ANSI/AHRI Standard 400 with Addenda 1 and 2
(Formerly ARI Standard 400)

2001 Standard for
Liquid To Liquid Heat Exchangers
AHRI Standard 400-2001 with Addendum 2, *Liquid to Liquid Heat Exchangers*, is comprised of only the shaded portions shown. The September 2005 Addendum 2 has been incorporated into the already published 2001 version of AHRI Standard 400 to avoid confusion.

Particular additions (shown shaded in the standard), deletions (shown with a strikethrough and shaded in the standard), and corrections (shown shaded in the standard) are as follows:

1. In **5.3**, the requirement for pressure drop not to exceed more than 110% of the published pressure drop was removed.
2. In **5.3**, a requirement for tested pressure drop not to exceed the published pressure drop by more than 10%, or 1.0 ft of fluid [0.3 m of fluid], whichever is greater, was added.
AHRI Standard 400-2001 with Addendum 1, *Liquid to Liquid Heat Exchangers*, is comprised of only the shaded portions shown. The June 2003 Addendum 1 has been incorporated into the already published 2001 version of AHRI Standard 400 to avoid confusion.

Particular additions (shown shaded in the standard), deletions (shown with a strikethrough and shaded in the standard), and corrections (shown shaded in the standard) are as follows:

1. In Table 1, units of measurement for minimum and maximum pressure drop were corrected.
2. In Table 1, the SI equivalents for minimum and maximum pressure drop were corrected.
4. In Appendix A, references to ASME MFC-5M, ASME MFC-6M, ASME MFC-16M, and ASME PTC 19.2 were deleted.
5. C4. *Instruments and Test Apparatus* (and associated subsections) was deleted.
IMPORTANT

SAFETY DISCLAIMER

AHRI does not set safety standards and does not certify or guarantee the safety of any products, components or systems designed, tested, rated, installed or operated in accordance with this standard/guideline. It is strongly recommended that products be designed, constructed, assembled, installed and operated in accordance with nationally recognized safety standards and code requirements appropriate for products covered by this standard/guideline.

AHRI uses its best efforts to develop standards/guidelines employing state-of-the-art and accepted industry practices. AHRI does not certify or guarantee that any tests conducted under its standards/guidelines will be non-hazardous or free from risk.

Note: This standard supersedes ARI Standard 400 with Addendum 1.
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Section 1. Purpose

1.1 Purpose. The purpose of this standard is to establish for Liquid to Liquid Heat Exchangers: definitions; test requirements; rating requirements; minimum data requirements for Published Ratings; marking and nameplate data; and conformance conditions.

1.1.1 Intent. This standard is intended for the guidance of the industry, including manufacturers, engineers, installers, contractors and users.

1.1.2 Review and Amendment. This standard is subject to review and amendment as technology advances.

Section 2. Scope

2.1 Scope. This standard applies to Liquid to Liquid Heat Exchangers as defined in Section 3, which includes the following types of heat exchangers:

a. Plate Heat Exchangers
c. Counter flow Shell-and-Tube Heat Exchangers

2.2 Exclusions. This standard does not apply to heat exchangers used for change of phase or non-liquid heat transfer applications.

Section 3. Definitions

All terms in this document shall follow the standard industry definitions in the current edition of ASHRAE Terminology of Heating, Ventilation, Air Conditioning and Refrigeration, unless otherwise defined in this section.

3.1 Clean Capacity. The total heat transfer rate of the heat exchanger with clean heat exchanger surfaces.

3.2 Cold Stream. The liquid stream with the lower inlet temperature.

3.3 Counter Flow Shell-and-Tube Heat Exchanger. A baffled shell and tube heat exchanger, circuited such that the shellside and tubeside liquids flow countercurrent to one another.

3.4 Field Fouling Allowance. Provision for anticipated fouling during use.

3.4.1 Fouling Factor. The thermal resistance due to fouling accumulated on the heat transfer surface.

3.5 Hot Stream. The liquid stream with the higher inlet temperature.

3.6 Liquid to Liquid Heat Exchanger. A heat transfer device used to exchange heat between two liquid streams that are single phase fluids.

