OPERATIONS MANUAL

LIQUID TO LIQUID HEAT EXCHANGERS CERTIFICATION PROGRAM

AHRI LLHE OM – MAY 2022

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PREFACE

The following manual outlines the procedures and policies of the Performance Certification Program for Liquid to Liquid Heat Exchangers (LLHE) operated by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI). This manual is to be used in conjunction with the AHRI General Operations Manual (GOM) for AHRI Certification Programs. Where the AHRI General Operations Manual and this product-specific manual differ, this product-specific operations manual shall prevail.

The revision of this manual supersedes all previous revisions. The current edition of this manual, as well as the AHRI General Operations Manual, can be accessed through the AHRI website, www.ahrinet.org.

The LLHE Certification Program by AHRI provides for independent verification of the Liquid to Liquid Heat Exchangers manufacturers' stated equipment performance. Safety criteria are not within the scope of this program.

Participation in the program is voluntary. Any manufacturer, regardless of AHRI membership, may obtain approval of Program Ratings and use of the AHRI LLHE Certification Mark hereinafter referred to as the "Mark". The Mark is the Participant's public representation that the ratings of randomly selected samples have been verified by an independent laboratory in accordance with test procedures prescribed by this operations manual. A Certification Agreement is executed between the manufacturer and AHRI specifying the conditions under which such Ratings and the Mark may be used. No manufacturer has the right to use Program Ratings or to state that their products have been tested in conformance with the procedures outlined in this Rating Procedure unless and until they have received written authority from AHRI to use the Mark as applied to the specific approved Program Ratings.

This Operations Manual has been prepared to assure that administration of the program is carried out in a uniform manner. It is an amplification of the Certification Agreement signed by licensees and AHRI. General information, procedural details, and copies of forms are included in this Operations Manual. Provisions of the Operations Manual may be amended as provided in the Certification Agreement.

This certification program complies with requirements of the ISO/IEC Standard 17065:2012, *General Requirements for Bodies Operating Product Certification Systems.*

Note:

This manual supersedes the AHRI Liquid to Liquid Heat Exchangers Operational Manual, October 2021.

Printed in U.S.A.

CERTIFICATION OPERATIONS MANUAL FOR

LIQUID TO LIQUID HEAT EXCHANGERS

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1. Program Overview

1.1 *Applicable Rating Standard*. It is mandatory for program Participants to comply with the provisions of the latest edition of AHRI Standard 400 (I-P), *Liquid to Liquid Heat Exchangers* (Standard) and the procedures outlined in this Operations Manual. A copy of this standard is available for download from the AHRI website, www.ahrinet.org.

1.2 *Product Definitions.* All terms in this document shall follow the AHRI General Operations Manual and the Standard definitions unless otherwise defined in this section.

1.2.1 *Liquid to Liquid Heat Exchanger*. A heat transfer device used to exchange heat between two (2) liquid streams that are single phase fluids.

1.2.2 *Gasketed Plate-Type Heat Exchanger*. A Liquid to Liquid Heat Exchanger that typically utilizes corrugated metal plates in a bolted frame with elastomer gaskets that seal the unit and direct the heat transfer stream in countercurrent flow.

1.3 *Program Scope*. This program applies to Production Models of Gasketed Plate-Type Heat Exchangers (Heat Exchangers), as defined in Section 1.2, that utilize any of the fluids defined in section 1.3.3 on one (1) or both circuits, for HVAC applications only.

1.3.1 *Program Scope Exclusions*. 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 240,000,000 Btu/h;
- Heat exchangers with a flow rate greater than 20,000 gpm;
- Heat exchangers with pass arrangements above 3 passes per side; or
- Heat exchangers with unequal number of passes per side.

1.3.1.1 Scope Exclusion Exception. Plate heat exchangers with three media in a 2/1-pass arrangement will be treated as two 1/1-pass heat exchangers in series and shall be included in the scope of this program. An example of an application where this arrangement is used is district heating energy transfer stations.

1.3.2 *HVAC Applications.* For the purpose of the LLHE Certification program, HVAC applications encompasses equipment located in a residential or commercial building exclusively used for conditioning spaces for the occupants of the building.

1.3.3 *Fluid Types.* The following fluid types shall be certified within the LLHE Certification Program:

- Water;
- Seawater;
- Ethylene Glycol[1, 2];
- Propylene Gycol[1, 2]

[1]10% - 50% concentration (v/v)
[2]Fluid properties shall be referenced from International Institute of Refrigeration Publications' "Properties of Secondary Working Fluids for Indirect Systems."

1.4 *Intended Market*. The Intended Market for this certification program includes all products defined in Section 1.3 that are sold for use in the U.S. (including U.S. Territories) and Canada.

1.5 *Basic Model Groups (BMGs)*. A Participant's listings shall be grouped by BMG. A BMG is a regular range of sizes of a similar type, design and construction, and having a common designation. All iterations of pressing patterns, variations of geometry, and quantities of plates for a given model shall be grouped in the same BMG.

1.5.1 *Optional Subdivisions of BMG*. The Participant may further sub-divide its BMGs. The following are examples of additional parameters that may be used to sub-divide BMGs:

- Port diameter;
- Fluid types;
- Heat transfer surface capacity;
- Construction variation; and
- Other prudent engineering reasons.

1.5.2 *Double Wall Heat Exchangers*. Double wall heat exchangers shall be clearly identified as a separate model designation.

2. Qualification Process

2.1 *Original Equipment Manufacturer (OEM) Applicants*. With the additions noted below, the OEM qualification process shall proceed according to the AHRI General Operations Manual, Section 4.

STEP 2.1.1 *Certification Application Package*. In addition to the Application for AHRI Certification, New Applicant License Fee Form – Sales Volume, and product-specific ratings and data, noted in the AHRI General Operations Manual, Section 4, STEP 4.1, Applicants shall submit the following documentation to AHRI:

- One test report for each BMG, as per Appendix A of this document;
- Copy of Applicant's Selection Rating Software (refer to Section 3.8); and
- If the Applicant chooses to conduct witness testing at its AHRI Approved Test Stand within a Facility (Facility), all required forms per Section 3.3.1 of this manual for Witness Testing Facility Approval shall also be submitted.

Electronic forms shall be obtained from AHRI (available on www.ahrinet.org under the Product-Specific Certification Program.

STEP 2.1.2 *Processing Application Package*.

STEP 2.1.2.1 *Performance Certification Agreement for Original Equipment Manufacturer (OEM Agreement)*. No further action required beyond that listed in Section 4, STEP 4.2 of the AHRI General Operations Manual.

STEP 2.1.2.2 *Participation and Licensing Fee Invoice*. Payment of the Participation and Licensing Fee is due within 30 calendar days of the invoice issue date. Testing shall not be conducted until the invoice is paid in full. No further action required beyond that listed in Section 4, STEP 4.2 of the AHRI General Operations Manual.

STEP 2.1.3 *Selection and Acquisition of Test Samples.*

STEP 2.1.3.1 *Selection Rating Software Approval*. AHRI shall provide the Applicant with a login/password to a personalized Virtual Machine (VM) to install their Selection Rating Software, or to create a shortcut to the Software's webpage. Once the Applicant notifies AHRI that the Selection Rating Software has been successfully installed, AHRI shall grant approval of the Selection Rating Software.

STEP 2.1.3.2 *Number of Qualification Tests*. 50% of an Applicant's BMGs shall be tested, with a minimum of three (3) models, Fractional numbers shall be rounded to the nearest whole number using traditional rounding methods.

STEP 2.1.3.3 *Acquisition of Qualification Test Samples/Selection Criteria*. Within 90 calendar days of a request from AHRI, the Applicant shall have samples available for selection. Samples shall be acquired in accordance with Section 3 of this manual.

