AHRI Standard 400 (I-P)

2015 Standard for

Performance Rating of Liquid to Liquid Heat Exchangers

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Note:

This standard supersedes AHRI Standard 400–2001 with Addenda 1 and 2.
For the SI ratings, see AHRI Standard 401 (SI)–2015.

AHRI CERTIFICATION PROGRAM PROVISIONS

The scope of the Liquid to Liquid Heat Exchangers (LLHE) & Liquid to Liquid Brazed & Fusion Bonded Plate Heat Exchangers (LLBF) certification programs are defined below. These scopes are current as of the publication date of the standard. Revisions to the scope of these certification programs can be found on the AHRI website www.ahrinet.org. The scope of these certification programs should not be confused with the scope of the standard as the standard covers products that are not covered by a certification program.

LLHE Certification Program Scope

This program applies to production models of gasketed plate-type heat exchangers that utilize water or sea water on one (1) or both loops, for HVAC applications only.

This certification program excludes all of the following:

- Heat exchangers used for phase-change heat transfer
- Heat exchangers used for non-liquid heat transfer
- Heat exchangers used for food-based processes
- Heat exchangers with a capacity greater than 24,000,000 Btu/h
- Heat exchangers with a flow rate greater than 2,000 GPM

LLBF Certification Program Scope

This program applies to production models of brazed & fusion bonded plate-type heat exchangers, that utilize water or sea water on one or both loops for HVAC applications only.

This certification program excludes all of the following:

- Heat exchangers used for phase-change heat transfer
- Heat exchangers used for non-liquid heat transfer
- Heat exchangers used for food-based processes
- Heat exchangers with a capacity greater than 16,000,000 Btu/h
- Heat exchangers with a flow rate greater than 1,200 GPM

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PERFORMANCE RATING OF LIQUID TO LIQUID HEAT EXCHANGERS

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:

2.1.1 Plate heat exchangers
2.1.2 Shell-and-tube heat exchangers
2.1.3 Shell-and-coil heat exchangers
2.1.4 Shell-and-U-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 will follow the standard industry definitions in the *ASHRAE Terminology* website (https://www.ashrae.org/resources--publications/free-resources/ashrae-terminology) unless otherwise defined in this section.

3.1 *Cold Stream*. The liquid stream with the lower inlet temperature.

3.2 *Field Fouling Allowance*. Provision for anticipated fouling during use.

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

3.3 *Hot Stream*. The liquid stream with the higher inlet temperature.

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

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

3.6 *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 elastomeric 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.

3.7 *Published Ratings.* A statement of the assigned values of those performance characteristics by which a unit may be chosen to fit its application. As used herein, the term Published Ratings includes all performance characteristics shown on the unit or published in specifications, advertising or other literature controlled by the manufacturer, at stated conditions.

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

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

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

3.9 *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 exchange 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.

3.10.1 *Shell-and-tube Heat Exchanger*. A bundle of tubes contained in a shell or container. The tube(s) carry a fluid through them, while the shell is also provided with an inlet and outlet for flow of another fluid.

3.10.2 *Shell-and-U-tube Heat Exchanger*. A heat-exchanger system consisting of a bundle of U tubes surrounded by a shell; one fluid flows through the tubes, and the other fluid flows through the shell, around the tubes.

3.10.2 *Shell-and-coil Heat Exchanger*. A heat-exchanger system consisting of helically corrugated tubes surrounded by a shell; one fluid flows through the tubes, and the other fluid flows through the shell, around the tubes.

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 ratings at conditions as elected by the manufacturer to facilitate the selection of equipment. Ratings shall contain all information shown in Section 6.2.1. When ratings include a Field Fouling Allowance, they shall be calculated by the method specified in Appendix D.

5.1.1 *Clean Surface Condition.* Ratings shall be based on tests with initially clean heat transfer surface(s) and conducted in accordance with Section 4.1.

