。

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 即： *R*min | | | |  | 0.80 − 0.36 | | | | *R* | |  |  1.22 *R*  2.44 | |  |
|  |  |  |  |  |  |
|  | *R*min | |  1 | 0.80 | | | |  |  | min | |  |  |  |
|  |  |  |  |  |  |  |  |
| 精馏段操作线方程： | | | | | | | | |  |  |  |  |  |  |
| *y*  | |  | *R* | *x* | | *xD* |  | 2.44 | | *x* | 0.80 | |  |  |
|  |  |  |  | | 2.44  1 | | |  |
|  |  | *R*1 | |  |  | *R*1 2.441 | | | | |  |



* 0.709 *x* 0.233

由作图知，总理论板数为12.6块，第11块是加料板。（图略）

19）已知塔顶、塔底产品及进料组成中苯的摩尔分率分别为：xD=0.98，

xW=0.05，xF=0.60，泡点进料和回流，取回流比为最小回流比的 1.5 倍，体系的

相对挥发度为 2.47。试用捷算法计算苯和甲苯体系连续精馏理论塔板数。

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 解：∵ q = 1 | | | | | |  |  |  |  | ∴ xe = xf = 0.6 | | | | | | | | | | |  |  |  |  |  |  |  |  |
|  |  |  |  |  | αxe | | | | | 2.47  0.6 | | | | | | | | | | |  |  |  |  |  |  |  |  |
|  | y e  |  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  0.787 | | |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 1  (α − 1)xe | | | | | | | | |  |  | 1  (2.47 − 1)  0 6 | | | | | | | | | | | | | |  |  |  |
|  | R min  | |  | xD − y e | | |  | | | 0.98 − 0.787 | | | | | | | | |  103. | | | | |  |  |  |  |  |
|  |  |  |  |  |  |  | |  | |  | |  |  |  |  |
|  |  |  |  | y e − xe | | | | | |  | 0.787 − 0.6 | | | | | | | | | |  |  |  |  |  |  |  |  |
| R = 1.5Rmin= 1.5×1.03 = 1.55 | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |
|  | R − R min | | | |  | 155. − 103. | | | | | | | |  0.204 | | | | | |  |  |  |  |  |  |  |  |  |
|  |  | | |  |  | |  | | |  |  | |  |  |  |  |  |  |  |  |
|  | R  1 | | | | | 155.  1 | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | N − N min | | | | | | |  |  |  0.44 | | | |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | | | N  1 | | | |  |  |  |  |  |  |  |  |  |  |
| 查吉利兰图得： | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 由芬斯克方程得： | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | xD | | | |  | 1 − xw | | | |  | |  |  |  |  |  | 0.98 1 − 0.05 | | | | | |  |
|  |  |  |  | log | |  |  |  |  |  |  |  | | |  | |  |  |  | log |  |  |  |  |  |  | |  |
|  |  |  | 1 − xD | | | |  |  | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | xw | | |  |  |  |  | 1 − 0.98 0.05 | | | | |  | |  |
|  | N min  | | |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  7.56 |  |
|  |  | | log α | | | | | | | | |  |  |  |  |  |  | log 2.47 | | | |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

* N = 14.3，取 NT = 15

20）用一连续精馏塔分离甲醇和水的混合物。已知原料中甲醇的摩尔分率为

0.35，进料量为 100kmol/h，泡点进料。塔顶馏出液中甲醇含量为 0.95，塔底产品中甲醇浓度为 0.04。操作回流比为 1.5，泡点回流，间接蒸汽加热。用作图法求完成分离任务所需的理论塔板数，并计算甲醇的回收率和塔釜蒸发量。

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| η  | xf − xw xD |  | 0.35 | − 0.04  0.95 | | 92.46% |  |
| xD − xw xf | 0.95 | − 0.04  0.35 |  |  |
| 解：甲醇回收率 |  |  |  |  |  |  |  |

由教材附录查得 CH3OH～H2O 的 VLE 数据，在 x～y 图上作出平衡曲线。

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | xD |  |  | 0.95 |  0.38 |  |
| 精馏线截距为 R  1 | | |  |  |
| 15.  1 | | |  |

由(0.95，0.95)和(0，0.38)作出精馏线

* q = 1 和(0.35，0.35)作出 q 线

连接(xw，xw)和 q 线与精馏线的交点得提馏线，

作图得理论板数 NT = 7 块，加料位置为第 5 块理论板。

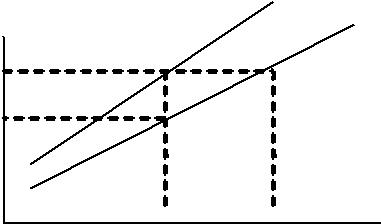
|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| D  F | xf − x w |  100  | 0.35 | − 0.04 |  34.07 |  |
|  |  |  |  |
|  | x D − x w | 0.95 | | − 0.04 | kmol/h |  |

∵q = 1－0 = ,故 V′  V  R  1D  15.  1  34.07  85175.kmol/h

21）在用作图法求理论板数时，可能遇到局部区域平衡线与操作线均为直线

且两直线甚靠近，不易求准梯级数的情况。设平衡线为，操作线为

，（K、C、a、b 均为常数），试推导由操作线上 x0 至 xN 所需理论板数 N 的数学解析式。



解： *y*1 *ax* *b*

*x*1( *y*1− *c*) / *k* ( *a*/ *k*) *x*0( *b*− *c*) / *k*

*y*2 *ax*1 *b*

*x*2( *y*2− *c*) / *k* ( *a*/ *k*)2 *x*0( *a*/ *k*)( *b*− *c*) /

*y*3 *ax*2 *b*

*x*3( *y*− *c*) / *k* ( *a*/ *k*)3 *x*0( *a*/ *k*)2( *b*− *c*) /

*k* ( *b*− *c*) / *k*

*k* ( *a*/ *k*)( *b*− *c*) / *k*

* ( *b*− *c*) / *k*

依次类推：

*xN* （ *a*/ *k*）*N x*0（ *a*/ *k*）*N*−（1 *b*− *c*）/ *k* （ *a*/ *k*）*N*−（2 *b*− *c*）/ *k*

* LL（ *a*/ *k*）（ *b*− *c*）/ *k* （ *b*− *c*）/ *k*

（ *a*/ *k*）*N x*0（[ *b*− *c*）/ *k*][（ *a*/ *k*）*N*−1（ *a*/ *k*）*N*−2LL

* *a*/ *k*）2（ *a*/ *k*）1]

（ *a*/ *k*）*N x*0（[ *b*− *c*）/ *k*][（ *a*/ *k*）*N* −1] /[（ *a*/ *k*）−1]

（ *a*/ *k*）*N x*0（[ *b*− *c*）（/ *a*− *k*）（] *a*/ *k*）*N* −（ *b*− *c*）（/ *a*− *k*）

*x* （ *b*− *c*）（/ *a*− *k*）

即：（ *a*/ *k*）*N*  *N*



*N*  *Ln*{[ *xN* （ *b*− *c*）（/ *a*− *k*）]/[ *x*0（ *b*− *c*）（/ *a*− *k*）]} *Ln*（ *a*/ *k*）



22）在某二元混合物连续、基本型精馏操作的基础上，若进料组成及流量不变，总理论板数及加料板位置不变，塔顶产品采集比 D/F 不变。试考虑在进料热状态参数 q 增大，回流比 R 不变的情况下 xD、xW 和塔釜蒸发量的变化趋势。只需定性分析。

解：设 *x*′*D*  *xD*，由于 *D*/ *F*不变， *Z f* 不变，故 *x*′*W*  *xW*，又因 *R*不变，精馏段操作线不变。

* + *q*增大，提馏段操作线更靠近对角线，所需理论板数减少，故 *xD*必朝增大方向变化， *xW*必朝减小方向变化。
* *F*， *D*/ *F*不变，则 *D*， *W*不变，又因 *R*不变，精馏段 *L*， *V*不变，由 *L*′ *L* *qF*， *V*′ *V* −（1− *q*） *F*知，随 *q*增加， *V*增加。

23）以连续精馏塔分离某二元混合物。塔顶采用全凝器。已知：xD=0.90，D=0.02kmol/s，回流比 R’=2.5，在操作中回流液有一定程度过冷。已知回流液体泡点为 83℃，汽化潜热 r=3.2×104kJ/kmol，该液体比热 CP=140kJ/(kmol·℃)，但回流液温度为 75℃。试求精馏段操作线方程。

解：

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 回流液 *qR*  | *r* *c* ∆ *t* | | |  | 3.2 104 140 （83 − 75） | | | | | | |  |
|  | *P* | |  |  |  |  |  |  1.035 | |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  | *r* |  |  |  | 3.2 104 | | | |  |  |  |  |
| 第一块板以下， | |  |  |  | ′ | | |  |  |  |  |  |
|  |  | *R*  *qR* 1.0352.52.588 | | | | | | | |  |  |  |
| 精馏段操作线方程： *y*  | | | | | | 2.588 | *x* | 0.90 |  |  0.721 *x* 0.251 | |  |
|  | 2.588 1 | |  |
|  |  |  |  |  | 2.588 1 | | |  |  |  |