STEP 2.1.3.4 *Witness Test Facility Approval and Sample Selection.* If the Applicant has applied to conduct witness testing at its facility, the Laboratory shall contact the Applicant to schedule a preliminary witness test facility inspection. Upon final approval of the Applicant's witness test facility and the approval of the Applicant's Selection Rating Software, the Laboratory shall contact the Applicant to schedule initial qualification testing. Section 3 further explains the requirements and procedures for applying and conducting witness testing.

Qualification testing may be scheduled simultaneously with facility inspection; however, should the facility fail inspection the testing must be delayed until the facility is brought into compliance.

If the Applicant has not applied to conduct witness testing at its facility, the qualification process shall continue with the approval of the Applicant's Selection Rating Software. Upon approval by AHRI, the Laboratory shall contact the Applicant to schedule initial qualification testing.

STEP 2.1.4 *Qualification Testing*. AHRI shall supply the Laboratory with the Published Ratings. The Laboratory shall conduct the testing of the samples in accordance with the Standard, against the Published Ratings.

STEP 2.1.4.1 *Successful Completion of All Qualification Tests*. If all qualification tests pass proceed to STEP 2.1.5.

STEP 2.1.4.2 *First Sample Qualification Test Failure*. Refer to Section 4, STEP 4.4.2 of the AHRI General Operations Manual for details regarding the first sample qualification failure options:

STEP 2.1.4.3 *Second Sample Qualification Test Failure*. Refer to Section 4, STEP 4.4.3 of the AHRI General Operations Manual for details regarding the second sample qualification failure options.

STEP 2.1.5 *Welcome to the Program*. No further action required beyond that listed in Section 4, STEP 4.5 of the AHRI General Operations Manual.

2.2 *Private Brand Marketer (PBM) Applicants*. With the additions noted below, the PBM qualification process shall proceed according to the AHRI General Operations Manual, Section 5.

PBM Applicants are not required to undergo qualification testing. PBM product certification is contingent upon the certification of the associated OEM product. PBM Selection Rating Software must directly correlate to OEM Selection Rating Software. If the software has variations, the PBM must register and test as an OEM.

STEP 2.2.1 *Certification Application Package*. In addition to the Application for AHRI Certification and product-specific ratings and data noted in the AHRI General Operations Manual, Section 5, STEP 5.1, Applicants shall submit the following documentation to AHRI:

- Copy of Applicant's Selection Rating Software (refer to Section 3.7)

STEP 2.2.2 *Processing Application Package*.

STEP 2.2.2.1 Selection Rating Software Approval. AHRI shall provide the Applicant with a login/password to a personalized Virtual Machine (VM) to install their Selection Rating Software, or to create a shortcut to the Software's webpage. Once the Applicant notifies AHRI that the Selection Rating Software has been successfully installed, AHRI shall grant approval of the Selection Rating Software.

STEP 2.2.2.2 *Performance Certification Agreement for Private Brand Marketer (PBM Agreement)*. No further action required beyond that listed in Section 5, STEP 5.2.1 of the AHRI General Operations Manual.

STEP 2.2.2.3 *OEM Agreement on Behalf of the PBM Applicant*. No further action required beyond that listed in Section 5, STEP 5.2.2 of the AHRI General Operations Manual.

STEP 2.2.2.4 *Licensing Fee Invoice*. Payment of the Licensing Fee is due within 30 calendar days of the invoice issue date.

STEP 2.2.3 *Welcome to the Program*. No further action required beyond that listed in Section 5, STEP 5.3 of the AHRI General Operations Manual.

3. Equipment Selection and Testing

3.1 Annual Testing *Requirement*. 25% of a Participant's BMGs shall be tested annually, with a minimum of two (2) models. Fractional numbers shall be rounded to the nearest whole number using traditional rounding methods. Annual testing of models shall be selected from all of a Participant's manufacturing locations where plates are pressed for AHRI models. At the beginning of each calendar year, the Participant shall provide a list to AHRI of all manufacturing locations around the world where plates are pressed for AHRI models. The annual number of required tests (for each Participant) shall not be affected by the number of locations where plates get pressed.

3.2 *Location of Test*. The Participant shall elect to conduct testing at the Laboratory or at the Facility and the sample shall be installed in accordance with the Participant's published installation instructions in printed or electronic format. When testing with glycol as the fluid type, tests shall be conducted at the Laboratory to ensure that similar properties of glycol are used across tests.

3.3 *Witness Testing Procedures and Operations*. This Certification Program allows witness testing; where Participant personnel witnessed by the Representative, conducts testing at a Facility. Witness testing requirements are covered in the AHRI General Operations Manual, Section 9 and as specified below.

3.3.1 *Application for Witness Testing*. A Participant shall submit all of the following to AHRI:

- Form LLHE-WT1, Application for Witness Testing;
- Form LLHE-WT2, Facility and Equipment Questionnaire;
- Form LLHE-WT3, Personnel Experience Questionnaire;
- A complete list of all instruments and equipment being used to perform certification testing in accordance with the Standard and a copy of each calibration report showing date of last calibration;
- A schematic drawing of the area of the test facility in which AHRI certification testing will be performed; and
- Photographs of the test facility in which AHRI certification testing will take place, which shall include sufficient views to show the location and connection of each instrument.

Electronic copies of these forms are available on the AHRI website.

3.3.2 *Inspection of Witness Test Facility*. Following preliminary facility approval based on submitted data, the Representative shall inspect the Facility to verify the submitted data and the Facility's compliance with the certification program requirements. Testing may be scheduled in conjunction with facility inspection; however, should the facility fail inspection, the testing must be delayed until the facility is brought into compliance.

3.3.2.1 *Non-Compliant Inspection Results*. If the results of the inspection indicate that a Facility is non-compliant with the certification program, all discrepancies must be resolved and resubmitted to AHRI, before approval can be granted to proceed with certified rating tests.

3.3.2.2 *Final Approval of Witness Test Facility*. Upon acceptable results of the inspection, AHRI shall notify the Facility of final acceptance and approval to proceed with certified ratings tests. AHRI shall provide the Participant with a certificate of approval that shall be displayed in the Facility.

3.3.5 *Witness Test Operations at a Facility*.

3.3.5.1 *Advance Set-Up of Sample in the AHRI-Approved Test Facility*. A Participant may set up the test sample in the Facility prior to the arrival of the Representative. Prior to test commencement, the Representative shall verify that the sample is the model selected by AHRI for testing and that the sample has been set up in the Facility in accordance with the Participant's installation instructions and referenced method of test.

3.3.5.2 *Duty Assignments of Representative*. Sample testing, data acquisition, and generation of test data shall be performed by the Participant personnel and assisted and witnessed by the Representative. Participant or Facility personnel shall be on-hand to assist the Representative as requested and are permitted to be present but are not permitted to tamper or adjust samples during tests, unless specifically approved by the Representative responsible for the test.

Verification of instrument application (in accordance with the procedures defined in the Standard) and verification of calibrations shall be performed by the Representative.

3.3.5.3 *Use of Instrumentation*. The Representative shall use primary test instruments belonging to the Facility, in accordance with certification program requirements. The Laboratory shall provide secondary instrumentation to verify measured temperatures and pressure drop. The results from the Facility's data acquisition system shall be used, provided that:

- The facility's equipment is under current calibration;
- All data acquisition is in accordance with the standard.
- Fluid temperature at each location does not differ from the Laboratory instrumentation measurements by more than 0.2°F (0.11°C); and
- Inlet and outlet fluid pressure does not differ from the Laboratory instrumentation measurements by more than 0.25 psi (1.7 kPa)

Should any of these criteria not be met, steps should be taken to ensure that the discrepancy is resolved. In cases where the discrepancy cannot be resolved and no damage is apparent, the Laboratory instrumentation data shall be used.

