Using PC Software to Predict Heat Exchanger Performance

How well will your heat exchanger perform under unexpected conditions? With this PC program, you can quickly predict performance variables
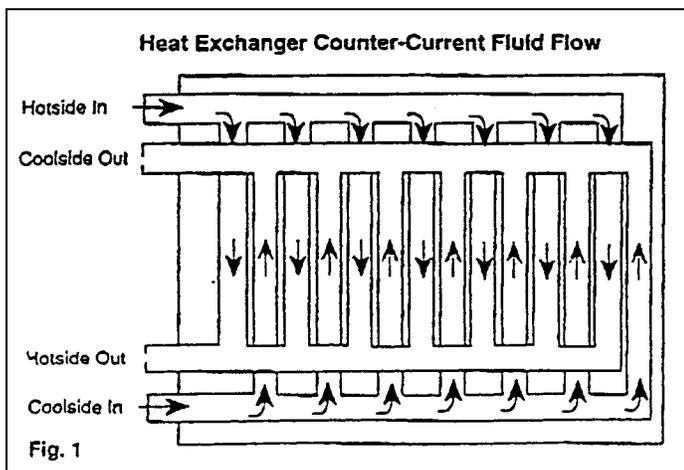
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Will your heat exchanger do the job if the cooling-tower temperature drops or increases? What happens to the exchanger's performance when excessive fouling occurs? Engineers often must answer such questions as these to determine the performance of their heat exchangers at other-than-design conditions.

Heat exchanger designers establish operational constraints when they develop a system. In practice, these constraints are conservatively stated, although rarely experienced, during the useful lifetime of a system. Usually, a designer assumes worst-case conditions with respect to the inlet cooling-water temperature and fouling. However, when operational variables change, such as thermal load and cooling-tower temperature, it is necessary to predict exchanger performance under the new conditions so that the impact on all variables in the process loop can be determined.

Heat exchanger variables used in predicting exchanger performance are:

Hotside data:
   Mass flow rate, m_{hs} (lb/hr)
   Inlet temperature, $T_{in\ hs}$ (°F)
   Specific heat, $C_{p\ hs}$ (Btu/lb °F)

Coldside data:
   Mass flow rate, m_{cs} (lb/hr)
   Inlet temperature, $T_{in\ cs}$ (°F)
   Specific heat, $C_{p\ cs}$ (Btu/lb °F)

Exchanger data:
   Surface area, A (ft^2)
   Transfer rate, U (Btu/hr ft^2 °F)
   Heat capacitance ratio, F ($m_{hs} C_{p\ hs}/m_{cs}\ C_{p\ cs}$)

Values to be calculated:
   Hotside outlet temperature, $T_{out\ hs}$ (°F)
   Coldside outlet temperature, $T_{out\ cs}$ (°F)

To help determine the effect of variable changes, the equations listed below were developed.

Heat exchanger with counter-current fluid flow (Fig. 1) output temperatures are:

$$T_{out\ hs} = T_{in\ hs} - \Delta T$$

$$T_{out\ cs} = T_{cs\ in} + (F\ x\ \Delta T)$$

when the heat capacitance ratio $F \neq 1.0$:

$$\Delta T = (T_{in\ hs} - T_{in\ cs})(1 - Y)/(F-Y)$$

where

$$Y = c^{UA(1-F)/m_{hs}C_{T}hs}$$

when F = 1.0:

$$\Delta T = UA(T_{in\ hs} - T_{in\ cs})/(m_{hs}C_{p\ hs}) - UA$$

Heat exchanger with co-current fluid flow (Fig. 2) output temperatures are:

$$T_{out\ hs} = T_{in\ hs} - \Delta T$$

$$T_{out\ cs} = T_{in\ cs} + (F)(\Delta T)$$

when the heat capacitance ratio $F \neq 1.0$:

$$\Delta T = T_{in\ hs} - T_{in\ cs})(Y-1)/Y(F+1)$$

Heat Exchanger Counter-Current Fluid Flow

Hotside In

Coolside Out

Hotside Out

Coolside In

Fig. 1

In the counter-current flow configuration, incremental temperature differentials along the exchange path are relatively consistent, resulting in smooth heat transfer. (Fig. 1)

where

$$Y = c^{UA(1+F)/m_{hs} C_{p\ hs}}$$

and when F = 1.0:

$$\Delta T = (T_{in\ hs} - T_{in\ cs})(Y-1)/2Y$$

where

$$Y = c^{2UA/m_{hs} C_{p\ hs}}$$

The equations should not be used indiscriminately. Although valid for many applications, they do not fit all uses. The method caveats are:

• LMTD (log mean temperature difference) correction factor is 1.0.

• Heat transfer rate is unaffected by temperature variations.

• Sensible heat transfer rates prevail.

To help you apply the equations, a BASIC program for an IBM PC-compatible computer has been developed and included here. (See accompanying sidebar.) Once the program source code is loaded, simply input variables one line at a time followed by a carriage return, and the outlet temperatures are automatically calculated.

