```
> restart;
> #Equations
  R := (T__hot1 - T__hot2)/(T__cold2 - T__cold1);
  S := (T__cold2 - T__cold1)/(T__hot1 - T__cold1);
  A__req := Q/(F*U*DeltaT__LM);
  DeltaT__LM := ((T__hot2 - T__cold1)-(T__hot1 - T__cold2))/ln(
  (T__hot2-T__cold1)/(T__hot1-T__cold2));
  T__hot2 := -(Q-m__hot*c__hot*T__hot1)/(m__hot*c__hot); #Kelvin
  T__cold2 := (c__cold*m__cold*T__cold1 + Q)/(m__cold*c__cold)
```

$$R := \frac{T_{hot1} - T_{hot2}}{T_{cold2} - T_{cold1}}$$

$$S := \frac{T_{cold2} - T_{cold1}}{T_{hot1} - T_{cold1}}$$

$$A_{req} := \frac{Q}{F\,U\,DeltaT_{LM}}$$

$$DeltaT_{LM} := \frac{T_{hot2} - T_{cold1} - T_{hot1} + T_{cold2}}{\ln\left(\frac{T_{hot2} - T_{cold1}}{T_{hot1} - T_{cold2}}\right)}$$

$$T_{hot2} := -\frac{-m_{hot}\,c_{hot}\,T_{hot1} + Q}{m_{hot}\,c_{hot}}$$

$$T_{cold2} := \frac{c_{cold}\,m_{cold}\,T_{cold1} + Q}{m_{cold}\,c_{cold}} \tag{1}$$

```
> #1 is in
  #2 is out
  print("====Specifications====");
  Q := 10*1000; #W
  m__hot := 90/1.204/60; #kg/s
  c__hot := 1.006*1000; #J/kg/K (Isobaric)
  T__hot1 := 20 + 273; #Kelvin
  c__cold := 4.2*1000; #J/kg/K (Isobaric)
  T__cold1 := 8 + 273; #Kelvin
```

```
print("=====Estimated=====");
m__cold := 1.5; #Kelvin
U__o_ass := 82; #W/m2/K
```

"====Specifications===="

$$Q := 10000$$

$$m_{hot} := 1.245847176$$

$$c_{hot} := 1006.000$$

$$T_{hot1} := 293$$

$$c_{cold} := 4200.0$$

$$T_{cold1} := 281$$

"=====Estimated====="

$$m_{cold} := 1.5$$

$$U_{o\_ass} := 82 \quad \textbf{(2)}$$

```
> R;
S;
A__req;
T__hot2;
T__cold2;
```