3.3.5.4 *Sample Start-Up and Operation*. Start-up and operation of the sample shall be in accordance with the Participant's published installation instructions in printed or electronic format.

3.4 *Selection of Test Samples.* AHRI shall make a Built-to-Specification Test Sample Selection based on data contained in the Directory AHRI shall utilize the Participant's AHRI approved Selection Rating Software(s) to select a sample to operate within the limits of rating conditions per the Standard. The selection specification sheet shall state the AHRI selected duty point. Refer to Section 9 of the AHRI General Operations Manual.

3.5 *Method of Acquiring Test Samples.* Selected samples shall be accompanied by the Participant's published installation instructions in printed or electronic format; or be available for Witness Testing at the Facility.

3.6 *Sample Acquisition Timeframe*. Upon notification of selections by AHRI, the Participants have 120 calendar days for units with port sizes larger than or equal to 12"and 90 calendar days for units with port sizes smaller than 12" to deliver to the Laboratory or the Facility or conduct witness testing at the Facility. Extended transit times must be approved by AHRI staff prior to selection. Prior to test, AHRI shall supply the Laboratory with the Published Ratings.

Upon notification of selections by AHRI, the Participant shall work with AHRI to determine mutually agreed upon test date which may require the Participant to accelerate product production.

3.7 *Preliminary Check*. Before testing, the laboratory shall check if the sample corresponds to the selection. The Laboratory shall verify:

- The nameplate;
- The number of plates;
- The unit dimensions;
- A-measurement

The Laboratory shall immediately notify AHRI if there are any issues with the samples.

3.7.1 *Sanity Check*. Upon a request from AHRI, the Laboratory shall conduct a sanity check after the regular test. Sanity check will comprise of opening the heat exchanger to check if the plate pattern, channel type and plate thickness are consistent with the selection. If there is any discrepancy with the selected unit, a Tier 2 program violation shall be issued.

3.8 *Selection Rating Software*

3.8.1 *Requesting Approval of Selection Rating Software*. A Participant shall request approval of its Selection Rating Software by submitting all of the following to AHRI:

- Selection Rating Software, shall be either personal computer (PC) based, run on MS Windows platform, or web-based software and allow for selection of any certified product at any application rating condition per the latest edition of the Standard;
- Software specification sheets to provide outputs for:
  - Participant's Name or Private Brand Manufacturer Name;
  - Date of Specification Sheet Output;
  - Model Number;
  - Volumetric Flow Rate on Both Circuits;
  - Inlet Temperatures on Both Circuits;
  - Outlet Temperatures on Both Circuits;
  - Pressure Drops on Both Circuits;
  - Surface Margin (also known as Excess Surface Area);
  - Heat Duty (also known as Heat Load);
  - Overall Heat Transfer Coefficient[1];
  - Heat Transfer Area;
  - Number of Plates;
  - Channel Arrangements on Both Circuits;
  - Number of Passes;
  - Plate Material and Thickness;
  - Connection Diameter;

- Design Pressure;
- Design Temperature;
- Unit Dimensions (Length, Width, and Height);
- A-Measurement;
- LMTD;
- Net Weight (Empty and Operating);
- Fluid Type on Both Circuits;
- Fluid Properties on Both Circuits (Density, Specific Heat Capacity, Viscosity, Thermal Conductivity);
- Concentration of glycol (v/v);
- Software Version number;
- Proper claim to AHRI Certification (Refer to Section 3.7.4);

[1]If both clean and fouled Overall Heat Transfer Coefficients are mentioned, the calculations must be in alignment with Appendix D of AHRI Standard 400.

- All necessary passwords to access software and updates;
- Instructions for use of the Selection Rating Software; and

If the Participant has more than one (1) Selection Rating Software available to users, each software shall be verified by AHRI.

3.8.1.1 *Installation of Selection Rating Software*. AHRI shall provide the Participant with a login/password to a personalized Virtual Machine (VM) to install their Selection Rating Software. Once the Participant notifies AHRI that the Selection Rating Software has been successfully installed, AHRI shall provide notice of approval or disapproval of the Selection Rating Software within seven (7) calendar days.

3.8.2 *Initial Approval of Selection Rating Software through Published Rating Comparison*. AHRI upon receiving the necessary materials shall, if applicable, utilize the Participant's Selection Rating Software to determine computer ratings for a certain set of conditions and compare them for the same conditions as those in the published catalog, if a published catalog exists. The Selection Rating Software output (printout and on-screen display) shall match the published certified ratings from the catalog, if applicable. AHRI may also request selection sheets from customers who have received bids. These selection sheets shall match the Selection Rating Software output.

The Participant shall be notified whether the rating software has been approved for certification. Upon approval from AHRI, the Participant may release the software to other users. Selection Rating Software released to other users prior to obtaining AHRI approval shall result in a program violation. Also, the Selection Rating Software shall be approved by AHRI prior to field release.

3.8.3 *Updates to Previously Approved Software.* Per the AHRI General Operational Manual, Section 9, AHRI shall have an updated copy of any Selection Rating Software being used in the field. Any updates shall promptly be provided to AHRI via installation to the Participant's VM. Major changes to software shall go through an Initial Approval as per Section 3.7.2. The Directory shall be locked and Participants shall not be allowed to make changes to Selection Rating Software version updates until the Participant has obtained approval from AHRI.

3.8.4 *Statements Regarding Certification – Certified Selections*. For units within the scope of the program, the AHRI Certified Mark should be included on the Selection Rating Software outputs for certified units in accordance with the Section 8 of the AHRI General Operations Manual.

"This Heat Exchanger is certified by the AHRI Liquid to Liquid Heat Exchangers Certification Program, based on AHRI Standard 400. AHRI certified units are subject to rigorous and continuous testing, have performance ratings independently measured and are third-party verified. Certified units may be found in the AHRI Directory at www.ahridirectory.org"

3.9 *Changes to Operating Conditions Profile Prior to Test*. To ensure random selection of a sample, the profile entering a given sample may be changed after the original selection of the sample by AHRI. The new profile shall be applicable to the selected sample per the Selection Rating Software and shall be selected by AHRI.

3.10 *Certified Data*. In accordance with the Standard, the following certified ratings at operating conditions designated by AHRI are verified by test:

- Total heat transfer rate, Btu/h;
- Cold stream pressure drop, psig; and
- Hot stream pressure drop, psig.

3.11 *Down-scaling Procedure*. Models selected for testing that are within the scope of the LLHE certification program but have selected operational points above the laboratory capacity limitations, will be tested per the LLHE Down-scaling Procedure (refer to Appendix B).

Per this procedure, a unit will be provided that is identical to the first sample with the exception of number of plates. The number of plates will be determined per the Down-scaling Procedure. If the original down-scaled conditions exceed the available laboratory capacity, AHRI shall down-scale the test unit to above 40 channels (total).

Temperature inlet measurements from the down-scaled test shall be within 1°F of the full-scaled unit's specification sheet. Flow rate measurements shall be within 1% of the calculated flow rates. If these conditions cannot be met, a new full-scaled specification sheet shall be generated based on these conditions. In either case, inlet temperature, outlet temperature, and flowrates from the downscaled test will be used to recalculate the full scale specification sheet. Pass fail criteria will be based on the heat duty and pressure drop from the new specification sheet.

3.12 *Test Failures*.

3.12.1 *Options Following First Sample Failure.* When the Participant is notified of a first sample certified rating failure, the Participant has seven (7) calendar days to select one of the following options:

- Re-rate all models within the failed sample's BMG proportionate to the failed test's results;
- Test second sample of the same model (sample must be available within the timeframe and procedure allotted in Section 3.6, following notification of decision to AHRI via Manufacturer's Decision Form [MDF]); or
- Obsolete the model, which also obsoletes all models within the corresponding BMG.