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

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

5.3 *Rating Tolerances (Applies to all Products Covered by this Standard).* To comply with this standard, measured test results shall not be less than 95% of the Published Rating for heat transfer rates and measured values of pressure drop shall not exceed Published Ratings by more than 15%, or 1.0 ft 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 information shown in Section 6.2.1. All claims to ratings within the scope of this standard shall be accompanied by the statement "Rated in accordance with AHRI Standard 400 (I-P)". All claims to ratings outside the scope of this standard shall be accompanied by the statement "Outside the scope of AHRI Standard 400 (I-P)." Wherever Ratings are published or printed, they shall include a statement of the conditions at which the ratings apply.

6.2 *Published Ratings.* Published Ratings (in catalogs or as computer output) shall include, or be capable of generating, unit designation(s), and the information below.

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

6.2.1.1 Hot stream inlet and outlet temperatures, °F
6.2.1.2 Cold stream inlet and outlet temperatures, °F
6.2.1.3 Total heat transfer rate, Btu/h
6.2.1.4 Identification of hot stream and cold stream liquids
6.2.1.5 Hot stream flow rate, gpm
6.2.1.6 Cold stream flow rate, gpm
6.2.1.7 Hot stream pressure drop, psid
6.2.1.8 Cold stream pressure drop, psid
6.2.1.9 Fouling Factor, $h \cdot ft^2 \cdot °F/Btu$
6.2.1.10 Hot stream NTU
6.2.1.11 Cold stream NTU

6.2.2 Published Ratings shall be accompanied by the following information:

6.2.2.1 Hot stream and cold stream design pressures, psig
6.2.2.2 Unit dimensions (length, width, height), in
6.2.2.3 All standard connection types and sizes, in
6.2.2.4 Dry weight, lb
6.2.2.5 Flooded weight (water), lb

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:

7.1.1 Name of manufacturer
7.1.2 Manufacturer's model or serial number
7.1.3 Hot stream side design pressure, psig
7.1.4 Cold stream side design pressure, psig

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 meet 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.

A1.1 ANSI/ASHRAE 41.1, *Standard Method for Temperature Measurement*, 2013, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.2 ANSI/ASHRAE 41.3, *Standard Method for Pressure Measurement*, 1989, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.3 ASHRAE Handbook - Fundamentals, 2013, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.4 ASHRAE Terminology, https://www.ashrae.org/resources--publications/free-resources/ashrae-terminology, 2015, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.5 ASME MFC-5M, 1985 (RA 2006), *Measurement of Liquid Flow in Closed Conduits Using Transit-Time Ultrasonic Flowmeters*, 2006, American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017, U.S.A.

A1.6 ASME MFC-11M, 2006 (RA 2014), *Measurement of Fluid Flow by Means of Coriolis Flow Meters*, 2014, American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017, U.S.A.

A1.7 ASME MFC-16M, 1995 (RA 2001), *Measurement of Fluid Flow in Closed Conduits by Means of Electromagnetic Flowmeters*, 2001, American Society of Mechanical Engineers, 345 East 47th Street, New York, NY, 10017, USA.

A1.8 ASME PTC 12.5, 2000, *Single Phase Heat Exchangers*, American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017, U.S.A.

A1.9 ASME PTC 19.2, 2010, *Pressure Measurement*, 2010, American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017, U.S.A.

A1.10 ASME PTC 19.5, 2004 (RA 2013), *Flow Measurement*, 2013, American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017, U.S.A.

A1.11 REFPROP Reference Fluid Thermodynamic and Transport Properties NIST Standard Reference Database 23, Version 9.1, 2013, U.S. Department of Commerce, NIST, Standards Reference Data Program Gaithersburg, MD 20899, U.S.A.

A1.12 Standards of the Tubular Exchanger Manufacturers Association, Ninth Edition, 2007, Tubular Exchanger Manufacturers Association, 25 North Broadway, Tarrytown, NY 10591, U.S.A.

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.