EXAMPLE 1:

A coiled-tube Heliflow heat exchanger is designed to cool 10,000 lb/hr of water from 300° F to 189° F. The design cooling media is tower water at 15,000 lb/hr and 80 °F. As determined from heat exchanger specifications, the effective surface area is 25 ft^2 and the transfer rate is 350 Btu/hr ft^2 °F.

Prior to installation, a revision is made and the actual inlet tower-water temperature was determined to be 95 °F. What is the approximate outlet temperature under these conditions? Flow is configured for counter-current temperatures. For approximation purposes, the specific heat of water is 1.0 Btu/lb °F.

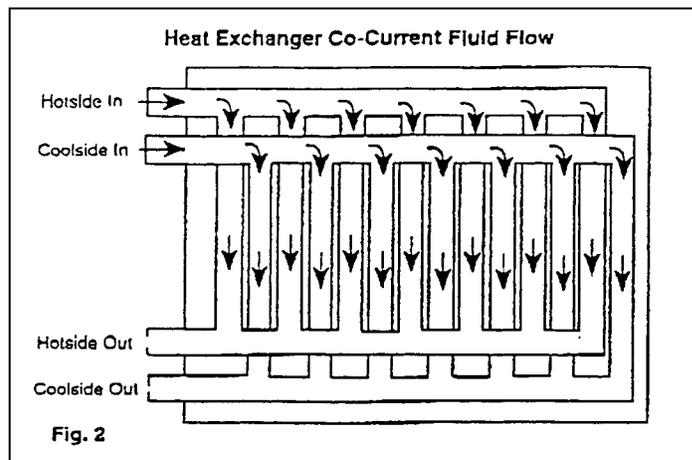$$F = (10,000)(1.0)/(15,000)(1.0) = 0.667$$

$$Y = c^{(350)(25)(1-0.667)/10,000 \times 1} = 1.3383$$

$$\Delta T = (300 - 95)(1 - 1.3383)/(0.667 - 1.3383) = 103.3$$

Therefore:

$$T_{out\ hs} = 300 - 103.3 = 196.7° F$$

$$T_{out\ cs} = 95 + (0.667 \times 103.3) = 163.9° F$$

In the co-current flow configuration, a relatively large temperature differential exists in the fluid-input region, resulting in rapid heat transfer. (Fig. 2)

EXAMPLE 2:

A plate heat exchanger is configured for co-current flow to limit the possibility of polymerization on the hotside. A polymer solution at a flow of 400,000 lb/hr is cooled from 250 °F to 222 °F. The polymer has a specific heat of 0.75 Btu/lb °F and polymerizes when the discharge temperature drops below 200 °F. Tempered water at 150 °F and 500,000 lb/hr is used as a cooling source. The unit manufacturer states surface area as 750 ft^2 and design transfer rate of 150 Btu/hr ft^2 °F. A fouling factor of 0.002 hr ft^2 °F/Btu is included in the design transfer rate.

The process engineer asked if performance with fouling removed would result in polymerization. Specifically, is $T_{out\ hs} \geq 200$ °F?

$$F = (400,000)(0.75)/(500,000 \times 1.0) = 0.6$$

When fouling occurs, the operating transfer rate is less than the new and clear rate. The rate is:

Clean transfer rate 　　$= (U^{-1} - \text{Fouling Factor})^{-1}$

　　　　　　　　　　$= (150^{-1} - 0.002)^{-1} = 214$

as a result:

$$Y = c^{(214)(750)(1+0.6)/(400,000)(0.75)} = 2.3537$$

so that:

$$\Delta T = (2.3537-1)(250-150)/(2.3537(1+0.6)) = 36$$

Therefore:

$$T_{out\ hs} = 250-36 + 214 °F$$

so the polymer should not polymerize,

$$T_{out\ cs} = 150 + (0.6)(36) = 171.6 °F$$

The equations allow quick determination of a heat exchanger's achievable performance when certain data are known. Knowing an exchanger's configuration — co-current or counter-current, inlet conditions for both hot and cold sides, effective surface area and transfer rate — achievable outlet temperatures are easily approximated.

The relationships described are applicable to sensible heat transfer (no phase change occurs), when there are no LMTD correction factors, and when the transfer rate is unaffected by temperature variations. The relationships should be used with caution when a fluid has a sharp viscosity vs. temperature gradient. For typical applications, the method works well.