3.12.1.1 Option to Test at a Different Facility. If a Participant selects Second Sample following a first sample failure, the second sample may be conducted at any Laboratory or AHRI-approved Facility.

3.12.2 *Options Following Second Sample Failure*. When the Participant is notified of a second-sample certified rating failure, the Participant has seven (7) calendar days to select one of the following options:

- Re-rate all models within the failed sample's BMG proportionate to the failed test's results; or
- Obsolete the model, which also obsoletes all models within the corresponding BMG.

3.13 *Re-rate Procedure*. After a participant chooses to re-rate, a statement will be added to the AHRI Certificate indicating the re-rate and software version number in which the selections were made. All software and other marketing materials shall be updated within 60 calendar days from the re-rate notification. After the

re-rate is completed in the software, AHRI shall complete the re-rate checklist to confirm the re-rates and send it to the participant.

4. Challenge Tests

Except as noted below, the Challenge Test process shall proceed according to the AHRI General Operations Manual, Section 10.

4.1 *Procedure for Initiating a Challenge Test*. Specification sheet verifications should be requested prior to the initiation of a challenge. The challenger shall provide AHRI with:

- The model number of the unit being challenged;
- A copy of the selection sheet showing the disputed ratings of a unit listed in the Directory or a copy of the published disputed ratings (for products that are non AHRI certified);
- The profile for which the unit being challenged was specified; and
- Data for a comparable unit from the challenger (5-10% surface area discrepancy is expected but not a cut-off for challenge viability).

4.2 *Selection Software Verification of Challenged Product*. Within seven (7) calendar days of the date the challenge is presented to AHRI, an official challenge verification will be run using the latest software. The challenge verification will use the current software version as listed in the AHRI Directory. If the challenge verification shows a re-rate of the challenged product, the challenger has the option to challenge the re-rated data or drop the challenge.

All challenge tests shall be followed by a Sanity Check as stated in Section 3.7.1.

4.3 *Obtaining Equipment for a Challenge Test*. Due to the complexities and costs of these units, AHRI shall approach the challenged party to obtain a sample. It shall be necessary to reveal that a product rating has been challenged; however, AHRI will not divulge the name of the challenger.

4.4 *Challenge Test Fees*. The same fees apply as those for Annual Testing and Unit costs as listed in Table 1. The cost of all fees (e.g. selection, sample shipment and disposition, witness testing facility rental, witness testing facility approval, if applicable, and testing) associated with the challenge test shall be borne by one of the two parties concerned.

Due to the variable cost of this product, Table 1 lists the unit costs that shall be paid to the challenged party by the challenger should the unit pass. Should the unit fail, the challenged party shall be responsible for all costs, and it is assumed that the challenged party will have already experienced the unit costs listed in Table 1. These values have been determined based on the estimated cost of labor to assemble and disassemble the unit, and the cost of equipment parts and instruments. The challenged unit shall remain in the possession of the challenged party after the test. If the challenged party elects to test a second sample following a failure, all associated costs for the second sample test shall be paid by the challenged party.

Unit costs for Challenge Tests based on port sizes are as follows for 2021. In subsequent years, these numbers shall be adjusted up by 2% annually.

Table 1. Unit Costs for Challenge Tests

Port Size	6" and Smaller	8/10"	12/14" and Larger
Cost	$6,531	$20,826	$37,837

5. AHRI Directory of Certified Product Performance

All certified products shall be listed in the Directory, www.ahridirectory.org. Certification shall not be implied nor claimed for any product not listed in the Directory. Except as noted below, the Participant shall follow the steps outlined in Section 11 of the AHRI General Operations Manual.

5.1 *Publication of Ratings in Certified Directory*. For each certified model, the Directory shows:

- AHRI Certified Reference Number;
- Model Status;
- Brand Name of Model;
- Model Number(s) or Designation(s);
- Fluid Type;
- Selection Rating Software Name; and
- Selection Rating Software Version Number.

5.2 *Data Forms*. Each Participant shall list its products by BMG. OEM and PBM Participants shall submit/edit product data via the Directory.

6. Assessment and Payment of Certification Fees

Refer to Section 12 of the AHRI General Operations Manual.

7. Issuance of Violations and/or Termination

Except as noted below, the Issuance of Violations and/or Termination process shall proceed according to the AHRI General Operations Manual, Section 14.

In order to maintain the integrity of the LLHE certification program, a Tier 1 program violation shall be issued to any participant that has an involuntary re-rate/obsoletion equal to or above 50% of the annual tests for two consecutive testing years. The two consecutive years will stack; for instance, if a participant has a re-rate/obsoletion rate of over 50% for 3 consecutive years, two (2) Tier 1 program violation will be issued. For each involuntary re-rate/obsoletion, two (2) penalty tests will be assigned.

8. Program Hierarchy, Complaints, and the Appeals Process

Refer to Section 15 of the AHRI General Operations Manual.

9. Proper Use of the AHRI Certification Mark and Claims to Certification

Except as noted below, the proper use of the AHRI Certification Mark and claims to Certification shall proceed according to Section 8 of the AHRI General Operations Manual.

9.1. *AHRI Verification and Monitoring of Selection Rating Software and Selection Methods*.

9.1.1 *Data Comparison between Selection Rating Software and Catalog*. AHRI shall make random comparisons of the catalog ratings, if applicable, and the ratings acquired through the Participant's Selection Rating Software(s) to verify that the Participant is not using separate software program(s) not approved for AHRI Certification.

Any published catalog shall make reference to the version number of the Selection Rating Software to which it corresponds. AHRI considers the Selection Rating Software output to be the primary source of information. If, at any time, the referenced computerized rating output is not in agreement with the

catalog, or if the catalog or Selection Rating Software output does not correspond to the version listed in the Directory, the Participant shall be issued a program violation notifying them of the discrepancy and shall have 60 calendar days to resolve the discrepancy.

9.1.2 *Additional Monitoring*. AHRI may request that Participants, users, consulting engineers, etc. to submit to AHRI copies of specific job conditions and ratings that they have utilized. Additionally, parties may request that AHRI verify certification of product ratings. AHRI shall compare the ratings with the results obtained through the Participant's Selection Rating Software. Comparison shall only be made on jobs in which the Selection Rating Software implemented by the user matches that of the verified rating method, including issue date or code, of the current software held by AHRI. AHRI provides verification services to all legitimate parties. All requesters shall be required to provide the following information before verifications are completed:

- Name of the Requester;
- Affiliation of the Requester;
- Contact information of the Requester;
- Original job submittal with the job name; and
- Manufacturer representative that provided the request.

9.1.3 *Responsibility of Participant for Catalog/Software Revisions*. Whenever a Participant's catalog (if applicable) and/or Selection Rating Software is revised, the Participant shall promptly notify and supply the revised version(s) to AHRI. Upon notification to AHRI, the Participant may release the software to other users. Selection Rating Software released to other users prior to notifying AHRI shall result in a program violation. Version numbers shall be constructed such that the revision level can be determined by AHRI. Selection Rating Software shall prominently include a revision code, date, or version identification. Catalogs shall be consistent with the current Selection Rating Software at time of publication. Current versions shall be listed in the Directory at the time of release.