B1.1 AHRI Guideline E-1997, *Fouling Factors: A Survey of Their Application in Today's Air-Conditioning Heating and Refrigeration Industry*, 1997, Air-Conditioning, Heating, and Refrigeration Institute, 2111 Wilson Blvd., Suite 500, Arlington, VA 22201, U.S.A.

B1.2 Cooper, A., Suitor, J.W., and Usher, J.D., *Cooling Water Fouling in Plate Heat Exchangers*, 1980, Heat Transfer Engineering, 1 (3), pages 50-55.

B1.3 Haider, S.I., Webb, R.L., and Meitz, A.K., *An Experimental Study of Tube Side Fouling Resistance in Water-Chilled Flooded Evaporators*, 1992, ASHRAE Transactions, 98(2), pages 86-103, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

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

C1 *Purpose*. This appendix prescribes methods of testing and calculating the thermal and hydraulic 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 evaluating thermal and hydraulic performance of 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-current flow or co-current 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* shall be applied.

The correction factor, R, is a multiplier applied to the Log Mean Temperature Difference to account for flow types other than counter-current flow or co-current 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 *Test Measurements and Instruments***.** Measurements from the instruments shall be traceable to primary or secondary standards calibrated by the National Institute of Standards and Technology (NIST) or to Bureau International des Poids et Mesures (BIPM) if a National Metrology Institute (NMI) other than NIST is used. In either case, the indicated corrections shall be applied to meet the required error limits stated in subsequent sections. Instruments shall be recalibrated on a regular schedule that is appropriate for each instrument, and calibration records shall be maintained. All instruments shall be applied in a manner that ensures compliance with the accuracy specified in the test plan.

C4.1 *Temperature Measurements*. Temperature measurements shall be made in accordance with ANSI/ASHRAE Standard 41.1 and shall employ a primary and confirming instrument to ensure validity of results. The primary and confirming instruments may be the same types of instruments.

Temperature measuring instrument calibration, measuring instrument calibration, instrument selection, and temperature measurement techniques shall be in accordance with ANSI/ASHRAE Standard 41.1.

C4.1.1 For measuring individual temperatures of water and other heat transfer liquids, the device(s) shall be accurate to ± 0.2ºF.

C4.1.2 For measuring/determining temperature differences in heat transfer liquids, the device(s) shall be accurate to ± 0.2ºF or ± 2% of the numerical value of the difference being measured, whichever is more rigorous.

C4.2 *Pressure Measurements.* Pressure measurements shall be made in accordance with ANSI/ASHRAE Standard 41.3, ASME PTC 19.2, and ASME PTC 12.5 Section 4.

Pressure measuring instrument calibration, instrument selection, and pressure measurement techniques shall be in accordance with ANSI/ASHRAE Standard 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.

C4.3 *Flow Measurements.* Liquid flow measuring instrument selection and liquid flow measurement techniques shall be in accordance with ASME PTC 19.5 and ASME MFC-5M, ASME MFC-11M and ASME MFC-16M. 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. Flow measurements shall be made with one or more of the following instruments:

C4.4.1 Liquid mass flow meter

C4.4.2 Liquid volume flow meter

C5 *Test Procedure*.

C5.1 *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. Refer to Appendix E, Lab Test Piping and Instrumentation Requirements. 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.

C5.2 *Testing for Performance.*

C5.2.1 The Test System shall be operated 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 limits:

C5.2.1.1 The individual temperature readings of liquids entering the heat exchanger shall not vary by more than 0.5°F from their average values.

C5.2.1.2. Differential pressures between cold and hot loops shall not exceed 15 psig at the inlet.

C5.2.1.3 Outlet pressures at each loop shall not be less than 15 psig.

C5.2.1.4 Individual flow rates shall not vary by more than ± 2% from their average values.

C5.2.2 After establishment of steady state conditions as specified in Section C5.2.1, the test period shall extend for a minimum of thirty (30) minutes and shall include one reading at the beginning of the test period, one reading at the end of the test period, and no less than five (5) readings during the test period at equally timed intervals.

C5.2.3 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_{tavg}, by more than ± 5%.

C5.2.4 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.