3.7 Number of Transfer Units (NTU). A dimensionless coefficient representing the magnitude of thermal demand. The equation for NTU is given in Appendix C.

3.8 Plate Heat Exchanger. Heat transfer device that typically utilizes corrugated metal plates in a bolted frame. An alternate technique is for the plates to have elastomer gaskets that seal the unit and direct the heat transfer stream in countercurrent flow. The corrugated plates can also be brazed together using a sacrificial alloy thus avoiding the need for a bolted frame.
3.9 Published Rating. A statement of the assigned values of those performance characteristics, under stated rating conditions, by which a unit may be chosen to fit its application. These values apply to all units of like nominal capacity and type (identification) produced by the same manufacturer. As used herein, the term Published Rating includes the rating of all performance characteristics shown on the unit or published in specifications, advertising or other literature controlled by the manufacturer, at stated rating conditions.

3.9.1 Application Rating. A rating based on tests performed at Application Rating Conditions (other than Mapped Rating Conditions).

3.9.2 Mapped Rating(s). Ratings falling within certain specified limits that are based upon tests performed across a range of operating conditions as defined by the product manufacturer.

3.10 "Shall" or "Should". "Shall" or "should" shall be interpreted as follows:

3.10.1 Shall. Where "shall" or "shall not" is used for a provision specified, that provision is mandatory if compliance with the standard is claimed.

3.10.2 Should. "Should" is used to indicate provisions which are not mandatory but which are desirable as good practice.

3.11 Shell Type Heat Exchanger. A heat transfer device utilizing an arrangement of multiple hollow cylindrical flow channels (tubes) contained within another larger hollow cylindrical flow channel (shell). The fluid flowing within the tubes exchanges thermal energy through the tube wall with another fluid flowing within the shell. This includes Shell-and-Tube, Shell-and-U-Tube, and Shell-and-Coil Heat Exchangers.

### Section 4. Test Requirements

4.1 Test Requirements. All Published Ratings shall be verified by tests conducted in accordance with Appendix C.

### Section 5. Rating Requirements

5.1 Ratings. Published Ratings of Liquid to Liquid Heat Exchangers shall consist of Mapped Ratings and may also consist of Application Ratings.

5.1.1 Mapped Ratings. The Mapped Ratings for each type of Liquid to Liquid Heat Exchanger shall be limited to the range of conditions set forth in Table 1.

5.1.2 Application Ratings. Application Ratings are ratings at conditions falling outside the boundaries of Mapped Rating Conditions as may be elected by the manufacturer to facilitate the selection of equipment. Application Ratings shall contain all information shown in 6.2.1. When Application Ratings include a Field Fouling Allowance, they shall be calculated by the method specified in Appendix D.
5.1.3 Clean Surface Condition. Ratings shall be based on tests with initially clean heat transfer surface(s) and conducted in accordance with 4.1.

The results of these tests are accepted as reflecting a Fouling Factor of zero. Fouling Factor or heat transfer margin (if used) shall be agreed upon by the end user and manufacturer.

5.2 The manufacturer shall provide published information as to the maximum and minimum recommended flow rates for clean liquid.

5.3 Tolerances. To comply with this standard, published or reported heat transfer rates shall be based on data obtained in accordance with the provisions of this section, and shall be such that any production unit selected at random and tested in accordance with this section at a specific operating condition shall have a total heat transfer rate not less than 95% of the Published Rating and a pressure drop not more than 110% of the published pressure drop. Measured values of pressure drop, shall not exceed published values by more than 10%, or 1.0 ft of fluid [0.3 m of fluid], whichever is greater.