APPENDIX A: MINIMUM TEST REPORT REQUIREMENTS FOR LIQUID TO LIQUID HEAT EXCHANGERS

Table A1: Test Report Requirements	
Parameter	**Parameter Units**
Manufacturer's Name	None
AHRI Test No.	None
Model No.	None
Date of Test	None
Location of Test	None
Connection Size / diameter	Inches
Number of Plates	None
Heat Transfer Rate, Hot Stream	Btu/h
Heat Transfer Rate, Cold Stream	Btu/h
Fluid Flow Rate, Hot Stream	GPM
Fluid Flow Rate, Cold Stream	GPM
Hot Stream Inlet / temperature	ºF
Hot Stream Outlet / temperature	ºF
Cold Stream Inlet / temperature	ºF
Cold Stream Outlet / temperature	ºF
Fluid Pressure Drop / Hot Stream	psid
Fluid Pressure Drop / Cold Stream	psid
Actual Pressure / Hot Stream	psi
Actual Pressure / Cold Stream	psi
Density	lb/ft^3
Specific Heat	Btu/(lb*°F)
Thermal Conductivity	Btu/(ft*h*°F)
Viscosity	cP

APPENDIX B: LLHE CERTIFICATION PROGRAM DOWN-SCALING METHOD

Models selected for testing that are within the scope of the LLHE certification program, but have selected operational points that are above the laboratory capacity limitations, will be tested per the LLHE Down-scaling Procedure in conjunction with the latest version of AHRI Standard 400.

B.1 Record the following performance and physical characteristics of the full-scale test unit (shall be obtained from the manufacturer's selection rating software):

$m_{HS, FS}$ = Mass flow rate of full-scale unit on hot side [lb/s];
$m_{CS, FS}$ = Mass flow rate of full-scale unit on cold side [lb/s];
$Q_{FS, Design}$ = Design Heat duty of the full-scale test unit [Btu/h]; (at tested conditions)
A_{FS} = Total heat transfer area of the full-scale unit [ft²];
U_{FS} = Overall heat transfer coefficient of the full-scale unit [Btu/ft²·h·°F];
CA_{FS} = Channel arrangement of full-scale unit represented as $1\cdot(N_{C1, HS} + N_{C2, HS})$ for hot side and $1\cdot(N_{C1, CS} + N_{C2, CS})$ for cold side; C1 = channel type 1, C2 = channel type 2 where C1 <= C2.
$n_{Pl,FS}$ = Number of plates in the full-scale unit
$T_{in,HS,FS}$ = Inlet temperature on hot side [°F]
$T_{out,HS,FS}$ = Outlet temperature on hot side [°F]
$T_{in,CS,FS}$ = Inlet temperature on cold side [°F]
$T_{out,HS,FS}$ = Outlet temperature on cold side [°F]
$LMTD_{FS}$ = Log mean temperature difference of full-scale unit [°F];
$\Delta P_{Total, HS, Design}$ = Design pressure drop on hot side [psid];
$\Delta P_{Total, CS, Design}$ = Design pressure drop on cold side [psid];
D_{Port} = Plate port diameter [in].
$C_{p,HS}$ = Specific heat on the hot side [Btu/(lb·°F)]
$C_{p,CS}$ = Specific heat on the cold side [Btu/(lb·°F)]
P_{HS} = Fluid density on the hot side [lb/in³]
P_{CS} = Fluid density on the cold side [lb/in³]

B.2 AHRI staff shall determine the down-scaling factors, X_{HS} and X_{CS}. The down-scaling factor shall be determined so that the resulted down-scale unit is able to be tested in an AHRI approved facility. The down scaling factors are chosen so that the number of channels, of the channel type in minority, becomes an integer. At a minimum, 40 channels are required in the down-scaled unit.

B.3 Calculate the channel arrangements for down-scale unit as follows:

$$n_{C1,HS} = \frac{N_{C1,HS}}{X_{HS}}$$

$$n_{C2,HS} = \mathrm{ROUND}\left(\frac{N_{C2,HS}}{X_{HS}}\right)$$

$$n_{C1,CS} = \left(\frac{N_{C1,CS}}{X_{CS}}\right)$$

$$n_{C2,CS} = \mathrm{ROUND}\left(\frac{N_{C2,CS}}{X_{CS}}\right)$$

Therefore, the channel arrangement for down scale unit is $1\cdot(n_{C1, HS} + n_{C2, HS})$ for hot side and $1\cdot(n_{C1, CS} + n_{C2, CS})$ for cold side. Number of plates ($n_{Pl, DS}$) in the down-scale unit is $(n_{C1, HS} + n_{C2, HS} + n_{C1, CS} + n_{C2, CS} + 1)$

B.4 Calculate the flow rates for the down-scale unit test as follows:

$$m_{HS,DS} = m_{HS,FS} \cdot \frac{(n_{C1,HS} + n_{C2,HS})}{(N_{C1,HS} + N_{C2,HS})}$$

$$m_{CS,DS} = m_{CS,FS} \cdot \frac{(n_{C1,CS} + n_{C2,CS})}{(N_{C1,CS} + N_{C2,CS})}$$

B.5 Run the test on down-scale unit at $m_{HS,DS}$ and $m_{CS,DS}$ and with the inlet temperatures initially determined for the full-scale unit test.

B.6 Record and calculate the following test results from the down-scale test (refer to Appendix C of AHRI Standard 400):

Q_{DS} = Heat duty of the down-scale test unit [Btu/h];
A_{DS} = Total heat transfer area of the down-scale unit [ft²];
U_{DS} = Overall heat transfer coefficient of the down-scale unit [Btu/ft²·h·°F];
$T_{in,HS,DS}$ = Inlet temperature on hot side [°F];
$T_{out,HS,DS}$ = Outlet temperature on hot side [°F];
$T_{in,CS,DS}$ = Inlet temperature on cold side [°F];
$T_{out,HS,DS}$ = Outlet temperature on cold side [°F];
$LMTD_{DS}$ = Log mean temperature difference of down-scale unit [°F];
$\Delta P_{Total,\ HS,\ DS}$ = Measured pressure drop on hot side [psid]; and
$\Delta P_{Total,\ CS,\ DS}$ = Measured pressure drop on cold side [psid].

B.7 Calculate the end effect coefficient for the down-scale unit test as follows:

$$\Delta T_{HS,DS} = T_{In,HS,DS} - T_{Out,HS,DS}$$
$$\Delta T_{CS,DS} = T_{Out,CS,DS} - T_{In,CS,DS}$$

$$NTU_{HS,DS} = \frac{\Delta T_{HS,DS}}{LMTD_{DS}}$$

$$NTU_{CS\ DS} = \frac{\Delta T_{CS,DS}}{LMTD_{DS}}$$

$$R_{DS} = \frac{NTU_{Min,DS}}{NTU_{Max,DS}}$$

Where:

$NTU_{min,DS}$ is the smaller of $NTU_{HS,DS}$ and $NTU_{CS,DS}$ and $NTU_{max,DS}$ is the larger.

Using Appendix C and the values from equations above (R_{DS}, $NTU_{max,DS}$ and $n_{Pl,DS}$), determine the end effect coefficient $F_{End,DS}$ for the down-scale unit. A more complete list of End Effects can be found at www.ahrinet.org

B.8 The pure channel U value will now be calculated as follows:

$$U = \frac{Q_{DS}}{A_{DS} \cdot LMTD_{DS} \cdot F_{End,DS}}$$

B.9 Calculate the end effect coefficient for the full-scale unit using similar steps as stated in D.7:

$\Delta T_{HS,FS} = T_{In,HS,FS} - T_{Out,HS,FS}$
$\Delta T_{CS,FS} = T_{Out,CS,FS} - T_{In,CS,FS}$
$NTU_{HS,FS} = \frac{\Delta T_{HS,FS}}{LMTD_{FS}}$
$NTU_{CS,FS} = \frac{\Delta T_{CS,FS}}{LMTD_{FS}}$
$R_{FS} = \frac{NTU_{Min,FS}}{NTU_{Max,FS}}$

Where:

$NTU_{min,FS}$ is the smaller of $NTU_{HS,FS}$ and $NTU_{CS,FS}$ and $NTU_{max,FS}$ is the larger.