C5.3 *Computation of Results.*

All parameters below are calculated from the average data at the end of the test period.

C5.3.1 Average the consecutive test readings as specified in Section C5.2.2. From the averaged test data, the heat transfer rate on the Cold Stream, Q_{cs}, shall be calculated using Equation C1:

$$Q_{cs} = w_{cs} \cdot c_{p,cs} \cdot \left(T_{cs,\,out} - T_{cs,\,in}\right) \qquad \text{C1}$$

Where:

$c_{p,cs}$ = Average of the specific heat at inlet, outlet, and average temperatures.

C5.3.2 From the averaged test data, the heat transfer rate of the Hot Stream, Q_{hs}, shall be calculated using Equation C2:

$$Q_{hs} = w_{hs} \cdot c_{p,hs} \cdot \left(T_{hs,in} - T_{hs,out}\right) \qquad \text{C2}$$

Where:

$c_{p,hs}$ = Average of the specific heat at inlet, outlet, and average temperatures.

C5.3.3 The total average heat transfer rate, Q_{tavg}, shall be calculated as the average of the hot stream heat transfer rate and the cold stream heat transfer rate:

$$Q_{tavg} = \left(\frac{Q_{hs} + Q_{cs}}{2}\right) \qquad \text{C3}$$

C5.3.4 The Number of Transfer Units, NTU of the heat exchanger, is calculated as follows:

$$NTU_{max} = \frac{\Delta T_{max}}{LMTD} \qquad \text{C4}$$

Where:

ΔT_{max} = Greater of ΔT_{hs} or ΔT_{cs}.

Derivation of *NTU*:

$$NTU = \frac{U \cdot A}{C_{\min}} \qquad \text{C5}$$

Where:

$C = w \cdot c_p$ = Capacity Rate
$C_{\min}$ = The lesser of $(w \cdot c_p)_{hs}$ or $(w \cdot c_p)_{cs}$

$$NTU = \frac{U \cdot A}{\left(w \cdot c_p\right)_{\min}} \qquad \text{C6}$$

From:

$Q = U \cdot A \cdot LMTD$

$$U \cdot A = \frac{Q}{LMTD} \qquad \text{C7}$$

From:

$$Q = \left(w \cdot c_p\right) \cdot \left(\Delta T\right) = Q_{hs} = Q_{cs}$$

$$Q = \left(w \cdot c_p\right)_{\min} \cdot \left(\Delta T\right)_{\max} = \left(w \cdot c_p\right)_{\max} \left(\Delta T\right)_{\min}$$

$$\left(w \cdot c_p\right)_{\min} = \frac{Q}{\left(\Delta T\right)_{\max}} \qquad \text{C8}$$

Substituting Equations C7 and C8 in C6:

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

$$NTU = \frac{\Delta T_{\max}}{LMTD} \qquad \text{C9}$$

C5.3.5 The overall heat transfer coefficient in the clean condition, U_c, shall be calculated as:

$$U_c = Q_{tavg} / (CLMTD \cdot A) \qquad \text{C10}$$

Where:

$$CLMTD = R \cdot LMTD \qquad \text{C11}$$

C5.3.6 *Physical and Thermodynamic Properties*. The physical and thermodynamic properties of heat transfer fluids shall be determined from the following sources:

C5.3.6.1 The heat transfer and thermodynamic properties of water shall be taken from Steam 95 Tables (REFPROP).

C5.3.6.2 The heat transfer and thermodynamic properties of fluids other than water shall be taken from REFPROP unless properties measurements indicate otherwise. If the fluid is not listed in the latest edition of the ASHRAE Handbook-Fundamentals, thermodynamic properties shall be obtained from the fluid supplier or end user.