24）以连续精馏塔分离某二元混合物。进料 xf=0.50（摩尔分率，下同），q=1，塔顶产品 D=50kmol/h，xD=0.95，塔顶馏出液中易挥发组分回收率η=0.96。塔顶采用一个分凝器及一个全凝器。分凝器液体泡点回流。已知回流液浓度 x0=0.88，离开第一块塔板的液相浓度 x1=0.79。塔底间接蒸汽加热。塔板皆为理论板，相对挥发度α为常数。试求：①加料流量 F；②操作回流比是 Rmin 的倍数；③精馏段、提馏段气相流量。

解：1)*η*  *D xD* /( *F xf* ) 即

0.96  50  0.95（/ *F* 0.50） *F* 98.96 *kmol*/ *h*

*x* （/1− *x* ）0.95（/1−0.95）

2） *α*  *D* *D*  2.59



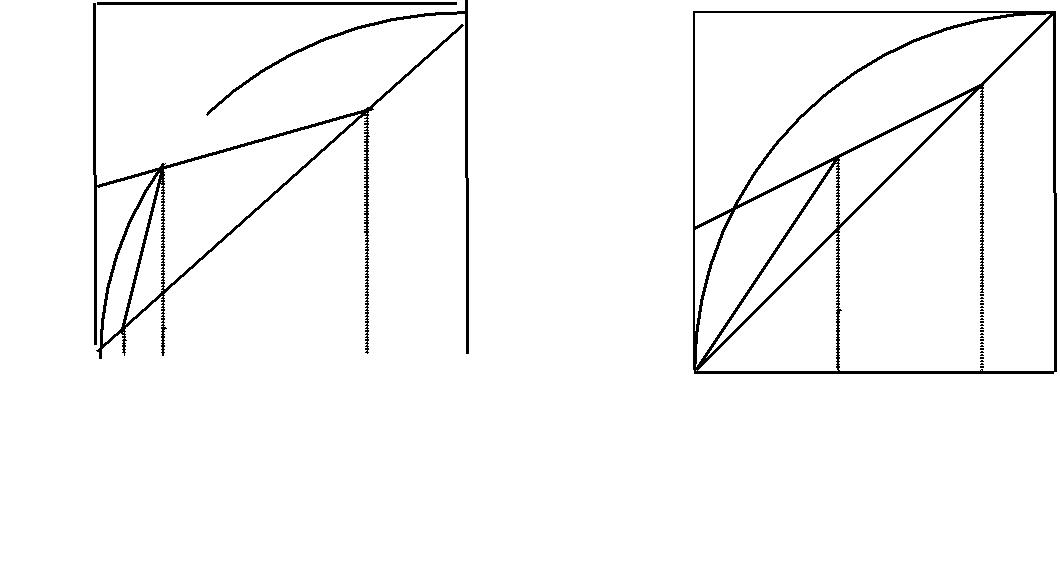
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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | *y*  | | 2.59  0.79 | | | | | |  0.9069 | | |  |  |
|  |  |  |  |  |  |  |  |  |
|  |  | 1 | | 1 1.59  0.79 | | | | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
|  | 平衡线： *y*\*2.59 *x*（/11.59 *x*）， *q*线：.*x* 0.50 | | | | | | | | | | | | |  |
|  | 则交点为： *xe* | | | | | | |  0.50， *ye* | | |  0.7214 | | |  |
|  | *R*  | | | *xD* − *ye* | | | |  | 0.95 − 0.7214 | | | |  1.033 |  |
|  |  | |  |  |  | | |  |  |
|  |  | min | |  | *ye* − *xe* | | |  | 0.7214 − 0.50 | | | | |  |
|  |  |  |  |  |  |  |
|  | *R*  | | *xD* − *y*1 | | |  | 0.95 − 0.9069 | | | | |  1.602 | |  |
|  |  | | |  | | | | |  |
|  |  |  | *y*1− *x*0 | | | | | 0.9069 − 0.88 | | | | | |  |
|  | *R*/ *R*min | | |  1.602 /1.033  1.55 | | | | | | | | | ） |  |
| ） | | *V*  *V* | | ′ （ | | | | ） | | （ |  |  |  |
| 3 |  |  |  1  *R D*  1 1.602  50  130.1*kmol*/ *h* | | | | | | | | |  |

25）在常压下用一连续精馏塔分离某两组分混合液，已知进料量为200kmol/h，其中轻组分的含量为 0.40（摩尔分率），泡点进料。塔顶产品流量为 100kmol/h。体系在常压下的相对挥发度为 2.6。若精馏塔的理论塔板数为无限多，试求：①当回流比为 1.0 时，塔顶、塔底产品中轻组分的含量各为多少？②当回流比为 2.0 时，塔顶、塔底产品中轻组分的含量各为多少？③画出两种情况下的精馏段、提馏段操作线和 q 线示意图。

解：①由于 NT = ∞，设 xq、yq 达到相平衡，则 R = Rmin= 1.0 ∵q = 1，∴xq = xf = 0.4

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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| y q |  |  |  |  | αxq | | | | | |  | 2.0  0.4 | | | | | |  |  0.571 | | |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 1  (α − 1)xq | | | | | | | | | |  | 1  (2 − 1)  0.4 | | | | | | | | | | |  |  |  |  |  |  |  |  |
| R min  | | | | | | | x D − y q | |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| y q − xq | | | | , |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 由 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| x D | yq | | | | − xq R min  y q  0.571 − 0.4  10.  0.571  0.742 | | | | | | | | | | | | | | | | | | | | | | | | |  |
|  |  |  |  |  |  |  |  | x | | | w |  |  | | | Fx f | − DxD |  | | 200  0.4 − 100  0.742 | | | | | | | | |  0.058 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  | |  |  |  | |  |  |
| 由物料衡算得： | | | | | | | | | | |  |  |  |  |  | W | | | | | | 100 | | |  |  |  | ＞0 |  |
| ∴假设正确，计算有效。 | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ②R = 2.0，设此时在 xq、yq 处达到相平衡 | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |
| xD  0571. − 0.4  2.0  0571.  0.913 | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |
| x w |  | |  | 80 − 100  0.913 | | | | | | | | | |  |  −0113. | | | | | | | |  |  |  |  |  |  |  |  |
|  | |  | |  | | | | | |  |  |  |  |  |  |  |  |
|  |  |  |  |  | 100 | | | |  |  |  |  |  |  |  |  | ＜0 | | | | | |  |  |  |  |  |  |  |  |
| 假设不成立，显然在 xw=0 处达到平衡，此时 | | | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |
| xD |  | | Fxf | |  |  | | 200  0.4 | | | | | | |  0.8 | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | |  |  | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  | D | 100 | | | | | | |  |  |  |  |  |  |  |  |  | x D |  |  |  | 0.742 | | |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  0.371 | |  |
| ③NT = ∞，R = 1.0 时，精馏段截距： R  1 | | | | | | | | | | | | | | | | | | | | | | |  |  | |  |
| 1  1 | | | |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | xD |  |  | 0.8 | |  |  0.267 | |  |  |
| NT = ∞，R = 2.0 时，精馏段截距： R  1 | | | | | | | | | | | | | | | | | | | | | | |  | |  |  |
| 2  1 | | | |  |  |  |  |

y y



xq,yq

0.371

0.267

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
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|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | xw=0.058,xf=0.4 | | |  |  |  | xD=0.742 | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | xw=0 | | |  | xf=0.4 | |  | xD=0.8 | | |  |  |  |
|  |  |  |  |  |  |  |  | |  |  |  | |  |
|  |  |  |  |  | x |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  | x |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  | |  |  |  |  |  |  |  |  |  | | |  |  |  |  |  |  |  |  |
|  |  |  | NT=∞，R=1.0 | | | | |  | | |  |  | NT=∞，R=2.0 | | | | |  |  |  |  |  |  |
| 26）某一精馏 | | |  |  |  |  |  | （含塔釜）用来分离苯 | | | | |  | | | | |  |  | 料量 | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |

* 100kmol/h，其中轻组分的含量为 0.40（摩尔分率），以泡点状态连续加入到第三块板上（从塔顶数起）。塔顶产品的流量为 20kmol/h，泡点回流操作回流比 R=2.8。已知体系的相对挥发度为 2.47。求塔顶和塔底产品的组成。（提示：用 xW=0.2878 作为试差初值）

解：W = F－D = 80 kmol/h

′

* + x w =0.2878，则

1. D  Fxf − Wxw ′  100  0.4 − 80  0.2878

D20



* 0.8488

精馏线

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| y  |  | R | | x  | | xD | | |  0.7368x  0.2234 | | | |  |  |
|  |  | | R  1 | | |  |  |
|  | R  1 | | | | y1 |  |  |  | 08488. |  |  |
| x1  | |  |  |  |  |  |  |  |  |  |  0.6944 |  |
| α − |  | | α − 1 y | | 1 |  | 2.47 − |  | 2.47 − 1  08488. |  |
|  |  |  |  |  |  |  |  |  |  |  |

y2 = 0.7368x1＋0.2234 = 0.7368×0.6944＋0.2234 = 0.7350

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| x2 |  |  |  |  | y 2 |  |  |  |  |  |  |  | 0.7350 |  |  05289. |  |
|  | α − |  | α − 1 y | 2 |  |  | 2.47 − |  | | 2.47 − 1  0.7350 | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| y3 = 0.7368x2＋0.2234 = 0.6131 | | | | | | | | | | | | | | |  |  |
| x3 |  |  |  |  | y 3 |  |  |  |  |  |  |  | 0.6131 |  |  0.3908 |  |
| α − | |  | α − 1 y | 3 |  | 2.47 − | |  | 2.47 − 1  0.6131 | | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |

∵x3 = 0.3908 ＜xf = 0.4，改用提馏线与平衡线计算

L ′  L  qF  RD  1  F  2.8  20  1  100  156 kmol/h

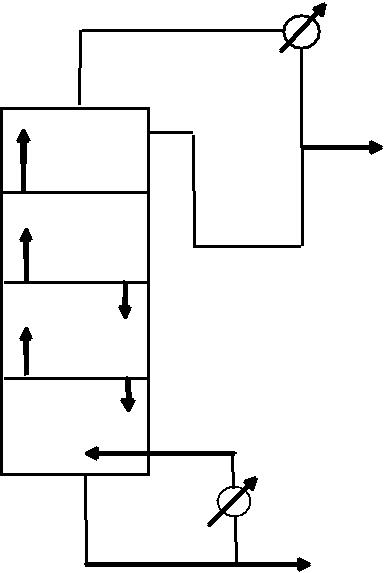
|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| y  | L ′ | x − | W | x |  | ′  | 156 | x − | 80 |  0.2878 |  |
|  |  | w |  |  |  |
| ∴提馏线V′V′ | | | | | 7676 | | | |  |  |

= 2.0526x－0.3029

y4 = yw = 2.0526x3－0.3029 = 2.0526×0.3908－0.3029 = 0.4993

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| x4  xw |  | y | 4 |  | 0.4993 |  0.2876 |  |
| α − (α − 1)y 4 | |  |  |
|  |  |  | 2.47 − (2.47 − 1)  0.4993 | |  |

xw 与假设值 x w ′ = 0.2878 非常接近，相对误差为 0.07%，故假设正确，



∴xD = 0.8488

xw = 0.2878

y1

1

D

2

F

xf 3



y2 x

y3 x2

y4=yw  x3

4=xw

27）在常压连续回收塔中分离甲醇～水混合溶液。进料组成为 0.10（摩尔分率），要求塔顶产品中甲醇的回收率为 0.90，塔底直接水蒸汽加热。试求：①当塔板数为无穷多时，塔顶、塔底产品组成及每摩尔进料消耗的水蒸汽量；②若蒸汽用量为最小用量的两倍时，完成分离任务时所需理论板数及塔顶、塔底产品组成。

常压下甲醇～水体系部分汽液平衡数据列于下表：

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 液相组成 x | 0.000 | 0.060 | 0.080 | 0.100 |
| 汽相组成 y | 0.000 | 0.304 | 0.365 | 0.418 |
|  |  |  |  |  |

解：①Smin = D F = W

η  Dx D



Fxf ， DxD  ηFxf

由 Fxf = DxD＋Wxw 得

Wxw = Fxf－DxD = Fxf(1－η) = 0.1Fxf ∵F = W

∴xw = 0.1xf = 0.1×0.1 = 0.01

∵NT = ∞，故在塔顶进料处， xf 与 xD 达相平衡，

* VLE 数据表得 xD = 0.418

全塔物料衡算 Fxf＋S 0 = DxD＋Wxw

Fxf = S xD＋0.1Fxf

S xD = 0.9 Fxf

Smin 0.9xf0.901.0.215

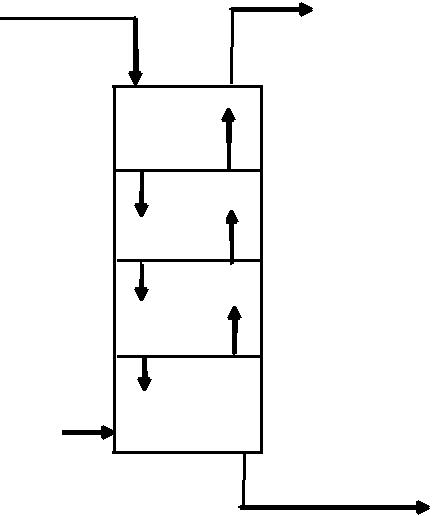


∴ F xD 0.418

②由上面计算可知 xw = 0.01(此值由回收率而定)

F xf＋S 0 = D xD＋W xw ∵S = D F xf = S xD’ ＋W xw

|  |  |  |
| --- | --- | --- |
| F，xf | D，xD |  |
|  |  |



y1

1

y2

2

x2 y3

3

x3

S

xw，W

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ′ |  | Fxf | − Wxw |  | Fxf | − 01.Fxf |  | 0.9Fxf |  | 0.9Fxf |  |
| xD |  |  |  |  |  |  |  |  |  |  |  |
|  | S |  | S | S | 2Smin |  |
| ∴ |  |  |  |  |  |  |  |

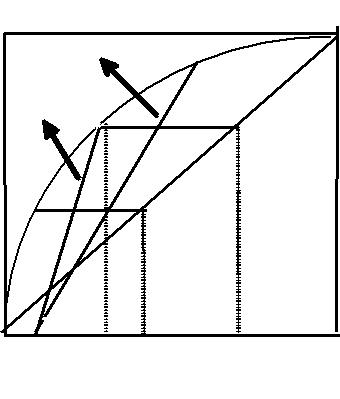
* 0.9xf  0.9  01.  0.209 Smin 2  0.215



2



F



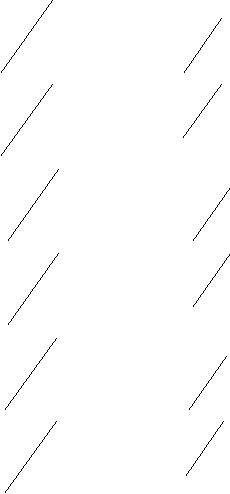
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| (注：当 S = 2Smin 时，xf 与 xD 不达相平衡) | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  | 2Smin | | | |  |  |  |  |
|  |  |  | L |  | | | F | | |  |  |  | F | | |  |  | F |  |  |  | | |  |  |  |  |  |  |  | |  |  |  |  |  |
|  |  |  |  | | |  |  |  |  |  |  |  |  2.326 | | |  |  |  | Smin | |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 斜率 S S | | | | | | | | |  |  |  | 2Smin | | | |  |  | 2  0.215F | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 点(xw，0)和点(xf，xD’)都在提馏线上， | | | | | | | | | | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |
| 故提馏线斜率： | | | | | | | | | | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | xD | ′ − 0 | | | | | | | 0.209 − 0 | | | | | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | |  |  |  |  |  |  |  |  |  2.322 | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | xf | − xw | | | | | | | 01. − 0.01 | | | | | | |  | 01.Fxf | |  | 01.xf | |  |  |  |  | xw | |  |  | xf | | xD’ | |  | xD |  |
|  |  |  | W | |  | | | |  |  | W | |  | | |  |  |  | 01.  01. |  |  |  | |  | |  |  |  |  |  |  |  |
|  |  |  | xw | | | |  |  | xw | | |  |  |  |  |  0.0233 | | | | | |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  | |  |  | |  | |  | |  |  |  |
| 截距 V | | | | | | | | |  |  |  | S | | | |  |  | S |  | S | | | 2  0.215 | |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | F | |  |  |  |  |  |  |  |  |  |  |  |  |



∴提馏线: y = 2.322x－0.0233

要逐板计算，必须要有 α，而 α 由下列方法获得，由本题附表可知：

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | y A1 | | | |  | 0.304 | | |  |  |  |  |
|  |  |  | y B1 |  | |  |  |  |  |  |
| α1 |  |  |  | 0.696 | | |  |  |  6843. |  |
| xA1 | | | | 0.060 | | |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  | xB1 | | |  | 0.940 | | |  |  |  |  |
|  |  |  | y A2 | | |  | 0.365 | | |  |  |  |  |
|  |  |  | y B2 | | |  |  |  |  |  |
| α2 |  |  |  |  | | 0.635 | | |  6.61 |  |
|  | xA2 | | | 0.080 | | |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  | xB2 | | |  | 0.920 | | | | |  |  |
|  |  |  | y A3 | | |  | 0.418 | | |  |  |  |  |
|  |  |  | y B3 | |  |  |  |  |  |  |
| α3 |  |  |  |  | 0582. | | |  |  6.464 |  |
|  | xA3 | | | 01. | | |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  | xB3 | | |  | 0.9 | | |  |  |  |  |