$$5.026639800$$

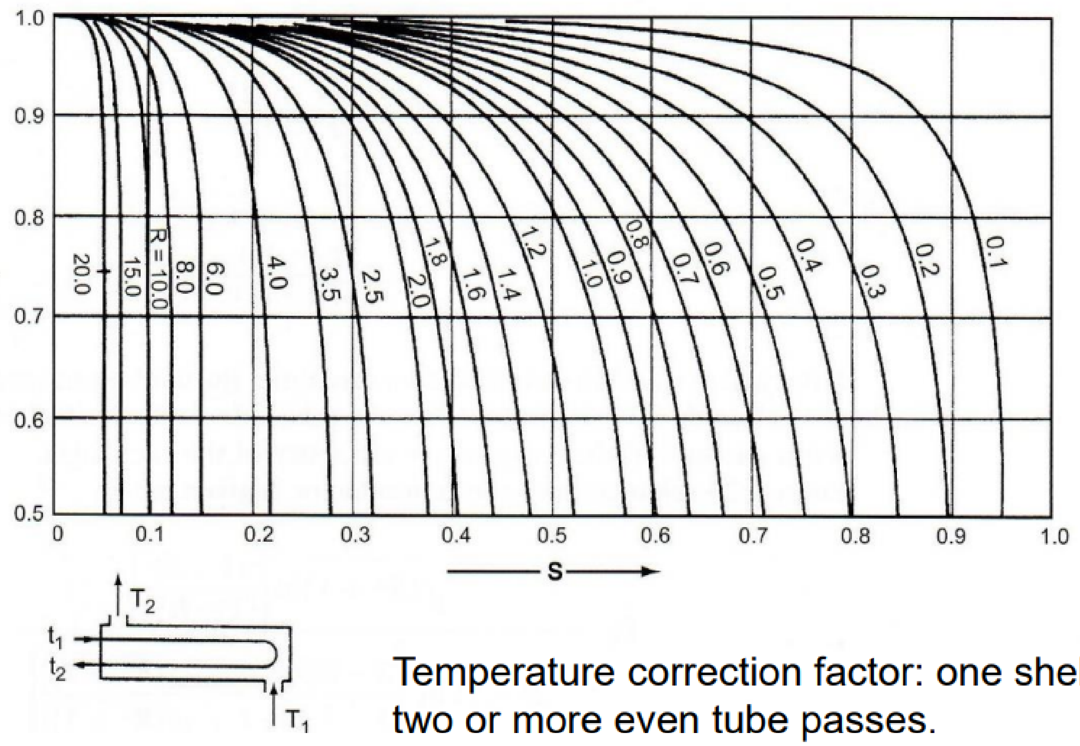
$$0.1322751417$$

$$\frac{1488.610389}{F\,U}$$

$$285.0212061$$

$$282.5873017 \quad \textbf{(3)}$$

The “correction factor” *F*



Temperature correction factor: one shell pass; two or more even tube passes.

```
> F := 0.98; #VERY ROUGH, NEED TO MEASURE PROPERLY
```

$$F := 0.98 \tag{4}$$

```
> U := U__o_ass; #TEMPORARY ASSUMPTION
  A__req; #m2
  DeltaT__LM;
```

$$U := 82$$

$$18.52427065$$

$$6.717674465 \tag{5}$$

```
> L__tube := 1.5; #tubes
  D__internal := 0.02; #m
  D__external := 0.025; #m
  #Fin type, Helical
  l__f := 0.005; #m
  t__f := 0.001; #m
  p__f := 0.003; #m

  #((L__tube*(1/p__f)*A__f)+A__b*(L__tube*(1/p__f)))

  r__f1 := D__external/2;
  l__fc := l__f + t__f/2; #corrected fin hight to account for
```

```
transfer in tip
r__f2c := r__f1 + l__fc;
A__f := 2*Pi*(r__f2c^2 - r__f1^2);
N__fin := L__tube/p__f;
A__b := Pi*D__external*(L__tube - N__fin*t__f);
A__o_one_tube := A__f*N__fin + A__b;
N__tt := A__req/A__o_one_tube;
```

$$L_{tube} := 1.5$$

$$D_{internal} := 0.02$$

$$D_{external} := 0.025$$

$$l_f := 0.005$$

$$t_f := 0.001$$

$$p_f := 0.003$$

$$r_{f1} := 0.01250000000$$

$$l_{fc} := 0.005500000000$$

$$r_{f2c} := 0.01800000000$$

$$A_f := 0.001054004335$$

$$N_{fin} := 500.0000000$$

$$A_b := 0.07853981635$$

$$A_{o\_one\_tube} := 0.6055419838$$

$$N_{tt} := 30.59122430 \qquad (6)$$

```
> #Chosen Layout is a triangular with 30 degrees rotation.
#Number of passes is 2
N__p := 6;
psi__n := 0.17;
C__1 := 0.866;
L__tp := 1.25 * D__external; #Based on TEMA standards
```

$$N_p := 6$$

$$\psi_n := 0.17$$

$$C_1 := 0.866$$

(7)

$$L_{tp} := 0.03125 \quad (7)$$

```
>
D__ctl := L__tp*(4*C__1*N__tt/3.14159265/(1-psi__n))^(1/2);
```