C6 *Symbols and Subscripts***.** The symbols and subscripts used in Equations C1 through C11 are as follows:

Symbols:

A	=	Surface area (provided in the manufacturer's software), ft^2
C	=	Capacity rate, Btu/h °F
c_p	=	Specific heat of liquid, Btu/lb_m °F
CLMTD	=	Corrected log mean temperature difference, °F
LMTD	=	Log mean temperature difference from Figures D1 or D2, °F
NTU	=	Number of thermal units
Q	=	Heat transfer rate, Btu/h
R	=	For counter flow or parallel flow, *R* = 1. For other situations, *R* is obtained from Section 7 of the *Standards of the Tubular Exchanger Manufacturers Association*.
T	=	Temperature, °F
ΔT	=	Temperature change ΔT_1 or ΔT_2 (from Appendix D) associated with the liquid
U	=	Overall heat transfer coefficient, Btu/h/ft^2 · °F

w = Mass rate of flow of liquid, lb_m/h

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:

C7.1.1 Inlet and outlet temperatures of Hot Stream, ºF
C7.1.2 Flowrate of Hot Stream, gpm
C7.1.3 Hot stream pressure drop through the heat exchanger, psi
C7.1.4 Hot stream heat transfer rate, Btu/h
C7.1.5 Hot stream liquid
C7.1.6 Inlet and outlet temperatures of Cold Stream, ºF
C7.1.7 Flowrate of Cold Stream, gpm
C7.1.8 Cold stream pressure drop through the heat exchanger, psi
C7.1.9 Cold stream heat transfer rate, Btu/h
C7.1.10 Cold stream liquid
C7.1.11 Average heat transferred (Equation C3), Btu/h
C7.1.12 Corrected Log Mean Temperature Difference, ºF
C7.1.13 Overall heat transfer coefficient in the clean condition, U_c, $Btu/h \cdot ft^2 \cdot {}^oF$
C7.1.14 Ambient dry bulb temperature, ºF

APPENDIX D. METHOD OF SIMULATING FIELD FOULING ALLOWANCE - NORMATIVE

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.

D3 *Calculation of Performance, Fouled.*

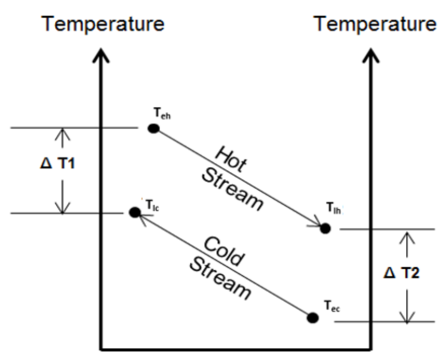
D3.1 *Determine Overall Heat Transfer Coefficient for Clean Surfaces.* From the results of the clean heat transfer surface(s) tests, calculate the overall heat transfer coefficient, U_c for clean heat transfer surface(s) using the following method:

$$U_c = \frac{Q_c}{(A) \cdot (LMTD_c)} \qquad \text{D1}$$

Where:

$$LMTD = \frac{\Delta T1 - \Delta T2}{\ln\left(\Delta T1 / \Delta T2 \right)} \qquad \text{D2}$$

With ΔT1 and ΔT2 defined in Figures D1 and D2 below:



Note: If ΔT1 = ΔT2, LMTD = ΔT

Figure D1. Counter Flow

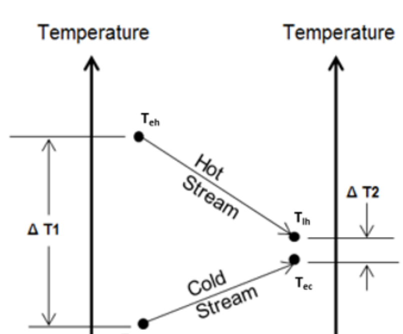


Figure D2. Parallel Flow

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:

D3.2.1.1 Based on outside surface area:

$$U_{fo} = \frac{1}{\frac{1}{U_{co}} + r_{fi} \cdot \left[\frac{A_o}{A_i}\right]} \qquad \text{D3}$$