Using Appendix C and the values from equations above (R_{FS}, $NTU_{max,FS}$ and $n_{PI,FS}$), determine the end effect coefficient $F_{End,FS}$ for the full-scale unit. (Note: if N > 99, use values from N = ∞)

B.10 Calculate the full-scale estimated $U_{FS,Computed}$ value as follows:

$U_{FS,Computed} = U \cdot F_{End,FS}$

B.11 Compute the heat duty, $Q_{FS,Computed}$, based on $U_{FS,Computed}$

$C_{CS} = m_{CS,FS} \cdot c_{p_{CS,average}}$
$C_{HS} = m_{HS,FS} \cdot c_{p_{HS,average}}$
C_{min} = the smaller of C_{CS} and C_{HS}
C_{max} = the larger of C_{CS} and C_{HS}
m_{MaxNTU} = mass flow rate of the side with the higher NTU, full scale
Cp_{MaxNTU} = specific heat of the side with the higher NTU, full scale

$R = \frac{C_{Min}}{C_{Max}}$

$\beta = \frac{1}{3600} \cdot U \cdot F_{End,FS} \cdot A_{FS} \cdot (\frac{1}{C_{Min}} - \frac{1}{C_{Max}})$

$\varepsilon_{MaxNTU} = \frac{1 - e^{-\beta}}{1 - R \cdot e^{-\beta}}$

$\Delta T_{MaxNTU} = \varepsilon_{MaxNTU} \cdot (T_{In,HS,FS} - T_{In,CS,FS})$

Therefore:

$Q_{FS,Computed} = m_{MaxNTU} \cdot Cp_{MaxNTU} \cdot \Delta T_{MaxNTU} \cdot 3600$

Note: 3600 is the conversion factor from hours to seconds

B.12 The criteria to pass the heat duty test for full-scale unit is as follows:

$\frac{Q_{FS,Computed}}{Q_{FS,Design}} \geq 0.95$

B.13 Calculate the port pressure drop in the down-scale unit and full scale-unit.

$$u_{Port,HS,DS} = \frac{m_{HS,DS}}{\rho_{HS,Average} \cdot \frac{\pi \cdot D_{Port}^2}{4}}$$

$$\Delta P_{Port,HS,DS} = 1.3 \cdot \frac{\rho_{HS,average} \cdot u_{Port,HS,DS}^2}{2 \cdot 386.4} \cdot number\ of\ passes$$

$$u_{Port,CS,DS} = \frac{m_{CS,DS}}{\rho_{CS,Average} \cdot \frac{\pi \cdot D_{Port}^2}{4}}$$

$$\Delta P_{Port,CS,DS} = 1.3 \cdot \frac{\rho_{CS,average} \cdot u_{Port,CS,DS}^2}{2 \cdot 386.4} \cdot number\ of\ passes$$

$$u_{Port,HS,FS} = \frac{m_{HS,FS}}{\rho_{HS,Average} \cdot \frac{\pi \cdot D_{Port}^2}{4}}$$

$$\Delta P_{Port,HS,FS} = 1.3 \cdot \frac{\rho_{HS,average} \cdot u_{Port,HS,FS}^2}{2 \cdot 386.4} \cdot number\ of\ passes$$

$$u_{Port,CS,FS} = \frac{m_{CS,FS}}{\rho_{CS,Average} \cdot \frac{\pi \cdot D_{Port}^2}{4}}$$

$$\Delta P_{Port,CS,FS} = 1.3 \cdot \frac{\rho_{CS,average} \cdot u_{Port,CS,FS}^2}{2 \cdot 386.4} \cdot number\ of\ passes$$

*Note: 1.3 is the velocity head loss coefficient
386.4 $lb_m \cdot in/lb_f \cdot s^2$ is the gravitational constant

B.14 Calculate the full scale total pressure drop:

$$\Delta P_{Total,HS,FS} = \Delta P_{Total,HS,DS} - \Delta P_{Port,HS,DS} + \Delta P_{Port,HS,FS}$$

$$\Delta P_{Total,CS,FS} = \Delta P_{Total,CS,DS} - \Delta P_{Port,CS,DS} + \Delta P_{Port,CS,FS}$$

B.15 The criteria to pass the pressure drop test for full-scale unit is as follows:

$$\frac{\Delta P_{Total,HS,FS}}{\Delta P_{Total,HS,Design}} \leq 1.15$$

$$\frac{\Delta P_{Total,CS,FS}}{\Delta P_{Total,CS,Design}} \leq 1.15$$

APPENDIX C - END EFFECT COEFFICIENTS

Table C1. End Effect Coefficients for 1-pass Arrangement														
R	NTU max	Number of Plates												
		30	40	50	60	70	80	90	100	200	300	400	500	800
1.0	0.2	0.9968	0.9976	0.9981	0.9984	0.9986	0.9988	0.9989	0.9990	0.9995	0.9997	0.9998	0.9998	0.9999
	0.4	0.9937	0.9953	0.9962	0.9968	0.9973	0.9976	0.9979	0.9981	0.9991	0.9994	0.9995	0.9996	0.9998
	0.6	0.9908	0.9931	0.9944	0.9954	0.9960	0.9965	0.9969	0.9972	0.9986	0.9991	0.9993	0.9994	0.9997
	0.8	0.9879	0.9909	0.9927	0.9939	0.9948	0.9954	0.9959	0.9963	0.9982	0.9988	0.9991	0.9993	0.9995
	1.0	0.9851	0.9888	0.9910	0.9925	0.9936	0.9944	0.9950	0.9955	0.9977	0.9985	0.9989	0.9991	0.9994
	1.5	0.9782	0.9836	0.9868	0.9890	0.9905	0.9917	0.9926	0.9934	0.9967	0.9978	0.9983	0.9987	0.9992
	2.0	0.9714	0.9784	0.9827	0.9855	0.9876	0.9891	0.9903	0.9913	0.9956	0.9971	0.9978	0.9982	0.9989
	3.0	0.9581	0.9683	0.9745	0.9787	0.9817	0.9840	0.9857	0.9871	0.9936	0.9957	0.9968	0.9974	0.9984
	5.0	0.9325	0.9487	0.9586	0.9654	0.9702	0.9739	0.9768	0.9791	0.9896	0.9931	0.9949	0.9960	0.9976
	7.0	0.9081	0.9298	0.9433	0.9525	0.9591	0.9641	0.9681	0.9713	0.9858	0.9908	0.9932	0.9947	0.9970
0.8	0.2	0.9971	0.9978	0.9982	0.9985	0.9987	0.9989	0.9990	0.9991	0.9996	0.9997	0.9998	0.9998	0.9999
	0.4	0.9943	0.9957	0.9966	0.9971	0.9975	0.9979	0.9981	0.9983	0.9991	0.9994	0.9996	0.9997	0.9998
	0.6	0.9916	0.9937	0.9949	0.9958	0.9964	0.9968	0.9972	0.9975	0.9987	0.9992	0.9994	0.9995	0.9997
	0.8	0.9890	0.9917	0.9934	0.9945	0.9952	0.9958	0.9963	0.9967	0.9983	0.9989	0.9992	0.9993	0.9996
	1.0	0.9864	0.9898	0.9918	0.9932	0.9941	0.9949	0.9954	0.9959	0.9979	0.9986	0.9990	0.9992	0.9995
	1.5	0.9800	0.9850	0.9879	0.9899	0.9914	0.9924	0.9933	0.9939	0.9970	0.9980	0.9985	0.9988	0.9992
	2.0	0.9738	0.9802	0.9841	0.9867	0.9886	0.9900	0.9911	0.9920	0.9960	0.9973	0.9980	0.9984	0.9990
	3.0	0.9613	0.9707	0.9765	0.9803	0.9831	0.9852	0.9868	0.9881	0.9940	0.9960	0.9970	0.9976	0.9985
	5.0	0.9364	0.9516	0.9609	0.9672	0.9717	0.9752	0.9779	0.9800	0.9899	0.9933	0.9950	0.9960	0.9975
	7.0	0.9115	0.9319	0.9446	0.9533	0.9597	0.9645	0.9683	0.9713	0.9854	0.9901	0.9925	0.9940	0.9962
0.6	0.2	0.9974	0.9980	0.9984	0.9987	0.9989	0.9990	0.9991	0.9992	0.9996	0.9997	0.9998	0.9998	0.9999
	0.4	0.9949	0.9961	0.9969	0.9974	0.9978	0.9981	0.9983	0.9985	0.9992	0.9995	0.9996	0.9997	0.9998
	0.6	0.9924	0.9943	0.9954	0.9962	0.9967	0.9971	0.9975	0.9977	0.9989	0.9992	0.9994	0.9995	0.9997
	0.8	0.9900	0.9925	0.9940	0.9950	0.9957	0.9962	0.9966	0.9970	0.9985	0.9990	0.9992	0.9994	0.9996
	1.0	0.9876	0.9907	0.9925	0.9937	0.9946	0.9953	0.9958	0.9962	0.9981	0.9987	0.9991	0.9992	0.9995
	1.5	0.9816	0.9861	0.9889	0.9907	0.9920	0.9930	0.9938	0.9944	0.9972	0.9981	0.9986	0.9989	0.9993
	2.0	0.9755	0.9815	0.9852	0.9876	0.9894	0.9907	0.9917	0.9925	0.9962	0.9975	0.9981	0.9985	0.9991
	3.0	0.9631	0.9720	0.9775	0.9811	0.9838	0.9858	0.9873	0.9886	0.9943	0.9962	0.9971	0.9977	0.9986
	5.0	0.9363	0.9511	0.9603	0.9666	0.9712	0.9746	0.9774	0.9796	0.9896	0.9930	0.9948	0.9958	0.9974
	7.0	0.9072	0.9274	0.9404	0.9494	0.9561	0.9612	0.9652	0.9685	0.9837	0.9890	0.9917	0.9933	0.9957
0.4	0.2	0.9977	0.9983	0.9986	0.9988	0.9990	0.9991	0.9992	0.9993	0.9997	0.9998	0.9998	0.9999	0.9999
	0.4	0.9954	0.9966	0.9972	0.9977	0.9980	0.9983	0.9985	0.9986	0.9993	0.9995	0.9997	0.9997	0.9998
	0.6	0.9932	0.9949	0.9959	0.9966	0.9971	0.9974	0.9977	0.9979	0.9990	0.9993	0.9995	0.9996	0.9997
	0.8	0.9909	0.9932	0.9945	0.9954	0.9961	0.9966	0.9969	0.9972	0.9986	0.9991	0.9993	0.9994	0.9997
	1.0	0.9886	0.9914	0.9931	0.9943	0.9951	0.9957	0.9962	0.9966	0.9983	0.9988	0.9991	0.9993	0.9996
	1.5	0.9828	0.9870	0.9896	0.9913	0.9925	0.9935	0.9942	0.9948	0.9974	0.9982	0.9987	0.9989	0.9993
	2.0	0.9767	0.9824	0.9858	0.9882	0.9898	0.9911	0.9921	0.9928	0.9964	0.9976	0.9982	0.9986	0.9991
	3.0	0.9635	0.9722	0.9776	0.9812	0.9838	0.9858	0.9873	0.9886	0.9942	0.9962	0.9971	0.9977	0.9986
	5.0	0.9325	0.9475	0.9571	0.9637	0.9686	0.9723	0.9752	0.9776	0.9885	0.9923	0.9942	0.9954	0.9971
	7.0	0.8960	0.9168	0.9307	0.9406	0.9480	0.9537	0.9583	0.9621	0.9801	0.9865	0.9898	0.9918	0.9949
0.2	0.2	0.9980	0.9985	0.9988	0.9990	0.9991	0.9992	0.9993	0.9994	0.9997	0.9998	0.9998	0.9999	0.9999
	0.4	0.9960	0.9970	0.9976	0.9980	0.9983	0.9985	0.9986	0.9988	0.9994	0.9996	0.9997	0.9998	0.9998
	0.6	0.9939	0.9954	0.9963	0.9969	0.9974	0.9977	0.9979	0.9981	0.9991	0.9994	0.9995	0.9996	0.9998
	0.8	0.9917	0.9938	0.9950	0.9958	0.9964	0.9969	0.9972	0.9975	0.9987	0.9992	0.9994	0.9995	0.9997
	1.0	0.9895	0.9921	0.9937	0.9947	0.9955	0.9960	0.9965	0.9968	0.9984	0.9989	0.9992	0.9994	0.9996
	1.5	0.9837	0.9877	0.9901	0.9917	0.9929	0.9938	0.9945	0.9950	0.9975	0.9983	0.9987	0.9990	0.9994
	2.0	0.9773	0.9828	0.9862	0.9884	0.9900	0.9913	0.9922	0.9930	0.9965	0.9976	0.9982	0.9986	0.9991
	3.0	0.9627	0.9714	0.9769	0.9806	0.9832	0.9853	0.9869	0.9881	0.9940	0.9960	0.9970	0.9976	0.9985
	5.0	0.9252	0.9410	0.9513	0.9585	0.9639	0.9680	0.9713	0.9740	0.9866	0.9909	0.9932	0.9945	0.9966
	7.0	0.8792	0.9008	0.9157	0.9267	0.9351	0.9418	0.9473	0.9518	0.9740	0.9822	0.9864	0.9891	0.9931
0.0	0.2	0.9983	0.9987	0.9990	0.9991	0.9993	0.9994	0.9994	0.9995	0.9997	0.9998	0.9999	0.9999	0.9999
	0.4	0.9965	0.9973	0.9979	0.9982	0.9985	0.9987	0.9988	0.9989	0.9995	0.9996	0.9997	0.9998	0.9999
	0.6	0.9945	0.9959	0.9967	0.9972	0.9976	0.9979	0.9982	0.9983	0.9992	0.9994	0.9996	0.9997	0.9998
	0.8	0.9925	0.9943	0.9954	0.9962	0.9967	0.9971	0.9975	0.9977	0.9989	0.9992	0.9994	0.9995	0.9997
	1.0	0.9903	0.9927	0.9941	0.9951	0.9958	0.9963	0.9967	0.9970	0.9985	0.9990	0.9993	0.9994	0.9996
	1.5	0.9843	0.9881	0.9904	0.9920	0.9931	0.9940	0.9946	0.9952	0.9976	0.9984	0.9988	0.9990	0.9994
	2.0	0.9774	0.9828	0.9861	0.9884	0.9900	0.9912	0.9922	0.9930	0.9964	0.9976	0.9982	0.9986	0.9991
	3.0	0.9607	0.9697	0.9754	0.9793	0.9821	0.9842	0.9859	0.9873	0.9935	0.9957	0.9968	0.9974	0.9984
	5.0	0.9151	0.9320	0.9432	0.9513	0.9573	0.9620	0.9658	0.9689	0.9837	0.9889	0.9916	0.9933	0.9958
	7.0	0.8591	0.8810	0.8968	0.9089	0.9183	0.9259	0.9323	0.9376	0.9649	0.9756	0.9813	0.9848	0.9903