Section 6. Minimum Data Requirements for Published Ratings

6.1 Minimum Data Requirements for Published Ratings. As a minimum, Published Ratings shall include all Mapped Ratings. All claims to ratings within the scope of this standard shall be accompanied by the statement “Rated in accordance with AHRI Standard 400”. All claims to ratings outside the scope of this standard shall be accompanied by the statement “Outside the scope of ARRI Standard 400”. Wherever Application Ratings are published or printed, they shall include a statement of the conditions at which the ratings apply.

6.2 Published Ratings. Published Ratings data (in catalogs or as computer output) shall include, or be capable of generating, unit designation(s), Mapped Ratings or Application Ratings.

6.2.1 Published Ratings shall state all the pertinent operating conditions and shall include the following:

a. Hot stream inlet and outlet temperatures, °F [°C]
b. Cold stream inlet and outlet temperatures, °F [°C]
c. Total heat transfer rate, Btu/h [W]
d. Identification of hot stream and cold stream liquids
e. Hot stream flow rate, gpm [L/s]
f. Cold stream flow rate, gpm [L/s]
g. Hot stream pressure drop, psig [kPa]
h. Cold stream pressure drop, psig [kPa]
i. Fouling Factor, h ft °F/Btu [m °C/W]
j. Hot stream NTU
k. Cold stream NTU

6.2.2 Published Ratings shall be accompanied by the following information:

a. Hot stream and cold stream design pressures, psig [kPa]
b. Overall dimensions, in [mm]
c. All standard connection types and sizes, in [mm]
d. Shipping weight, lb [kg]
e. Operating weight, lb [kg]

If only clean heat transfer surface ratings are published, a statement shall be included to contact the manufacturer if fouled heat transfer surface ratings are required.
Section 7. Marking and Nameplate Data

7.1 Marking and Nameplate Data. As a minimum, each heat exchanger shall be marked with the following information, along with any other information required by governing codes and regulations:

   a. Name of manufacturer
   b. Manufacturer’s model or serial number
   c. Hot stream side design pressure, psig [kPa]
   d. Cold stream side design pressure, psig [kPa]

Section 8. Conformance Conditions

8.1 Conformance. While conformance with this standard is voluntary, Conformance shall not be claimed or implied for products or equipment within the standard’s Purpose (Section 1) and Scope (Section 2) unless such product claims meets all of the requirements of the standard and all of the testing and rating requirements are measured and reported in complete compliance with the standard. Any product that has not met all the requirements of the standard cannot reference, state, or acknowledge the standard in any written, oral, or electronic communication.
APPENDIX A. REFERENCES - NORMATIVE

A1 Listed here are all standards, handbooks, and other publications essential to the formation and implementation of the standard. All references in this appendix are considered as part of this standard.


APPENDIX B. REFERENCES - INFORMATIVE

B1 Listed here are standards, handbooks and other publications which may provide useful information and background but are not considered essential. References in this appendix are not considered part of the standard.


APPENDIX C. METHOD OF TEST OF LIQUID TO LIQUID HEAT EXCHANGERS – NORMATIVE

C1 Purpose. This appendix prescribes methods of testing and calculating the thermal performance of Liquid to Liquid Heat Exchangers.

C2 Scope. This appendix applies to Liquid to Liquid Heat Exchangers as defined in Section 3 of this standard. This appendix applies to laboratory testing for purposes of rating heat exchangers within its scope. This appendix is not intended for field testing of heat exchangers of any type.

C3 Definitions. Definitions for this appendix are identical with those in Section 3 of this standard, with additions as noted below.

C3.1 Log Mean Temperature Difference (LMTD). For heat exchangers exhibiting counter flow or parallel flow, LMTD is defined by Figures D1 and D2.

C3.2 Corrected Log Mean Temperature Difference (CLMTD). For Shell-and-Tube Heat Exchangers with various combinations of shell and tube side passes, the correction factor, R, from Section 7 of the Standards of the Tubular Exchanger Manufacturers Association should be applied.

The correction factor, R, is a multiplier applied to the Log Mean Temperature Difference to account for flow types other than counter flow or parallel flow.