D3.2.1.2 Based on inside surface area:

$$U_{fi} = \frac{1}{\frac{1}{U_{ci}} + r_{fi}} \qquad \text{D4}$$

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

D3.2.2.1 Based on outside surface area:

$$U_{fo} = \frac{1}{\frac{1}{U_{co}} + r_{fo}} \qquad \text{D5}$$

D3.2.2.2 Based on inside surface area:

$$U_{fi} = \frac{1}{\frac{1}{U_{ci}} + r_{fo} \cdot \left[\frac{A_i}{A_o}\right]} \qquad \text{D6}$$

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

$$U_f = \frac{1}{\frac{1}{U_c} + r_f} \qquad \text{D7}$$

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

$$Q_f = U_f \cdot A \cdot LMTD \qquad \text{D8}$$

D3.4 *Symbols and Subscripts*. The symbols and subscripts used in Equations D1 through D6 are as follows:

Symbols:

A = Total heat transfer surface, ft^2
A_o/A_i = Ratio of outside to inside surface area
A_i/A_o = Ratio of inside to outside surface area

ΔT1	=	Temperature difference as defined in Figures D1 and D2, $(T_1 - T_4)$, °F
ΔT2	=	Temperature difference as defined in Figures D1 and D2, $(T_2 - T_3)$, °F
LMTD	=	Log Mean Temperature Difference as defined in Equation D2, °F
Q	=	Heat transfer rate, Btu/h
r	=	Heat transfer resistance, $h \cdot ft^2 \cdot EF/Btu/h$
T	=	Temperature, °F
U	=	Overall heat transfer coefficient, $Btu/h/ft^2 \cdot °F$

Subscripts:

c	=	Clean
ec	=	Entering, cold
eh	=	Entering, hot
f	=	Fouled or fouling
i	=	Inside
lc	=	Leaving, cold
lh	=	Leaving, hot
o	=	Outside

APPENDIX E. LAB TEST PIPING AND INSTRUMENT REQUIREMENTS - NORMATIVE

E1 *Connection to the Test Article*. Connection to the test article shall be made using straight pipe of the same nominal diameter as the connection or a diameter appropriate for testing. Pipe length shall be a minimum of six nominal pipe diameters long. The inside of this pipe shall be straight and smooth. Connection shall be made using pipe with the mating fitting matching the test article.

E1.1 Flanged or studded connections on the article shall be made using flanges.

E1.2 Female threaded connections on the article shall be made using a pipe having the mating thread directly on the pipe. For example, a unit with a female thread is not to be connected with a pipe union, coupling, or other, attached to the test article, then a threaded pipe inserted into the fitting.

E1.3 Male threaded connections shall be made using a commercial pipe coupling, then the straight pipe either threaded or welded into the coupling.

E2 *Temperature Measurement.* Devices shall be located as follows. This appendix applies to all heat transfer devices used to exchange heat between two liquid streams.

E2.1 Prior to measurement of liquid temperature, assurance shall be established that the flow is thoroughly mixed. All stratification shall be eliminated. This applies to the inlet flow and the outlet flow. This is accomplished by using mixing devices upstream of temperature measurement. Mixing devices are either traditional "mixing pot" design with a minimum of four cross baffles, or of a "static mixer" design with a minimum of six pairs of angled baffles.