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Program to Calculate Achievable Exchanger Performance

```
´    MHS, HOTSIDE MASS FLOWRATE IN LB/HR
´    MCS, COLDSIDE MASS FLOWRATE IN LB/HR
´    CPHS, HOTSIDE SPECIFIC HEAT IN BTU/LB F
´    CPHS, COLDSIDE SPECIFIC HEAT IN BTU/LB F
´    TINHS, HOTSIDE INLET TEMPERATURE IN DEG F
´    TINCS, COLDSIDE INLET TEMPERATURE IN DEG F
´
´    AREA, HEAT EXCHANGER SURFACE AREA IN FT²
´    U, TRANSFER RATE IN BTU/HR FT² F
´    COUNTER = 1.0, COUNTERCURRENT FLOW
´    COCURR = 1.0, COCURRENT FLOW
´
´    METHOD PROVISIONS
´    LMTD CORRECTION FACTOR IS 1.0
´    SENSIBLE HEAT TRANSFER ONLY
´    TRANSFER RATE INSENSITIVE TO TEMPERATURE VARIA-
     TIONS
´
         DIM IS(9), AIN(9)
         GOSUB 99

1    COUNTER = 0!
         COCURR = 0!
         IF (AIN(1)=0) THEN
         COUNTER = 1
         IF (AIN(1)=1) THEN COCURR = 1
         MHS = AIN(2)
         CPHS = AIN(3)
         MCS = AIN(4)
         CPCS = AIN(5)
         TINHS = AIN(6)
         TINCS = AIN(7)
         AREA = AIN(8)
         U = AIN(9)
         F = MHS* CPHS/(MCS * CPCS)

´    DETERMINE IF FLOW IS COUNTER OR COCURRENT,
     COUNTER = 1 IS COUNTERCURRENT
´    COCURR = 1 IS COCURRENT
IF (COCURR = 1!) GOTO 100
´    METHOD FOR COUNTERCURRENT TEMPERATURE PROFILE
         IF (F = 1!) GOTO 20
         Y = EXP(U * AREA * (1 - F)/(MHS * CPHS))
         DT = (TINHS - TINCS) * (1 - Y)/(F - Y)
         GOTO 200
20 DT = U * AREA * (TINHS - TINCS)/(MHS * CPHS + (U
    * AREA))
         GOTO 200

´ METHOD FOR COCURRENT TEMPERATURE PROFILE

100 IF (F = 1!) GOTO 30
         Y = EXP(U * AREA * (1 + F)/(MHS * CPHS))
         DT = (TINHS - TINCS) * (Y - 1) / Y * (F + 1))
         GOTO 200

30 Y = EXP((U * AREA * 2)/(MHS * CPHS))
         DT = (TINHS - TINCS) * (Y - 1) / (2 * Y)
         GOTO 200

200
         TOUTHS = TINHS - DT
         TOUTCS = TINCS + (F * DT)

**********************************************
•
´ PRINT OUTPUT
´
         CLS
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```
         COLOR 14
         LOCATE 1, 32:PRINT "ACTUAL PERFORMANCE"
         PRINT
         COLOR 2
         PRINT " SIDE FLOW T-IN T-OUT"
         PRINT "#/HR degF degF"
         COLOR 12
         PRINT "HOT SIDE";:PRINT USING
         "############.#";
         MHS: TINHS; TOUTHS
         PRINT "COLD SIDE";:PRINT USING
         "############.#";
         MCS; TINCS; TOUTCS
         COLOR 7
         LOCATE 23, 1:INPUT "Do you want to change
         anything (Y,y,1 = yes)", ABC$
         IF (ABC$ = "Y" OR ABC$ - "y" OR ABC$ = "1")
         THEN
         GOSUB 99
         GOTO 1
         END IF
         END
**********************************************
*
´ INPUT SUBROUTINE........................
´
99   I$(1) = "Flow Type: 0=counter current, 1=cocurrent"
         I$(2) = "Hot Side Flow Rate (#/hr)....."
         I$(3) = "Hot Side Specific Heat (Btu/lb F)......"
         I$(4) = "Cold Side Flow Rate (#/hr)......"
         I$(5) = "Cold Side Specific Heat (Btu/lb F)......"
         I$(6) = "Hot Side Inlet Temperature (F)......"
         I$(7) = "Cold Side Inlet Temperature (F)......"
         I$(8) = "Surface Area (sq.ft.)......"
         I$(9) = "Transfer Rate (Btu/hr sq.ft. F)......"

COLOR 7

LG = LEN(I$(1)) + 10
CLS
     FOR I = 1 TO 9
LINEN = 1
LOCATE LINEN, 1
PRINT USING "###";I;:PRINT "-" - I$(I)
LOCATE LINEN, LG: PRINT USING "#########.###";
     AIN(1)
     NEXT 1

FOR I = 1 TO 9
LINEN = I
LOCATE LINEN, LG
COLOR 14: LINE INPUT NEWVAL$:
COLOR 15
L = LEN(NEWVAL$)
     IF L > 0 THEN
AIN(I) = VAL(NEWVAL$)
LOCATE LINEN, 1
COLOR 13: PRINT USING "###";
     I;:PRINT "-" + I$(I)
LOCATE LINEN, LG: PRINT USING "#########.###";
     AIN(I):
         COLOR 7
     END IF
         NEXT I
RETURN
```