C3.3 Test Apparatus. Ancillary equipment such as holding tanks, mixing sections, pumps, piping, and preconditioning heat exchangers that function to deliver the proper Hot and Cold Streams to the heat exchanger being tested.

C3.4 Test System. The combination of test apparatus, test article, and instrumentation.

C4 Instruments and Test Apparatus...

C4.1 General.

C4.1.1 Instruments, whose types and accuracies are listed below, shall be calibrated against traceable standards at calibration intervals appropriate to the instrument.

C4.2 Temperature Measuring Instrument

C4.2.1 Temperature measurements shall be made in accordance with ANSI/ASHREA 41.1 and should employ a primary and confirming instrument as good practice to ensure validity of results. The primary and confirming instruments may be the same types of instruments.

C4.2.2 Temperatures of process liquids shall be measured by immersing the sensing element(s) directly in the fluid or by using thermometer wells installed in the conduit. Thermal conducting liquid or grease shall be used to assure good thermal contact when wells are used. It is recommended that turbulence methods be employed upstream of the measuring station to assure that there is no temperature stratification in the stream being measured.

C4.2.3 Temperature measurements shall be made with one or more of the following instruments:

a. Mercury in glass thermometers
b. Thermistors
c. Electric resistance thermometers (RTDs)
C4.2.4 Temperature measuring instruments and instrument systems shall have accuracies within the limits specified for the following measurements:
   a. For measuring individual temperatures of water and other heat transfer liquids, the device(s) shall be accurate to ± 0.1º F [± 0.06º C].
   b. For measuring/determining temperature differences in heat transfer liquids, the device(s) shall be accurate to ± 0.1º F [± 0.06º C] or ± 2% of the numerical value of the difference being measured, whichever is more rigorous.

C4.3 Pressure Measurements
   a. Individual flow rates shall not vary by more than ± 2% from their average values.
   b. The heat transfer rates calculated for the Cold Stream, Q_{cs}, and the Hot Stream, Q_{hs}, shall not differ from their total average, Q_{avg}, by more than ± 5%.

C4.3.1 Pressure measurements shall be made in accordance with ANSI/ASHRAE 41.3 and ASME PTC 19.2.

C4.3.2 Pressure measurements shall be made with one or more of the following instruments:
   a. Mercury column
   b. Bourdon tube gage
   c. Anoroid pressure gage
   d. Calibrated pressure

C4.3.3 The accuracy of pressure measuring shall permit determination of the pressure or pressure differential to within ± 2% of the numerical value of the quantity being measured.

C4.4 Flow Measuring Instruments

C4.4.1 Flow measuring instruments shall be applied and used in accordance with the following standards (as applicable):
   a. ASME PTC 19.5
   b. ASME MFC-5M

C4.4.2 Flow measurements shall be made with one or more of the following instruments:
   a. Liquid mass rate meter
   b. Liquid volume rate meter

C4.4.3 Accuracy of flow meters shall be within ±1% of the flow rate measured.

C4.4.4 To convert mass flow rate to volumetric flow rate, the temperature of liquid shall also be measured at the meter location.

C5 Test Instrumentation

C5.1 Temperature Measuring Instruments. Temperature measuring instrument calibration, measuring instrument calibration, instrument selection, and temperature measurement techniques shall be in accordance with ANSI/ASHREA Standard 41.1. Instruments shall be accurate to within ± 0.2ºF [± 0.1ºC].

C5.2 Pressure Measuring Instruments. Pressure measuring instrument calibration, instrument selection, and pressure measurement techniques shall be in accordance with ANSI/ASHRAE 41.3. The accuracy of pressure measurements shall permit determination of the pressure or pressure differential to within ± 2% of the numerical value of the quantity being measured.

C5.3 Liquid Flow Measuring Instruments. Liquid flow measuring instrument selection and liquid flow measurement techniques shall be made in accordance with ASME PTC 19.5 and ASME MFC-11M. Accuracy of flow measurements shall be within ± 1% of the flow rate measured. All instruments used in a test must be calibrated prior to the test. Calibrations must be traceable to primary or secondary standards calibrated by the U.S. National Institute of Standards Technology (NIST) or derived from accepted values of natural physical constants.
C6 Test Procedure.