$$D_{ctl} := 0.1992156305 \quad (8)$$

```
> L__bb := 0.0127; #Baffle bypass clearance
```

$$L_{bb} := 0.0127 \quad (9)$$

```
>
D__s := D__ctl + L__bb + D__external;
L__B := 0.8*D__s; #Baffle spacing
```

$$D_s := 0.2369156305$$

$$L_B := 0.1895325044 \quad (10)$$

```
> P__v := L__tp * cos(3.14159265/6);
N__r := D__ctl / P__v;
BaffleCut := 0.25; #%
N__tcc := (1-BaffleCut)*N__r;
```

$$P_v := 0.02706329388$$

$$N_r := 7.361100662$$

$$BaffleCut := 0.25$$

$$N_{tcc} := 5.520825496 \quad (11)$$

```
> T__coldAvg := (T__cold1 + T__cold2)/2;
```

$$T_{coldAvg} := 281.7936508 \quad (12)$$

```
> #properties of water, tube side
rho__t := 999.70; #kg/m3
mu__t := 1.308*10^(-3); #Pa*s
k__t := 0.58; #W/m/K
C__pt := 4200; #J/kg/K
```

$$\rho_t := 999.70$$

$$\mu_t := 0.001308000000$$

$$k_t := 0.58$$

$$C_{pt} := 4200 \quad (13)$$

```
> #Calculating Tube side cross-sectional flow area
N__per_pass := N__tt/N__p;
A__internal := (3.14159/4)*D__internal^2; #m2
A__t := N__per_pass * A__internal; #m2
```

$$N_{per\_pass} := 5.098537383$$

$$A_{internal} := 0.0003141590000$$

$$A_t := 0.001601751406 \tag{14}$$

```
> #Water key equations
  v__t := m__cold/(rho__t*A__t);
  Re__t := (rho__t*v__t*D__internal)/mu__t;
  Pr__t := (C__pt*mu__t)/k__t;
  mu__corr := 1;
  Nu__t := 0.023*Re__t^0.8*Pr__t^0.4*(mu__corr);
  h__i := (Nu__t *k__t)/D__internal; #W/m^2/K
```

$$v_t := 0.9367559344$$

$$\Re_t := 14319.18819$$

$$Pr_t := 9.471724138$$

$$\mu_{corr} := 1$$

$$\mathrm{N}_t := 119.4082050$$

$$h_i := 3462.837945 \tag{15}$$

```
> #properties of air, shell side
  rho__s := 1.204; #kg/m3 (air at 20C)
  mu__s := 1.825*10^(-5); #kg/m/s
  k__s := 0.02514; #W/m/K
  C__ps := 1007;
```

$$\rho_s := 1.204$$

$$\mu_s := 0.00001825000000$$

$$k_s := 0.02514$$

$$C_{ps} := 1007 \tag{16}$$

```
> Q__air := m__hot/rho__s;
  A__face := L__tube*(D__ctl + D__external);
  u__f := Q__air/A__face;
  u__max := u__f*(L__tp/(L__tp - D__external));
```

$$Q_{air} := 1.034756791$$

$$A_{face} := 0.3363234458$$

$$u_f := 3.076671591$$

$$u_{\max} := 15.38335796 \tag{17}$$

```
> Pr__s := C__ps*mu__s/k__s;
  Re__s := rho__s * u__max * D__external/mu__s;
  Nu__s := 0.134*Re__s^0.681*Pr__s^0.33*((p__f-t__f)/l__f)^0.2*
  (p__f/t__f)^0.1134;
  h__s := Nu__s * k__s/D__external;
```

$$Pr_s := 0.7310163087$$

$$\Re_s := 25372.00408$$

$$\mathrm{N}_s := 113.7847026$$

$$h_s := 114.4218969 \quad \textbf{(18)}$$

```
> #Defining Thermal Conductivity Variables
  k__tube := 50; #W/m/K
  k__fin := 205; #W/m/K
  Rf__o := 0.0003526; #m2*K/W
  Rf__i := 0.00018; #m2*K/W
```