α m  α1  α2  α3  6.639

* 3



|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| x1 | |  |  | y | 1 |  |  |  |  | | xD |  |  |  | 0.209 | | |  0.0383 |  |
| α − (α − 1)y1 | | | | | |  |  |  |  |  |  |  |
| ∴ | |  |  |  | α − (α − 1)xD | | | | 6.639 − (6.639 − 1)  0.209 | | | |  |
| y2 = 2.322x1－0.0233 = 0.0656 | | | | | | | | | | | |  |  |  |  |  |  |  |  |
| x2  | |  | y 2 | |  |  |  | |  |  |  | 0.0656 | | |  |  0.0105 | |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | α − (α − 1)y 2 | | | | | | |  | 6.639 − (6.639 − 1)  0.0656 | | | | | | | | |  |
| y3 = 2.322x2－0.0233 = 0.00108 | | | | | | | | | | | | |  |  |  |  |  |  |  |
| x3  |  |  | y 3 | |  |  | |  |  |  |  | 0.00108 | | |  |  |  163.  10−4 | |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | α − (α − 1)y 3 | | | | | | | 6.639 − (6.639 − 1)  0.00108 | | | | | | | | | |  |
| x3＜xw = 0.01 | | | | | 0.0105 − 0.01 | | | | | | |  |  |  |  |  |  |  |  |
| ∴ N T | |  2  | |  |  2 |  |  |  |  |  |  |  |
| 0.0105 − 163.  10−4 | | | | | | | | (含釜) | | | | | |  |

28）有两股丙酮（A）与水（B）的混合物分别加入塔内进行连续精馏分离。第一股进料摩尔流量为 F1，q1=1，xf，1=0.80（摩尔分率，下同），在塔的上部加入；第二股进料摩尔流量为 F2，q2=0，yf，2=0.40，且 F2=4F1。塔顶产品浓度 xD=0.93，塔底产品浓度 xW=2.6×10-3，塔顶采用全凝器，液体泡点回流，塔釜间接加热，常压操作。试求 Rmin。当 R=2.0Rmin，写出第二塔段的操作线方程。常压下“丙酮～水”的平衡数据如下：

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 温度 | 液相中丙酮 | 气相中丙酮 | 温度 | 液相中丙酮 | 气相中丙酮 |
| t ℃ | 摩尔分率 x | 摩尔分率 y | t ℃ | 摩尔分率 x | 摩尔分率 y |
| 100 | 0.0 | 0.0 | 60.4 | 0.40 | 0.839 |
| 92.7 | 0.01 | 0.253 | 60.0 | 0.50 | 0.849 |
| 86.5 | 0.02 | 0.425 | 59.7 | 0.60 | 0.859 |
| 75.8 | 0.05 | 0.624 | 59.0 | 0.70 | 0.874 |
| 66.5 | 0.10 | 0.755 | 58.2 | 0.80 | 0.898 |
| 63.4 | 0.15 | 0.798 | 57.5 | 0.90 | 0.935 |
| 62.1 | 0.20 | 0.815 | 57.0 | 0.95 | 0.963 |
| 61.0 | 0.30 | 0.830 | 56.13 | 1.0 | 1.0 |
|  |  |  |  |  |  |

解：1)全塔物料衡算：

|  |  |  |  |
| --- | --- | --- | --- |
| *F* 0.804 *F* 0.400.9302.610−3 *W* LL（1） | | | |
| 1 |  | 1 |  |
| *F*1 |  4 *F*1 |  *D* *W* | LLLLLLLLLL（2） |

联立（1），（2）式解得： *D*/ *F*1  2.574，*W* / *F*1  2.426

2）作平衡关系曲线。由第一股加料状况作 *q*1线，与平衡线交点 *A*是

（0.80，0.898），由第二股加料状况作 *q*2线，与平衡线交点 *B*

是（0.0185，0.40）。如下图所示：

1. *R*min的确定：

根据 *xD*， *xW*值及平衡曲线形状，可知决定 *R*min的有两种可能情况，一种是操作线通过 *A*点，另一种是操作线通过 *B*点。假设 *R*min的操作线通过 *A*点：

（按 *R*min条件计算）

0.93 − 0.898

*R*min 0.3265



塔顶第一塔段： *L*Ι *R*min *D*0.32652.574 *F*10.840 *F*1

*V*Ι（1 *R*min） *D*（10.3265）2.574 *F*13.414 *F*1

第二塔段： *L* Π

*L* Ι

*q F* 11

0.840 *F*  *F*  1.840 *F*

1 1 1

*V*  *V* −（1− *q*） *F*  *V* −3.414 *F*

 Ι 1 1 Ι 1

（ *L*/ *V*）1.840 / 3.4140.539

Π

*AB*直线斜率（0.898−0.40）（/0.80−0.0185）0.637



由于 *AB*斜率大于（ *L*/ *V*），可判明决定 *R* 的是 *B*点。要确定 *R* ，须试差



 min min

法。假设 *R*min时，一、二塔段操作线交点 *A*′为（0.80，0.8816），则：

0.93 − 0.8816

*R*min 0.5931



*L*Ι0.59312.574 *F*11.527 *F*1， *V*Ι1.59312.574 *F*14.101 *F*1

1.  2.572 *F*， *V*  4.101 *F*，（ *L*/ *V*）  0.6162

Π1Π1Π

*A*′ *B*斜率（0.8816−0.40）（/0.80−0.0185）0.6163



|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |
| 因（ | ）与 ′ 的斜率基本一致，故 | | | | | *R*min | 。 |  |
|  | *L*/ *V* | Π *A B* | | |  |  0.5931 |  |
|  |  | *R* 2.0 *R*min | | |  2.0  0.5931  1.186 | |  |  |

*L*Ι1.1862.574 *F*13.053 *F*1

*V*Ι（11.186）2.574 *F*15.627 *F*1

*L*Π *L*Ι *F*13.053 *F*1 *F*14.053 *F*1

*V*Π *V*Ι5.627 *F*1

作控制体如附图，物料衡算式为：

*F*1 *xf*，1 *V*Π *y*  *L*Π *x* *DxD*

则： *y* （ *L*/ *V*） *x*（ *Dx* −

 *D*

*F x* ，）/ *V*1*f*1Π

（4.053 / 5.627） *x*（2.574 *F*1  0.93 − 0.80 *F*1）/5.627 *F*1

* 0.720 *x* 0.283

此式即为第二塔段的操作线方程。

29）常压下，用一块理论板、全凝器与塔釜组成的连续精馏塔分离某二元混合液。已知：进料 xf=0.20，q=1，进料从塔上方加入。塔顶产品浓度 xD=0.30，塔顶用全凝器，泡点回流，回流比为 3.0。易挥发组分回收率η=0.85，若平衡

关系可用表示，试估算 A 值。

解：1)*η*  *D xD*  *D*0.300.85



*F xf*

*F*

0.20

*D*/ *F* 0.567,

*W* / *F* 0.433

* + 1.  *xD* − *xf F xD* − *xW*
  + 0.433 （0.30 − 0.20）（/0.30 − *xW*） *xW* 0.0691



2）提馏段： *L*′  *R D* *qF*

* 3.0  0.567 *F*  *F*  2.701 *F* *V*′ *V* −（1− *q*） *F*  *V* −（1 *R*） *D*

（1  3.0） 0.567 *F*  2.268 *F*

提馏段操作线：（ *y*− *xW*）（/ *x*− *xW*） *L*′/ *V*′

即（ *y*−0.0691）（/ *x*−0.0691）2.701/ 2.268

*y* 1.191 *x*−0.0132

3） *y*2  *A xw*， *x*1  *xD* / *A*，（ *x*， *y*）处在提馏段操作线上，故：

*A*0.06911.191（0.30 / *A*）−0.0132

解得： *A*2.18

30）以回收塔回收某水溶液中的易挥发组分。α=2.50，进料 xf=0.20（摩尔分率，下同），q=1.10，操作中控制塔底排出液浓度 xW=0.002。要求馏出液浓度为 0.36。试计算所需的理论板数。

解：1）进料 *q*线方程：

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | *q* | | | *xf* | | | |  |
| *y*  |  |  | *x*− | |  |  |  |  |  |
|  |  | *q*−1 | | | |  |
|  |  | *q*−1 | | |  |
|  |  | 1.10 | |  | *x*− | 0.20 | |  11 *x*− 2 |  |
| 1.10 −1 | | | |  | |  |
|  | 1.10 −1 | | | |  |

2）提馏段操作线方程：

*q*线与 *y*  *xD*直线交点（ *xq*， *yq*）： *yq* 0.3611 *xq* −2， *xq* 0.2145连接（0.2145，0.36）与（0.002，0.002）两点的直线即为提馏段操作线

该操作线为：

*y*−0.002 0.36 − 0.002



*x*−0.002 0.2145 − 0.002

* *y* 1.685 *x*−1.36910−3

# 第8章 塔设备

1）拟用清水吸收空气与丙酮混合气中的丙酮。混合气含丙酮 4.5%（体积）。操作条件：常压，25℃，塔底液相质量流速 GL=6.34kg/(s·m2)，液相与气相质量流量之比为 2.50，取操作气速为泛点气速的 70%。试比较采用 25×25×2.5mm 瓷质拉西环乱堆与采用 25×3.3mm 瓷之矩鞍形填料两种方案的空塔气速及每 m 填料层压降。按塔底条件计算，液相物性按水计。

解：液相；按250 *C*清水计， *ρ* *L* 997 *kg*/ *m*3， ** *L* 0.8937 *CP* 气相：*M* 2995.5%584.5%30.3，