C6.1 Test Setup. The heat exchanger to be tested shall be connected to the test apparatus, filled with the appropriate test liquids and checked for leaks and proper installation. Care shall be taken to bleed any entrapped air out of the entire system. Care shall also be taken to avoid heat losses/gains to the ambient to improve heat balance. Similarly, insulation shall be used where appropriate to prevent heat losses/gains between the heat exchanger to be tested and the temperature measuring stations.

C6.2 Testing for Rating.

C6.2.1 The test system shall be run to determine proper functioning of all components and instruments. Obtain and maintain the specified conditions in accordance with the following tolerances. After establishment of steady state thermal conditions, all required readings shall be within these specified conditions:

a. The individual temperature readings of liquid entering and leaving the heat exchanger shall not vary by more than 0.5°F [0.3°C] from their average values.

C6.2.2 After establishment of steady state conditions as specified in C6.2.1, the test period shall extend for a minimum of thirty (30) minutes and shall include no less than five (5) readings at equally timed intervals.

C6.2.3 The test record shall include the date, names of observers, essential identifying physical data of the heat exchanger tested, manufacturer’s model number, liquids used, all test readings, reference to instrument calibrations and computations, and the determined results.

C6.3 Computation of Results.

C6.3.1 Average the consecutive test readings as specified in C6.2.2. From the averaged test data, the heat transfer rate on the Cold Stream, \( Q_{cs} \), shall be calculated as:

\[
Q_{cs} = w_{cs} c_{p,cs} \left( T_{cs, out} - T_{cs, in} \right)
\]

(C1)

C6.3.2 From the averaged test data, the heat transfer rate on the Hot Stream, \( Q_{hs} \), shall be calculated as:

\[
Q_{hs} = w_{hs} c_{p,hs} \left( T_{hs, in} - T_{hs, out} \right)
\]

(C2)

C6.3.3 The total average heat transfer rate, \( Q_{avg} \), shall be calculated as the average of the hot stream heat transfer rate and the cold stream heat transfer rate:

\[
Q_{avg} = \frac{Q_{hs} + Q_{cs}}{2}
\]

(C3)

C6.3.4 The Number of Transfer Units, NTU of the heat exchanger is calculated as follows:

\[
* \quad NTU = \frac{\Delta T_{max}}{LMTD}
\]

(C4)

*Derivation of NTU:

\[
NTU = \frac{U \cdot A}{C_{fan}}
\]

(C4.1)

where: \( C = w \cdot c_p = \text{Capacity Rate} \)
\[ NTU = \frac{U \cdot A}{(w \cdot c_p)_{\text{min}}} \] (C4.2)

From:

\[ Q = UAA LMTD \]

\[ U \cdot A = \frac{Q}{LMTD} \] (C4.3)

From:

\[ Q = (w \cdot c_p)(\Delta T) = Q_{hs} = Q_{cs} \]

\[ Q = (w \cdot c_p)_{\text{min}} (\Delta T)_{\text{max}} = (w \cdot c_p)_{\text{max}} (\Delta T)_{\text{min}} \]

\[ (w \cdot c_p)_{\text{min}} = \frac{Q}{(\Delta T)_{\text{max}}} \] (C4.4)

Substituting equations C4.3 and C4.4 in C4.2:

\[ NTU = \frac{Q}{LMTD} \left[ \frac{\Delta T_{\text{max}}}{Q} \right] \]

\[ NTU = \frac{\Delta T_{\text{max}}}{LMTD} \] (C4)

**C6.3.5** The overall heat transfer coefficient in the clean condition, \( U_c \), shall be calculated as:

\[ U_c = \frac{Q_{\text{avg}}}{(CLMTD \cdot A)} \] (C5)

**C6.3.6** *Physical and Thermodynamic Properties.* The physical and thermodynamic properties of heat transfer fluids shall be determined from the following sources:

**C6.3.6.1** The heat transfer and thermodynamic properties of water shall be taken from the *ASHRAE Fundamentals Handbook.*

**C6.3.6.2** The heat transfer and thermodynamic properties of fluid other than water shall be taken from the *ASHRAE Fundamentals Handbook.* If the fluid is not listed in the latest edition of the handbook, thermodynamic properties of secondary coolants shall be obtained from the fluid manufacturer.