$$k_{tube} := 50$$

$$k_{fin} := 205$$

$$Rf_o := 0.0003526$$

$$Rf_i := 0.00018 \quad \textbf{(19)}$$

```
> #Fin equations
  m := simplify(((2*h__s)/(k__fin * t__f))^(1/2));
  eta__f := tanh(m * l__f) / (m * l__f);
  N__fin := L__tube/p__f;
```

$$m := 33.41124344$$

$$\eta_f := 0.9908000928$$

$$N_{fin} := 500.0000000 \quad \textbf{(20)}$$

```
> #Outside area calculations
  A__f := A__f;
  A__b := A__b;
  A__f_total := N__fin * A__f * N__tt;
  A__b_total := A__b * N__tt;
  A__o := A__f_total + A__b_total;
```

$$A_f := 0.001054004335$$

$$A_b := 0.07853981635$$

$$A_{f\_total} := 16.12164151$$

$$A_{b\_total} := 2.402629138$$

$$A_o := 18.52427065 \tag{21}$$

```
> #Internal Area calculations
  A__i := 3.14159 * D__internal * L__tube * N__tt;
```

$$A_i := 2.883152530 \tag{22}$$

```
> eta__o := (eta__f *  A__f_total + A__b_total)/A__o
```

$$\eta_o := 0.9919933360 \tag{23}$$

```
> #Calculating all thermal resistances
  R__shell_conv := 1/eta__o/h__s; #Air side convection
  R__tube_conv := 1/(h__i*(A__i/A__o)); #Water side convection
  R__wall_cond := (D__external * ln(D__external/D__internal))/(2*
  k__tube);
  R__fouling := (Rf__i * (A__o/A__i))+(Rf__o /eta__o);
```

$$R_{shell\_conv} := 0.008810125643$$

$$R_{tube\_conv} := 0.001855416143$$

$$R_{wall\_cond} := 0.00005578588780$$

$$R_{fouling} := 0.001511946913 \tag{24}$$

```
> #Calculating U
  R__total := R__shell_conv + R__tube_conv + R__wall_cond +
  R__fouling;
```

$$R_{total} := 0.01223327459 \tag{25}$$

```
> print("============================");
  U__o_calc := 1/R__total; #W/m2/K
  print("============================");
```

"============================"

$$U_{o\_calc} := 81.74426174$$

"============================" (26)

```
> #Tube side pressure drop

  f__t := 0.0035 + 0.264/Re__t^0.42;
  L__total := L__tube * N__p;
  K := 1.8*N__p;
  DP__t_friction := 4*f__t*(L__total/D__internal)*(rho__t*v__t^2/2)
  ;
  DP__t_return := K*(rho__t*v__t^2)/2;
```

```
DP__t := DP__t_friction + DP__t_return;
```

$$f_t := 0.008243710754$$

$$L_{total} := 9.0$$

$$K := 10.8$$

$$DP_{t\_friction} := 6508.604064$$

$$DP_{t\_return} := 4737.141506$$

$$DP_t := 11245.74557 \quad \textbf{(27)}$$

```
> #Shell side pressure drop using Kern's method

A__s := (L__tp - D__external)*D__s*L__B/L__tp;
G__s := m__hot/A__s;
u__s := G__s/rho__s;
d__e := 1.10/D__external*(L__tp^2 - 0.917*D__external^2);
Re__s := G__s*d__e/mu__s;
```