*ρ* *V*  1.013105  30.3（/8314  298） 1.239 *kg*/ *m*3

* *GL* / *GV*）（ *ρL* / *ρ V*）0.52.50（1.239 / 997）0.50.0881
  + *Ec*ker *t*图，乱堆填料泛点线纵坐标为0.15，即
    - *U f* 2 *ϕ ψ* / *g*）（ *ρ V* / *ρ L*） * L*0.50.15

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| （1）25  25  2.5 *mm*瓷拉西环乱堆： *ϕ*  450 *m*−1 | | | | | | | |  |  |  |
| *U f* | 2 |  450 1 | 1.239 | | |  | 0.2 | *U f* |  1.64 *m*/ *s* |  |
|  |  | （ | | |  |  | ）（0.8937）  0.15 |  |
|  |  |  |  |  |
|  |  | 9.81 | 997 | | |  |  |  |  |  |
| （2）25  3.3 *mm*瓷矩鞍形填料乱堆： *ϕ*  320 *m*−1 | | | | | | | |  |  |  |
| *U f* | 2 |  320 1 | 1.239 | | |  | 0.2 | *U f* |  1.945 *m*/ *s* |  |
|  |  | （ | |  | |  | ）（0.8937）  0.15 |  |
|  |  |  | |  |
|  |  | 9.81 | 997 | | |  |  |  |  |  |



两方案计算压降方法相同。在 *Ec*ker *t*图上纵坐标为0.720.150.0735，横坐标为0.0881，由等压线查得：90 *mmH*2 *O*/ *m*填料。

2）承第 1 题，试计算采用瓷矩鞍形填料时的 kGa，该填料的名义尺寸为 25mm。

解：250 *C*清水， *σ*  71.49 10−3 *N*/ *m*，查得 *σC*  61*dyn*/ *cm* 6110−3 *N*/ *m*

*α*  258 *m*2 / *m*3

（1）计算 *α* *W*：

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *α* | *w* |  | *σ* | *C* 0.75 | | *G* | 0.1 | *G* 2 | *α* | |  | −0.05 | *G* | 2 |  |  |
|  |  |  | *L* | *L* |  |  |  | *L* | 0.2 | |  |
|  |  |  1 − exp[−1.45（ |  |  | ）（ |  | ）（ |  |  |  | ） （ | |  |  | ） ] |  |
|  |  |  |  | *α  L* | *ρ L*2 | |  |  |  |  |
| *α* | |  | *σ* |  |  |  | *g* | |  | *ρ L σ α* | | |  |

* 1 − exp[−1.45（ 61 ）0.75（ 6.34 103 ）0.1 

71.94258  0.8937



|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 6.342 | |  258 | −0.05 | 6.342 | 0.2 | | |  |
| （ |  |  |  | ） （ |  |  | ） | ] |  |
| 997 | 2 |  9.81 | 997  71.94 10−3 |  258 |  |
|  |  |  |  |  |

* + 0.5216

*α* *w* 0.5216*α*  0.5216  258  134.6 *m*2 / *m*3

2)计算 kL 与 KLm：

计算丙酮在水中的分子扩散系数 DL：

0.8937 10−3

摩尔体积 *VA* （14.83）（3.76）7.474

1.  7.4 10−（82.6 18）0（.5273.2  25） 1.277 10−5 *cm*2 / *s*

*L*0.8937  740.6



* 1.277 10−9 *m*2 / *s*

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | *ρ* | | *L* 1/ 3 | | |  |  |  | *GL* | | 2 / 3 | | |  |  | *L* | | −1/ 2 | 0.4 |  |
| *k*（ |  |  |  |  |  | ） |  0.0051（ | |  |  |  |  | ）（ | | |  |  |  | ）（ *α dp*） | |  |
|  |  |  |  |  | *α* |  | ** |  | *ρ* |  | *D* |  |
| *L * | | | | *L* | *g* | |  |  | *W* | *L* | | |  | *L* |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  | *L* |  |  |  |
| 即 *k*（ | | |  |  | 997 103 | | | 1/ 3 |  0.0051（ | | | | |  | 6.34103 | | | | | 2 / 3 |  |
|  |  |  |  |  | ） |  |  |  |  |  |  | ） |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  | *L* | 0.8937  9.81 | | | | | | |  |  |  | 134.6  0.8937 | | | | | | | |  |  |



（997 1.277 10−9 ）−0.5 （258 2510−3）0.4 *kL* 1.17710−4 *kmol*（/ *s m*2 *kmol m*−3）

*kLa*  *kL*  *α W*

 1.177 10−4 134.6

 0.0158 *kmol*（/ *s m*3 *kmol m*−3）

3）承第 1 题，试计算采用瓷矩鞍形填料时的 kLa，该填料的名义尺寸为 25mm。

解： *kG RT*/( *α DG*)5.23[ *GV* /( *α G*)]0.7[ *G* /( *ρ G DG*)]1/ 3( *α dp*)−2

|  |  |  |
| --- | --- | --- |
| *G*  *G* / 2.506.34 / 2.502.536 *g*/( *s m*2), *α* 258 *m*2 | | / *m*3 |
| *V* | *L* |  |
| 气相物性数据按1*atm*，250 *C*空气计： | |  |
| *ρG*  1.185 *kg*/ *m*3 | |  |
| ** |  1.835 10−5 *Pa s* |  |
| *G* |  |  |

1. 10−5 *T*1（.51/ *M* *A* 1/ *MB*）1/ 2

|  |  |  |  |
| --- | --- | --- | --- |
| *DG*  |  |  |  |
| 1/ 3 | 1/ 3 2 |  |
|  | *P*（ *VA* |  *VB* ） |  |

* *T* − *K*， *P*− *KPa*， *VA*， *VB* − *cm*3/ *mol*）
* 4.36 10−（5298.2）1（.51/ 58 1/ 29）1/ 2  9.45310−6 *m*2 / *s* 101.3（741/ 3  29.91/ 3）2



|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | *kG* 8.314298.2 |  | 2.536 | 0.7 |  |
| 则 |  |  5.23（ |  | ）  |  |
| 258  9.45310−6 | 258 1.835 10−5 |  |

1.835 10−5 1/ 3 258  25 /100 −2

（ ）（ ）



1.185  9.45310−6

解得： *kG* 1.18610−5 *kmol*（/ *s m*2 *kPa*）

*kGa*  *kG α W* 1.18610−5134.6

* + 1.596 10−3 *kmol*（/ *s m*3 *kPa*）

4）某“乙醇～水”精馏塔，塔顶、底温度分别为 78.2℃与 102℃，进料中含乙醇 16%（摩尔），试查取全塔效率。

解：平均温度 *tm* （78.2102）/290.10 *C*

90.10 *C*时， *α*  8.60，液相水 **1  0.3162 *CP*，液相乙醇 ** 2  0.38 *CP*

* + *L*  0.84  0.3162  0.16  0.38  0.326 *CP* *α* ** *L* 8.60  0.326  2.80

查 *O*′*connell*图，得 *ET* 37.5%

5）某“苯～甲苯”精馏塔，进料含苯 2 0 %（摩尔，下同），塔顶产品含苯 98%，塔底产品含苯 2.0%，泡点进料，泡点回流，塔顶用全凝器，物系相对挥发度α =2.47。操作回流比为最小回流比的 1.5 倍。已知气相默弗里单板效率 EmV 随液相浓度变化不大，可按 0.55 计。试确定所需实际塔板数及加料板位置。

# 第10章 固体干燥

1） 已知空气总压为p为1.013\*10^5Pa,空气的干球温度为 60℃，湿球温度为 30℃，试计算空气的湿含量 H，相对湿度 ，焓 I 和露点温度 。

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 解：查表得 | *t* | *w* |  300 *C*时 | | *p* 4.247 *kPa* | | |  |
|  |  |  |  | *s*, *tw* |  |  |  |
|  | *Hs*, *tw* | | |  0.622 *Ps* /( *p*− *ps* )  0 0272 | | | |  |
|  | *H*  *Hs*, *tw* −[( *t*− *tw*) / *rtw*](*α*/ *KHh*) | | | | | | |  |
| 300 *C*时 |  |  | *r* |  2427 | *α* / *K* | *H* |  1.09 |  |
|  |  |  | *tw* |  |  |  |  |

*H* 0.0137

*t* 600 *C* *ps* 19.923 *kPa*

* *H* 0.0137求得此时 *p* 2.18 *kPa*

Φ *p*/ *ps* 1100

*I* (1.011.880.0158)6024900.0158

* + 96.44 *kJ* / *kg*干空气



由 *ps* 2.18 *kPa*,

查表得

*t* 18.40 *C*

*td* 18.40 *C*

2 ） 利用湿空气的 I — H 图完成本题附表空格项的数值，湿空气的总压 。

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 序 | 号 | 干球温度 | 湿球温度 | 湿 | 度 | 相对湿度 | 焓 | 露 | 点 | 水气分压 |
|  |  | 0C | 0C | kg 水 /kg | | 0/0 | kJ/kg 绝 | 0C |  | kPa |
|  |  |  |  | 绝干空气 | |  | 干气 |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  | 1 | 60 | 30 |  | 0.015 | 13.3 | 98 | 21 |  | 2.5 |
|  | 2 | 40 | 27 |  | 0.016 | 33 | 79 | 20 |  | 2.4 |
|  | 3 | 20 | 17 |  | 0.012 | 80 | 50 | 16 |  | 2 |
|  | 4 | 30 | 29 |  | 0.026 | 95 | 98 | 28 |  | 4 |