**C6** *Symbols and Subscripts.* The symbols and subscripts used in Equations C1 through C5 are as follows:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A )</td>
<td>Surface area, ( \text{ft}^2 ) [( \text{m}^2 )]</td>
</tr>
<tr>
<td>( C )</td>
<td>Capacity rate, ( \text{Btu/h °F} ) [( \text{kJ/s °C} )]</td>
</tr>
<tr>
<td>( c_p )</td>
<td>Specific heat of liquid, ( \text{Btu/lb °F} ) [( \text{kJ/kg °C} )]</td>
</tr>
<tr>
<td>( CLMTD )</td>
<td>Corrected log mean temperature difference = ( R \cdot LMTD ), °F [°C]</td>
</tr>
<tr>
<td>( LMTD )</td>
<td>Log mean temperature difference from Figures D1 or D2, °F [°C]</td>
</tr>
<tr>
<td>( Q )</td>
<td>Heat transfer rate, ( \text{Btu/h} ) [( \text{kW} )]</td>
</tr>
<tr>
<td>( R )</td>
<td>For counter flow or parallel flow, ( R = 1 ). For other situations, ( R ) is obtained from Section 7 of the <em>Standards of the Tubular Exchanger Manufacturers Association.</em></td>
</tr>
<tr>
<td>( T )</td>
<td>Temperature, °F [°C]</td>
</tr>
<tr>
<td>( \Delta T )</td>
<td>Temperature change (( \Delta T_1 ) or ( \Delta T_2 ) from Appendix D) associated with the liquid stream</td>
</tr>
</tbody>
</table>
\( U \) = Overall heat transfer coefficient, 
\[ \text{Btu/h} \equiv \text{ft}^2 \equiv \text{EF} \ [\text{W/m}^2 \equiv \text{EC}] \]

\( w \) = Mass rate of flow of liquid, \( \text{lb}_m \text{/h} \ [\text{kg/s}] \)

Subscripts:

- \( c \) = Clean
- \( cs \) = Cold stream
- \( hs \) = Hot stream
- \( in \) = Entering
- \( max \) = Maximum
- \( min \) = Minimum
- \( out \) = Leaving
- \( tavg \) = Total average

**C7 Expression of Test Results**

**C7.1** Test results shall consist of the following overall data and calculation results:

- a. Inlet and outlet temperatures of Hot Stream, °F [°C]
- b. Flowrate of Hot Stream, gpm [L/s]
- c. Hot Stream pressure drop through the heat exchanger, psig [kPa]
- d. Hot Stream fluid
- e. Inlet and outlet temperatures of Cold Stream, °F [°C]
- f. Flowrate of Cold Stream, gpm [L/s]
- g. Cold Stream pressure drop through the heat exchanger, psig [kPa]
- h. Cold Stream liquid
- i. Average heat transferred (Equation C3), Btu/h [W]
- j. Corrected log mean temperature difference, \( CLMTD \)
- k. Overall heat transfer coefficient in the clean condition, \( U_c \), Btu/h ft\(^2\) F [W/m\(^2\) C]
- l. Ambient dry bulb temperature, °F [°C]
APPENDIX D. METHOD OF SIMULATING FIELD FOULING ALLOWANCE - INFORMATIVE

D1 Purpose. The purpose of this appendix is to establish a method for simulating Field Fouling Allowance ratings for Liquid to Liquid Heat Exchangers.

D2 Scope. This appendix applies to all heat transfer devices used to exchange heat between two liquid streams that are single phase fluids.