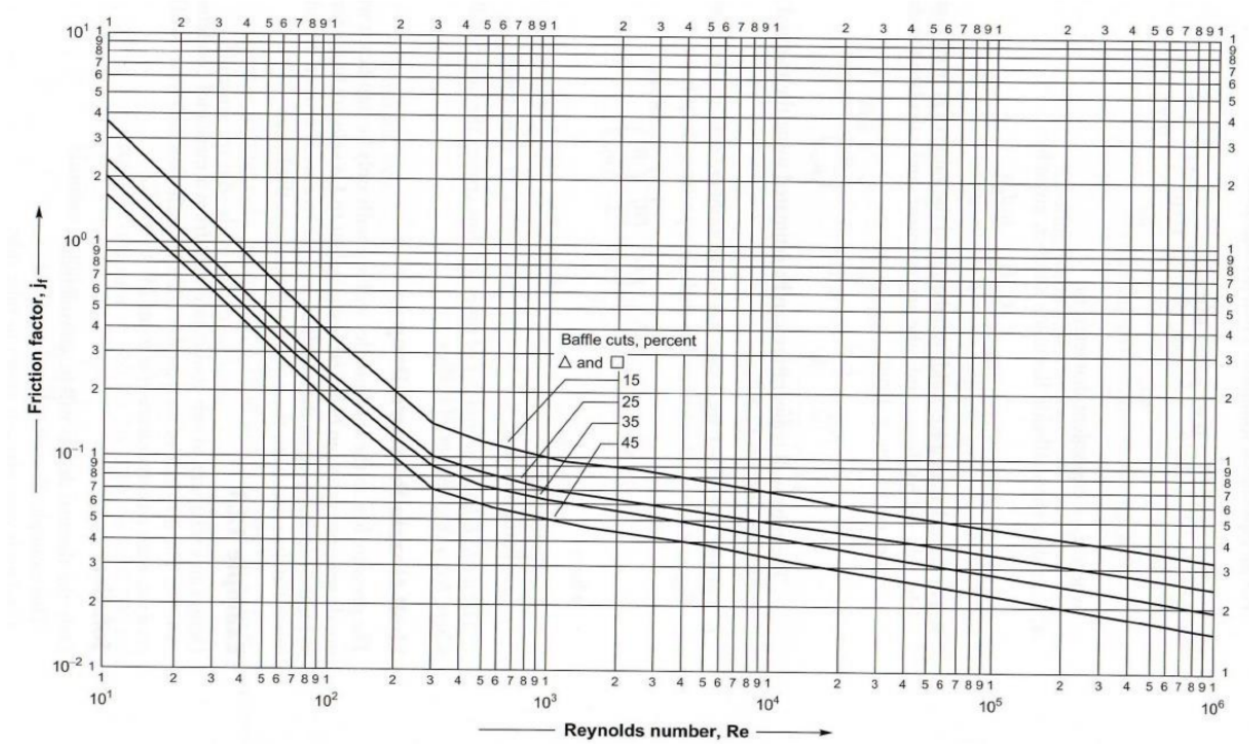
$$A_s := 0.008980642557$$

$$G_s := 138.7258393$$

$$u_s := 115.2207968$$

$$d_e := 0.01775125000$$

$$\Re_s := 134934.6332 \quad \textbf{(28)}$$




```
> j__f := 0.04;
```

$$j_f := 0.04 \quad \textbf{(29)}$$

```
> DP__s := 8*j__f*(D__s/d__e)*(L__tube/L__B)*(rho__s*u__s^2/2)*
  (mu__s/mu__s)^(-0.14);
```

$$DP_s := 270134.8088 \quad \textbf{(30)}$$

```
> print("=====summary=====");
  Re__t := Re__t;
  Re__s := Re__s;
  DP__t := DP__t; #Pa
  DP__s := DP__s; #Pa
  U__o_calc := U__o_calc;
  U__o_ass := U__o_ass;
```

"=====summary====="

$$\Re_t := 14319.18819$$

$$\Re_s := 134934.6332$$

$$DP_t := 11245.74557$$

$$DP_s := 270134.8088$$

$$U_{o\_calc} := 81.74426174$$

$$U_{o\_ass} := 82 \quad \textbf{(31)}$$