3） 湿空气（ =20℃， ）经预热后送入常压干燥器。试求：①将空气预热到 100℃所需热量：②将该空气预热到 120℃时相应的相对湿度值。

解：1） .比热 *CH*  1.01 1.88 *H*  1.01 1.88 *H* 0.22 *kJ*（/ *KG*绝干气 0 *C*）

*Q*  *CH* ∆ *t* 80 *CH* 83.8 *kJ* /( *kg*绝干气0 *C*）

|  |  |
| --- | --- |
| 2）1200 *C*时 | *p* 198.64 *kPa*f101.3 *kPa*, *H* 0.02 *kg*水/ *kg*干气 |
|  | *s* |

1.  0.662Φ *ps* /( *p*− Φ *ps* ) 解得 Φ  3.12 0 0



4） 湿度为 的湿空气在预热器中加热到 128℃后进入常压等焓干燥器中，离开干燥器时空气的温度为 49℃，求离开干燥器时露点温度。

解： I = (1.01+1.88H)t＋2500H

∵等焓 ∴ I1 = I2

∴(1.01+1.88H1)t1＋2500H1 = (1.01+1.88H2)t2＋2500H2

(1.01+1.880.018) 128＋25000.018= (1.01+1.88H2) 49＋2500H2

* H2 = 0.0498 kg 水/kg 干气

|  |  |  |  |
| --- | --- | --- | --- |
| H  | p |  0.622 |  |
|  |  |

* P − p

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | 0.0498  0.622  | p |  |  |
|  |  | − p |  |
| ∴ | 1013.  10 5 | |  |
|  |  |  |  |

* p = 7510 Pa

查表得 td = 40℃

5） 在一定总压下空气通过升温或一定温度下空气温度通过减压来降低相对湿度，现有温度为 40℃，相对湿度为 70%的空气。试计算：①采用升高温度的方法，将空气的相对湿度降至 20%，此时空气的温度为多少？②若提高温度后，再采用减小总压的方法，将空气的相对湿度降至 10%，此时的操作总压为多少？

解： (1) t = 40℃时查表 ps = 7.377KPa，∴ p = ϕps = 0.77.377 = 5.1639 Kpa

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| ∵H1 = H2 | | | | ∴ p = p’= 5.1639Kpa | | |  |
| p | ′ |  | p′ |  | 51639. |  258195.KPa |  |
| s | 0.2 |  |  |
| ∴ |  | 0.2 | |  |  |

查表得 t = 63.3℃

(2) ∵t 不变 ∴ps = 25.8195KPa

* 63.3℃, ϕ = 10% 查图得 H = 0.014kg 水/kg 干空气

p′

H  0.622



P − p′

2.58195

0.014  0.622



P′ − 2.58195 ∴P’=117.29Kpa

6 ） 某干燥器冬季的大气状态为  ℃ ，  ，夏季空气状态为  ℃ ，  。如果空气离开干燥器时的状态均为  ℃ ，

。试分别计算该干燥器在冬、夏季的单位空气消耗量。

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 解： *t* 400 | *C*, | *p* | *s*,2 |  7.3766 *kPa* |  |
| 2 |  |  |  |  |
| *p*2  Φ 2 *ps*,2 |  5.9 *kPa* | |  |  |  |

*H*20.662Φ *ps* /( *p*− Φ *ps* )0.0385 *kg*/ *kg*干气

冬季： *t*050 *C* *ps* 0.8728 *kPa*

*H*00.662Φ *ps* /(101.33− Φ *ps* )

Φ  30%

 0.0016 *kg*/ *kg*干气

*L*（冬）1（/ *H*2− *H*0）

27.1*kg*干气 / *kg*水

夏季： *t*0300 *C* *ps* 4.2474 *kPa* Φ  65%

0  0.622Φ *s* /(101.3− *ps*Φ)0.01742 *kg*/ *kg*干气

*L*（夏）1（/ *H*2− *H*0）

47.4 *kg*干气 / *kg*水

7） 在常压连续干燥器中，将某物料从含水量 10%干燥至 0.5%（均为湿基），绝干物料比热为 1.8kJ/(kg.℃)，干燥器的生产能力为 3600kg 绝干物料/h，物料进、出干燥器的温度分别为 20℃和 70℃。热空气进入干燥器的温度为 130℃，湿度为 0.005kg 水/kg 绝干空气，离开时温度为 80℃。热损失忽略不计，试确定干空气的消耗量及空气离开干燥器时的温度。

|  |  |
| --- | --- |
| 解： *x*10.1/(1−0.1)0.111 | *x*20.005 |

*W*  *G*( *x*1− *x*2)381.6 *kg*水/ *h*

*I*1(1.011.880.005)13024900.005144.97 *kJ*/ *kg*干气

*I*2(1.011.88 *H*)802490 *H* 80.82640.4 *H*

*I*'1 *Csθ* 1 *x*1 *Cwθ* 1

* (1.8  0.111 4.187)  20
* 45.30 *kJ*/ *kg*干料

*I*'2 *Csθ* 2 *x*2 *Cwθ* 2

* (1.8  0.005  4.187)  70
  + 127.46 *kJ* / *kg*干料

又根据物料衡算，热量衡算可得：

*W*  *L*( *H*2− *H*1)

‘ ’

*GC* ( *I* 2− *I* 2) *L*( *I*1− *I*2)

联立方程，解得

*L* 25572 *kg*干气/ *h*

*H* 0.01992 *kg*水/ *kg*干气

8）在常压连续干燥器中，将某物料从含水量 5%干燥至 0.2%(均为湿基)，绝干物料比热为 1.9kJ/(kg.℃)，干燥器的生产能力为 7200kg 湿物料/h，空气进入预热器的干、湿球温度分别为 25℃和 20℃。离开预热器的温度为 100℃，离开干燥器的温度为 60℃，湿物料进入干燥器时温度为 25℃，离开干燥器为 35℃，干燥器的热损失为 580kJ/kg 汽化水分。试求产品量、空气消耗量和干燥器热效率。

解：（1） *G*（1 − *W*） *G*（1 − *W*）

2 2 1 1

*G*27200（1−0.05）（/1−0.002）6854.0 *kg*湿料/ *h*

（2） *X*1  0.05（/1 − 0.005）

0.05263 *X*10.002（近似）

查 *H* − *I*图 *t*0250 *C* *tW*0

 200 *C*时

*H*00.013 *kg*/ *kg*干气

*G*  *G*（1− *W*）7200（1−0.005） *C* 1 1

6840 *kg*干气 / *h*

*W*  *G*（ *X* − *X* ）6840（0.05263− *C* 1 2

0.002）

346.31 *kg*/ *h*

对干燥器热量衡算：

‘

*I* 1 *Csθ* 1 *X*1 *Cwθ* 1

* 1.9  25  0.05263 4.187  25  53.01*kJ*/ *kg*干料

*I*’1.9350.0024.1873566.79 *kJ*/ *kg*干料

2

*I*1（1.011.88 *H*0） *t*12490 *H*0

（1.01 1.88  0.013）100  2490  0.013

* 135.81*kJ* / *kg*干气

*I*2（1.011.88 *H*2） *t*22490 *H*2

* 60.6  26028 *H*

*L*  *W*（/ *H*2− *H*1）346.31（/ *H*2−0.013） *kg*干气/ *h QL* 580346.3 *kJ* / *h*

*G*（ *I*’− *I*’） *Q* 

*C* 2 1 *L*

*L*（ *I* − *I* ）12

解得： *H*20.024 *kJ* / *kg*干气 *L* 

29348

*kg*/

*h*

（3） *η* （ *t*1 − *t*2）（/ *t*1 − *t*0） 53.3%

9） 采用废气循环干燥流程干燥某物料，温度 为 20℃、相对湿度 为 70%

的新鲜空气与干燥器出来的温度 为 50℃、相对湿度 为 80%的部分废气混合后进入预热器，循环的废气量为离开干燥器废空气量的 80%。混合气升高温度后再进入并流操作的常压干燥器中，离开干燥器的废气除部分循环使用外，其余放空。湿物料经干燥后湿基含水量从 47% 降至 5% ，湿物料流量为

，设干燥过程为绝热过程，预热器的热损失可忽略不计。试求：①新鲜空气的流量；②整个干燥系统所需热量；③进入预热器湿空气的温度。

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 解： *pS*0 |  2.3346 *kPa* Φ0 | |  70% | *ps*212.340 *kPa* Φ280% |
| 求得 *H*0 | |  0.0102 *kg*水 / *kg*干气 | | *H*20.0671*kg*水/ *kg*干气 |
| *X*1 |  *W*1（/1− *W*1）0.47（/1−0.47）0.8868 | | | |
| *X*2 |  *W*2（/1− *W*2）0.05（/1−0.05）0.05263 | | | |
| *G* |  *G*（1− *W*）1500（1−0.47）795 *kg*干料/ *h* | | | |
| *C* | 1 | 2 |  |  |
| 1）由物料衡算： *L*  *G*（ *X*1 − *X*2）（/ | | | | *H*2− *H*0）11658.1*kg*干气/ *h* |
| 新鲜空气流量： *L*（1 *H*）11777.1*kg*空气/ *h* | | | | |
| 2）干燥过程为绝热过程 | | | *Q*  *L*（ *I*2− *I*1） | |