D3 Calculation Fouled Ratings.

D3.1 Determine Overall Heat Transfer Coefficient for Clean Surfaces. From the results of the clean heat transfer surface(s) tests, calculate the overall heat transfer coefficient, $U_c$ for clean heat transfer surface(s) using the following method:

$$U_c = \frac{Q_e}{(A)\cdot(LMTD_e)}$$  \hspace{1cm} (D1)

where:

$$LMTD_e = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$  \hspace{1cm} (D2)

with $\Delta T_1$ and $\Delta T_2$ defined in Figures D1 and D2 below:

Figure D1. Counter Flow

Figure D2. Parallel Flow

Note: If $\nabla T_1 = \nabla T_2$, LMTD = $\nabla T$
**D3.2  Determine Overall Heat Transfer Coefficient for Fouled Surfaces.** The reciprocal of the overall heat transfer coefficient for fouled surface(s) is determined by mathematically adding the specified Field Fouling Allowance to the reciprocal coefficient for clean heat transfer surfaces, $U_c$.

**D3.2.1** The following equations are for tubular exchangers with fouling inside tubes:

a. Based on outside surface area:

$$U_{fo} = \frac{1}{\frac{1}{U_{co}} + \left[ \frac{A_o}{A_f} \right] r_{fi}}$$  \hspace{1cm} (D3)

b. Based on inside surface area:

$$U_{fi} = \frac{1}{\frac{1}{U_{ci}} + r_{fi}}$$  \hspace{1cm} (D4)

**D3.2.2** The following equations are for Shell-and-Tube Heat Exchangers with fouling outside tubes:

a. Based on outside surface area:

$$U_{fo} = \frac{1}{\frac{1}{U_{co}} + r_{fo}}$$  \hspace{1cm} (D5)

b. Based on inside surface area:

$$U_{fi} = \frac{1}{\frac{1}{U_{ci}} + r_{fo} \left[ \frac{A_o}{A_v} \right]}$$  \hspace{1cm} (D6)

**D3.2.3** The following equation is for fouling for Plate Heat Exchangers:

$$U_f = \frac{1}{\frac{1}{U_c} + r_f}$$  \hspace{1cm} (D7)

**D3.3  Determination of Ratings with Fouling Allowances.** Ratings with fouling allowances are calculated using the following relationship:

$$Q_f = U_f \cdot A \cdot LMFD$$  \hspace{1cm} (D8)
D3.4 Symbols and Subscripts. The symbols and subscripts used in Equations D1 through D6 are as follows:

Symbols:

\[ A = \text{Total heat transfer surface, ft}^2 [m^2] \]
\[ A_o/A_i = \text{Ratio of outside to inside surface area} \]
\[ \Delta T_1 = \text{Temperature difference as defined in Figures D1 and D2, } (T_1 - T_4), \text{ EF [EC]} \]
\[ \Delta T_2 = \text{Temperature difference as defined in Figures D1 and D2, } (T_2 - T_3), \text{ EF [EC]} \]
\[ LMTD = \text{Log mean temperature difference as defined in Equation D2} \]
\[ Q = \text{Heat transfer rate, Btu/h [W]} \]
\[ r = \text{Heat transfer resistance, } h=\text{ft}^2\text{EF/Btu [m}^2\text{EC/W]} \]
\[ T = \text{Temperature, EF [EC]} \]
\[ U = \text{Overall heat transfer coefficient, } \text{Btu/h=ft}^2\text{EF [W/m}^2\text{EC]} \]

Subscripts:

\[ c = \text{Clean} \]
\[ e = \text{Entering} \]
\[ ec = \text{Entering, cold} \]
\[ eh = \text{Entering, hot} \]
\[ f = \text{Fouled or fouling} \]
\[ i = \text{Inside} \]
\[ l = \text{Leaving} \]
\[ lc = \text{Leaving, cold} \]
\[ lh = \text{Leaving, hot} \]
\[ o = \text{Outside} \]