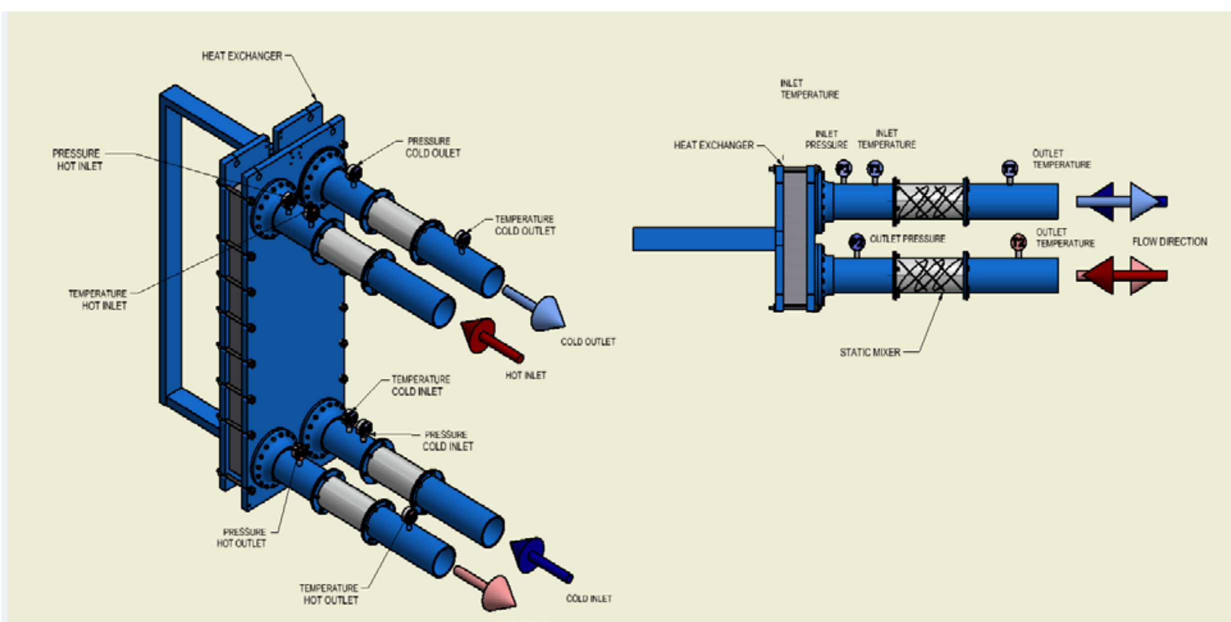


Figure E1. Usage of an In-line Static Mixer

E2.2 Metal pipe longer than ten pipe diameters between the test article and the point of temperature measurement shall be insulated. Plastic pipe, or hose, longer than twenty pipe diameters shall be insulated.

E2.3 Temperature taps mounted radially.

E2.3.1 Probes shall be of sufficient length to have the sensing area in the center of the pipe.

E2.3.2 When the pipe size is sufficiently small to cause contact between the tip of the probe and the opposite side of the pipe wall when attempting to correctly position the probe, the radial mounting method shall not be used. The axial method of Section E2.4 shall be used to avoid contact with wall of the pipe instead.

E2.4 Temperature taps mounted through a pipe elbow shall be positioned on the probe in the center of the upstream pipe.

E2.4.1 Probes shall be of sufficient length to have the sensing area fully in the straight portion upstream of the elbow.

E3 *Pressure Measurement.* Devices shall be located as follows:

E3.1 The inlet pressure tap shall be located four nominal pipe diameters upstream of the connection face of the test article. The tolerance is plus/minus one diameter. Pipe shall be the same nominal size as the connection.

E3.2 The outlet pressure tap shall be located ten nominal pipe diameters downstream of the connection face of the test article. Tolerance is plus/minus one diameter.

E3.3 At each of these tap locations, at least three penetrations through the pipe are required in order to construct a “piezo ring”, as follows:

E3.3.1 Penetrations shall be approximately equally spaced around the circumference of the pipe.

E3.3.2 Penetration through pipe of nominal IPS-4-inch and smaller shall be 1/8" diameter or smaller.

E3.3.3 Penetration through pipe larger than nominal size IPS-4-inch shall be between 1/16" and 7/16".

E3.3.4 The penetration shall be a smooth round-hole.

E3.3.5 The edge of the hole toward the interior of the pipe shall be smooth, sharp, and free of burrs. No burrs may protrude either into the pipe or into the hole. Chamfering the hole is not permitted.

E3.3.6 The axis of the hole shall be nominally perpendicular to the surface of the pipe**.**

E3.4 The penetrations shall be interconnected using tubing or pipe on the outside in order that they form a common chamber to tap into. The minimum nominal diameter of such tubing or pipe shall be 1/8”.

E3.5 Pressure measurement devices are then connected to this tap.