*Q* 11658.1（[1.011.880.0671）50−（1.01

* + 1.88  0.0102） 20  2490 （0.0671 − 0.0102）
* 2.07 106 *kJ* / *h*

3）混合后： *Hm*  0.2 *H*0  0.8 *H*2  0.0557

*Im* 0.2 *I*00.8 *I*2

*tm* 44.50 *C*

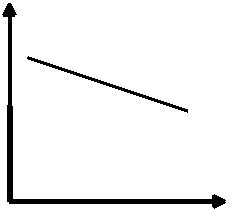
10） 某干燥系统，干燥器的操作压强为 101.3 ，出口气体温度为 60℃，相对湿度为 72%，将部分出口气体送回干燥器入口与预热器后的新鲜空气相混合，使进入干燥器的气体温度不超过 90℃、相对湿度为 10%。已知新鲜空气的

质量流量为 ，温度为 20℃，湿度为 ，试求：①空气的循环量为多少？②新鲜空气经预热后的温度为多少度？③预热器需提供的热量。

解:

气

t



A

M

B

H

B 点：60℃ ϕ = 72% 查图 H = 0.16kg 水/kg 干空

M 点：90℃ ϕ = 10% 查图 H = 0.048kg 水/kg 干空气

∵AMB 在一直线上

∴A 点：H = 0.0054kg 水/kg 干空气, t = 127℃

BM 新鲜空气中绝干空气质量 55. 0.49 ∵ MA  循环空气中绝干空气质量  4.4  W



* W = 0.392 kg 干空气/s
* W’ = W(1+H) = 0.392(1+0.16) = 0.455 kg/s

Q = 0.49(1.01+1.880.0054) (127－20) = 53.49 kJ/s

11） 干球温度 为 20℃、湿球温度为 15℃的空气预热至 80℃后进入干燥器 ，

空气离开干燥器时相对湿度 为 50%，湿物料经干燥后湿基含水量从 50%降至5%，湿物料流量为 2500kg/h。试求：①若等焓干燥过程，则所需空气流量和热量为多少？②若热损失为 120kW，忽略物料中水分带入的热量及其升温所需热量，则所需空气量和热量又为多少？干燥器内不补充热量。

解：1）由 *t*0200 *C tW* 150 *C*

得： *H*00.0088 *kg*水/ *kg*干气

*I*0（1.011.880.0088）2024900.0088

* 42.4 *kJ* / *kg*干气

*I*1（1.011.880.0088）8024900.0088104.0 *kJ*/ *kg*干气

*X*11

*X*20.0526 *GC* 1250 *kg*干料/ *h*

*W*  *G*（ *X* − *X* ）

*C* 1 2

1184.3 *kg*水 / *h*

查图得（等焓干燥）

*t*2410

*C*

*H*2

0.0245 *kg*水 / *kg*干气

*L*  *W*（ *H*2− *H*0）

75433.1*kg*干气 / *h*

*Q* 

*L*（ *I*1− *I*0）

4.65 106

*kJ* /

*h*

2） *L*（ *I*1 − *I*2） 120  3600 *kJ* / *h*

*L*（ *H*2− *H*1）1184.3 *kg*水/ *h*

经试差得： *H*20.023 *kg*水/ *kg*干气

*t*239.50 *C*

*L* 83401*kg*干气/ *h*

*Q*  *L*（ *I*1− *I*0）5.14106 *kJ* / *h*

12） 某湿物料在常压理想干燥器中进行干燥，湿物料的流率为 ， 初始湿含量（湿基，下同）为 3.5%，干燥产品的湿含量为 0.5%。空气状况为：

初始温度为 25℃、湿 度为 ，经预热后进干燥器的温度为 160 ℃，如果离开干燥器的温度选定为 60℃或 40℃，试分别计算需要的空气消耗量及预热器的传热量。又若空气在干燥器的后续设备中温度下降了 10℃，试分析以上两种情况下物料是否返潮？

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | X1 |  | w1 |  0.036 |  |
|  |  |  |  |  |
| 解： (1) w1= 0.035，w2= 0.005，∴ | | | | 1 − w1 | | kg 水/kg 干物料 |  |
| X2 |  | w 2 |  0.005 |  |  |  |  |
|  |  |  |  |  |
|  | 1 − w 2 | | kg 水/kg 干物料 | | |  |  |

绝干物料：Gc = G1(1－w1) = 1(1－0.035) = 0.965 kg/s

水分蒸发量：W= Gc(X1－X2) = 0.03 kg/s

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | L  |  |  | W |  |  |  |
| 空气消耗量： | H | 2 | − H1 | H1= H0 | = 0.005 kg 水/kg 干空气 |  |
|  |  |
|  |  |  |  |  |

t2 = 60℃时 ∵干燥为等焓过程

∴查图 H2 = 0.0438 kg 水/kg 干空气

∴L = 0.773 kg 干空气/s

1. = L(I1－I0) = L(1.01+1.88H0)(t1－t0)
   * 0.773 (1.01+1.880.005) (160－25) = 106.4 kJ/s t2 = 40℃时，查图 H2 = 0.0521kg 水/kg 干空气

∴L = 0.637 kg 干空气/s

∴Q = L(I－I0) = 87.68 kJ/s

(2) H = 0.0438 kg 水/kg 干空气时 td = 38℃ ＜ 50℃ ∴不返潮 H = 0.0521 kg 水/kg 干空气时 td = 40℃ ＞ 30℃ ∴返潮

13） 常压下已知 25℃时氧化锌物料在空气的固相水分的平衡关系，其中当  时 ，  ， 当  时 ，

。设氧化锌含水量 ，若与温度为 25 ℃、相对湿度 为 40%的恒定空气条件长时间充分接触，问该物料的平衡含水量，结合水分和非结合水分分别为多少？

解： x\*= 0.007 kg 水/kg 干料

结合水分 x = 0.02 kg 水/kg 干料

非结合水 x = 0.35－0.02 = 0.33 kg 水/kg 干料

14） 由实验测得某物料干燥速率与其所含水分直线关系。即 。 在某干燥条件下，湿物料从 60 ㎏减到 50 ㎏所需干燥时间 60 分钟。已知绝干物料重 45 ㎏， 平衡含水量为零。试问将此物料在相同干燥条件下，从初始含水量干燥至初始含水量的 20%需要多长时间？

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 解： | 由题意： *X*1（60−45）/451/ 3 | | | *X*2 | （50 − 45）/45  1/ 9 |
|  |  | 1/ 3 |  |  |  |
|  | 则 | *Kxτ* ∫1/ 9 | *dx*/ *x* |  |  |
|  |  | 60 *Kx*  *Ln*3 |  |  |  |
|  | *W*’2（60−45）/6020%1/ 20 | | | *x*’2 |  1/19 |
|  |  | 1/ 3 |  |  |  |
|  |  | *Kxτ* ‘∫1/ 9 | *dx*/ *x* |  |  |

’

*Kxτ*  *Ln*（19 / 3）

*τ*‘ 100.8分

15） 某物料经过 6 小时的干燥，干基含水量自 0.35 降至 0.10，若在相同干燥条件下，需要物料含水量从 0.35 降至 0.05，试求干燥时间。物料的临界含水

量为 0.15，平衡含水量为 0.04，假设在将速阶段中干燥速率与物料自由含水量 成正比。

解： *τ* 1 *G*( *X*1− *XC* ) / *C US* 0.2 *G*/ *UC S*

*τ* 2 *G*( *XC* − *X*\*) *Ln*( *XC* − *X*\*) /( *X*2− *X*\*)]/ *UC S*

* + 0.067 *G*/ *UC* *S*

*τ*  *τ* 1 *τ* 2  0.267 *G*/ *UC* *S*  6 *hr*

同理：

*τ* '  0.46 *G*/ *UC* *S* *τ* '10.42 *hr*

16） 在恒定干燥条件下的箱式干燥器内，将湿染料由湿基含水量 45%干燥到 3%，湿物料的处理量为 8000 ㎏湿染料，实验测得：临界湿含量为 30%，平衡湿含量为 1%，总干燥时间为 28h。试计算在恒速阶段和降速阶段平均每小时所蒸发的水分量。

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| X1 |  |  | w1 |  |  |  0.818 |  |  |
|  |  |  |  |  |  |
| 解：w1 = 0.45 |  | 1 − w1 | | | | | kg 水/kg 干料 |  |
|  |  | w 2 |  |  |  |  |
| X2 |  |  |  |  0.031 | |  |  |
|  |  |  |  |  |
| w2 = 0.03 | 1 − w | | | 2 |  |  | kg 水/kg 干料 |  |
|  |  |  |  |  |  |  |
| 同理 X0 = 0.429 kg 水/kg 干料 | | | | | | | X\* = 0.01 kg 水/kg 干料 τ = 28h |  |

τ1  G c X1 − X0 



Au0

τ 2  Gc (X0 − X\* ) ln X0 − X\*

Au0X2 − X\*



|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | τ1 |  |  | X1 − X0 | |  |  |  | 0818. − 0.429 | | |  0.31 |  |
|  | τ 2 | (X0 | − X\* ) ln | X0 | − X\* |  | 0.429 − 0.01ln | 0.429 − 0.01 |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  | 0.031 − 0.01 | |  |  |
|  | |  | X2 | − X\* |  |  |  |  |
|  |  |  |  |  |  |  |  |

τ1 = 0.31τ2

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 又 ∵ τ1+ τ2 = τ = 28h | | | | ∴ τ1 = 6.6hτ2 = 21.4h |  |
| Gc = 8000×(1－0.45) = 4400 kg 干料 | | | | |  |
|  | G c X1 | − X0  | |  |  |
|  |  |  |  259.3 | |  |
| ∴τ | |  |  |
| 1 |  | kg 水/h |  |

G c X0 − X2   818.



τ2 kg 水/h

17） 在恒定干燥条件下进行干燥实验，已测得干球温度为 50℃，湿球温度

* 43.7℃，气体的质量流量为 ，气体平行流过物料表面，水分只

从物料上表面汽化，物料由湿含量 变到 ，干燥处于恒速阶段，所需干燥

时间为 1 小时，试问：①如其它条件不变，且干燥仍处于恒速阶段，只是干球温度变为 80℃，湿球温度变为 48.3℃，所需干燥时间为多少？②如其它条件不变，且干燥仍处于恒速阶段，只是物料厚度增加一倍，所需干燥时间为多少？

解：(1) t = 50℃，tw = 43.7℃，rtw = 2.398 kJ/kg，τ1 = 1h

τ1  G c rtw (X1 − X2 )



αA(t − t w )

t’ = 80℃， tw’ = 48.3℃，rtw

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| τ | ′ | |  | |  | Gc rtw ′ (X1 − X2 ) | | | | |  |  |
| 1 |  |  | αA(t ′ − t w ′ ) | | | | | |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | r |  | ′ | | |  |
|  |  |  | τ |  |  |  | t ′ − t |  | | |  |
|  |  |  | 1 |  |  |  | tw | w | | |  |
|  |  |  |  |  |  |  |  |  |  5.06 | |  |
| ∴ | | | τ1′ | |  |  | rtw ′ t − t w  | | | | |  |
|  |  |  |  |  |  |  |  |  |  |

’ = 2385.6 kJ/kg

* + τ1′  0.2h

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | τ1 | |  | Gc |  | 1 |  |  |  |
|  |  | | ′ |  |  |  |
| (2) | τ | 2 |  | 2 | | ∴ τ2 |  2τ1  2h |  |
|  |  |  | Gc |  |  |  |

18） 试设计一气流干燥器，用以干燥某颗粒状物料。基本数据如下：①干燥

器的生产能力：  ； ② 空气状况：进预热器  =15 ℃ ，

，离开预热器 =95℃，离开干燥器 =60℃；③物料状况：物料干基含水量从 0.2 降至 0.002，物料进、出干燥器温度分别为 20℃

和 50℃，物料密度为 ，绝干物料比热为 ，颗粒平均

直径为 m，临界含水量为 。④干燥器的热损失：

取蒸发水分量的 15%。

解：（1）干燥管的直径 *D* [4 *LVH* （/ *π Ug*）0.5

式中： *V* (0.7721.244 *H*)(273 *t*) / 273

* (0.772 1.244  0.007)  (273  95) / 273
* 1.05 *m*3 / *kg*干气

*GC*  *G*1（/1 *X*1）

 200 /[（1  0.2） 3600]  0.0463 *kg*/ *s*

*W*  *G*（ *X* − *X* ）

*C* 1 2

* 0.0463（0.2 − 0.002） 0.00917 *kg*/ *s*

*I*1（1.011.88 *H*1） *t*12490 *H*1

（0.01 1.88  0.007） 95  2490  0.007  114.63 *kJ* / *kg* *I*2（1.011.88 *H*2） *t*22490 *H*2

（1.01 1.88 *H*2） 60  2490 *H*2 （60.6  2602.8 *H*2）

|  |  |  |
| --- | --- | --- |
| ‘ | （ *CS*  *CW X*1） *θ* 1 |  |
| *I* 1 |  |

（1.3  4.187  0.2） 20  42.75 *kJ* / *kg*

’ （ ）

*I* 2 *CS*  *X*2 *CW* *θ* 2

（1.3  4.187  0.002） 50  65.42 *kJ* / *kg*

*QL* 15% *W*（24901.88 *t*2）

* 15%  0.00917 （2490  1.88  50） 3.58 *kJ* / *s*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | ‘ | ’ | *Q* |  |  |
| 由 *L*（ *I* − *I* ） *G*（ *I* 2− | | | *I* 1） |  |  |
| 12 |  | *C* |  | *L* |  |  |
|  | ‘ | ’ |  | *I* − *I* ） | |  |
| 得： *L* [ *G*（ *I* 2 | | − *I* 1） *Q* ]（/ | |  |
| *C* |  |  | *L* | 1 | 2 |  |
|  [0.0463（65.42 − 42.750  3.58]（/54.03 − 2602.8 *H*） | | | | | |  |
|  4.630（/54.03 − 2602.8 *H*）LLLLLLLLLLLL（1） | | | | | |  |
| 由 *L*（ *H* − *H*） *G*（ *X* − *X* ） *W* | | | | | |  |
| 2 | 1 | *C* | 1 | 2 |  |  |
| 得： *L*  *W*（/ | *H*2− *H*1） | |  |  |  |  |
|  0.00917（/ *H* − 0.007） | | | | | LLLLLLLLLL（2） |  |

联立（1）式及（2）式，解得

*H*20.01582 *kg*/ *kg*干气

*L* 0.7962 *kg*/ *S*

取 *Ug* 10 *m*/ *s*，将 *H*2， *L*代入直径 *D*的公式中，即：

*D* [4 *LVH* （/ *π Ug*）]0.5

* [4  0.7962 1.05（/10*π* ）]0.5
* 0.326 *m*

(2)干燥管高度 *Z*  *τ*（ *Ug* − *U*0）

1），计算 *U*0：

* Re0  1 ~ 1000，则 *ζ*  18.5 / Re0 0.6

代入 *U*0[4 *gdP ρ S*（/3*ζ ρg*）]0.5并整理，得：

*U*0  [（4 *ρ* *S*− *ρ* *g*） *gdp*0.6 ]1/1.4 KKKKKK（3）



55.5 *ρ* *g* *Vg*0.6

空气温度取进出干燥器的平均温度：

*tm* （ *t*1 *t*2）/2（9560）/277.50 *C*

在附录中查干空气的物性数据为：

*λ* *g* 3.0310−5 *kw*（/ *m* 0 *C*） *ρ* *g* 1.007 *kg*/ *m*3

* +  2.110−5 *Pa S*

*Vg*  ** / *ρ g*2.08510−5 *m*2/ *s*

将上述物性数据代入式（3），得： *U*0  0.866 *m*/ *s* 核算 Re0  *dpU*0 / *Vg*

* 2 10−4  0.866 / 2.085 10−5  8.307 （1，1000）

故假设正确 *U*00.866 *m*/ *s*

2）计算 *Ug*：

*Ug* 10（27377.5）（/27395）9.524 *m*/ *s* 3）计算时间 *τ*：

由传热速率公式得： *τ*  *Q*（/ *α SP*∆ *tm*）

1，求 *SP*：

*SP* 6 *GC* / *dpρ S*

* + 6 0.0463（/210−4 1500）
* 0.926 *m*/ *s*

2，求 *Q*： *Q* *Q*Ι  *Q*Π

第一阶段：

根据 *t* 1950 *C*， *H*10.007 *kg* / *kg*绝干气，查 *H* ~ *I*图得：

*tw*132.00 *C*，相应水的汽化热； *γ tw*12419.2 *kJ* / *kg*

* *Q*Ι *GC*（[ *X*1−XC） *γ tw*1（ *CW*  *CW X*1）（ *tw*1− *θ* 1）]
  + 0.0463（[0.2 − 0.01455） 2419.2 （1.3  4.187  0.2）（30 − 20）]
  + 21.96 *kw*

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 第二阶段： | | | | |  |  |  |  |  |
| *t* | *m* | （*θ* | 2 |  *t* ）/ 2（5032）/ 241.00 | *C* | ， *γ* | *tm* |  2410 *kJ* / *kg* |  |
|  |  | *w*1 |  |  |  |  |

* *Q*Π *GC*（[ *XC* − *X*2） *γ tw*！（ *Cs*  *Cw X*2）（ *θ*2− *tw*1）]
  + - * 0.0463（[0.01455 − 0.002） 2410 （1.3  4.18 0.002）（50 − 32）
    - 2.49 *kw*

*Q* *Q*Ι *Q*Π21.492.4924.45 *kw*

3）求∆ *tm*：

∆ *tm* （[ *t*1− *θ* 1）−（ *t*2− *θ* 2）]/ *Ln*（[ *t*1− *θ*1）（/ *t*2− *θ*2）]

（[95 − 20）−（60 − 50）]/ *Ln*（[95 − 20）（/60 − 50）]

* 32.260 *C*