Table C2. End Effect Coefficients for 2-pass Arrangement														
R	**NTU**	**Number of Plates**												
	max	**32**	**40**	**52**	**60**	**72**	**80**	**92**	**100**	**200**	**300**	**400**	**500**	**800**
1.0	**0.2**	0.9982	0.9985	0.9988	0.9990	0.9992	0.9992	0.9993	0.9994	0.9997	0.9998	0.9998	0.9999	0.9999
	0.4	0.9956	0.9964	0.9972	0.9976	0.9980	0.9982	0.9984	0.9986	0.9993	0.9995	0.9996	0.9997	0.9998
	0.6	0.9924	0.9939	0.9953	0.9959	0.9966	0.9969	0.9973	0.9975	0.9987	0.9992	0.9994	0.9995	0.9997
	0.8	0.9886	0.9908	0.9929	0.9938	0.9949	0.9954	0.9960	0.9963	0.9981	0.9988	0.9991	0.9993	0.9995
	1.0	0.9843	0.9874	0.9902	0.9915	0.9929	0.9936	0.9944	0.9949	0.9974	0.9983	0.9987	0.9990	0.9994
	1.5	0.9717	0.9773	0.9824	0.9847	0.9872	0.9885	0.9900	0.9908	0.9954	0.9969	0.9977	0.9981	0.9988
	2.0	0.9571	0.9654	0.9732	0.9767	0.9805	0.9825	0.9847	0.9859	0.9929	0.9953	0.9965	0.9972	0.9982
	3.0	0.9239	0.9384	0.9521	0.9583	0.9651	0.9685	0.9725	0.9747	0.9872	0.9914	0.9936	0.9949	0.9968
	5.0	0.8520	0.8787	0.9045	0.9164	0.9295	0.9362	0.9442	0.9485	0.9737	0.9823	0.9867	0.9893	0.9933
	7.0	0.7815	0.8184	0.8551	0.8723	0.8916	0.9016	0.9135	0.9199	0.9585	0.9720	0.9789	0.9830	0.9893
0.8	**0.2**	0.9984	0.9987	0.9990	0.9991	0.9993	0.9993	0.9994	0.9995	0.9997	0.9998	0.9999	0.9999	0.9999
	0.4	0.9962	0.9969	0.9976	0.9979	0.9983	0.9984	0.9986	0.9987	0.9994	0.9996	0.9997	0.9997	0.9998
	0.6	0.9934	0.9947	0.9959	0.9964	0.9970	0.9973	0.9977	0.9978	0.9989	0.9993	0.9995	0.9996	0.9997
	0.8	0.9902	0.9921	0.9939	0.9947	0.9956	0.9960	0.9965	0.9968	0.9984	0.9989	0.9992	0.9994	0.9996
	1.0	0.9866	0.9892	0.9917	0.9927	0.9939	0.9945	0.9952	0.9956	0.9978	0.9985	0.9989	0.9991	0.9994
	1.5	0.9759	0.9806	0.9850	0.9869	0.9891	0.9902	0.9914	0.9921	0.9960	0.9974	0.9980	0.9984	0.9990
	2.0	0.9632	0.9704	0.9771	0.9801	0.9834	0.9850	0.9869	0.9880	0.9940	0.9960	0.9970	0.9976	0.9985
	3.0	0.9340	0.9467	0.9586	0.9639	0.9698	0.9727	0.9762	0.9781	0.9889	0.9926	0.9944	0.9955	0.9972
	5.0	0.8674	0.8913	0.9144	0.9250	0.9367	0.9426	0.9497	0.9535	0.9759	0.9835	0.9874	0.9898	0.9933
	7.0	0.7975	0.8312	0.8647	0.8803	0.8979	0.9069	0.9177	0.9236	0.9587	0.9710	0.9772	0.9810	0.9867
0.6	**0.2**	0.9986	0.9989	0.9991	0.9992	0.9994	0.9994	0.9995	0.9995	0.9998	0.9998	0.9999	0.9999	0.9999
	0.4	0.9968	0.9974	0.9980	0.9982	0.9985	0.9987	0.9988	0.9989	0.9995	0.9996	0.9997	0.9998	0.9999
	0.6	0.9945	0.9956	0.9966	0.9970	0.9975	0.9977	0.9980	0.9982	0.9991	0.9994	0.9995	0.9996	0.9998
	0.8	0.9919	0.9934	0.9949	0.9956	0.9963	0.9967	0.9971	0.9973	0.9987	0.9991	0.9993	0.9995	0.9997
	1.0	0.9889	0.9910	0.9931	0.9940	0.9950	0.9955	0.9961	0.9964	0.9982	0.9988	0.9991	0.9993	0.9995
	1.5	0.9800	0.9839	0.9876	0.9892	0.9910	0.9919	0.9929	0.9935	0.9967	0.9978	0.9984	0.9987	0.9992
	2.0	0.9695	0.9754	0.9810	0.9835	0.9862	0.9875	0.9892	0.9900	0.9950	0.9966	0.9975	0.9980	0.9987
	3.0	0.9440	0.9548	0.9649	0.9694	0.9744	0.9769	0.9798	0.9814	0.9906	0.9937	0.9952	0.9962	0.9976
	5.0	0.8797	0.9011	0.9218	0.9313	0.9418	0.9472	0.9536	0.9570	0.9772	0.9842	0.9877	0.9898	0.9930
	7.0	0.8030	0.8338	0.8648	0.8795	0.8961	0.9047	0.9151	0.9207	0.9550	0.9672	0.9734	0.9772	0.9830
0.4	**0.2**	0.9988	0.9990	0.9993	0.9994	0.9995	0.9995	0.9996	0.9996	0.9998	0.9999	0.9999	0.9999	1.0000
	0.4	0.9973	0.9978	0.9983	0.9985	0.9988	0.9989	0.9990	0.9991	0.9996	0.9997	0.9998	0.9998	0.9999
	0.6	0.9956	0.9964	0.9972	0.9976	0.9980	0.9982	0.9984	0.9985	0.9993	0.9995	0.9996	0.9997	0.9998
	0.8	0.9935	0.9948	0.9959	0.9965	0.9971	0.9973	0.9977	0.9979	0.9989	0.9993	0.9995	0.9996	0.9997
	1.0	0.9912	0.9929	0.9945	0.9952	0.9960	0.9964	0.9969	0.9971	0.9985	0.9990	0.9993	0.9994	0.9996
	1.5	0.9844	0.9874	0.9903	0.9915	0.9929	0.9936	0.9944	0.9949	0.9974	0.9983	0.9987	0.9990	0.9994
	2.0	0.9761	0.9807	0.9851	0.9870	0.9891	0.9902	0.9915	0.9921	0.9961	0.9974	0.9980	0.9984	0.9990
	3.0	0.9550	0.9636	0.9717	0.9754	0.9794	0.9814	0.9838	0.9850	0.9924	0.9949	0.9962	0.9969	0.9981
	5.0	0.8938	0.9125	0.9306	0.9390	0.9483	0.9531	0.9588	0.9618	0.9799	0.9862	0.9894	0.9913	0.9942
	7.0	0.8072	0.8355	0.8647	0.8788	0.8950	0.9034	0.9138	0.9195	0.9549	0.9679	0.9746	0.9788	0.9851
0.2	**0.2**	0.9990	0.9992	0.9994	0.9995	0.9996	0.9996	0.9997	0.9997	0.9998	0.9999	0.9999	0.9999	1.0000
	0.4	0.9979	0.9983	0.9987	0.9989	0.9990	0.9991	0.9992	0.9993	0.9996	0.9998	0.9998	0.9999	0.9999
	0.6	0.9966	0.9973	0.9979	0.9982	0.9985	0.9986	0.9988	0.9989	0.9994	0.9996	0.9997	0.9998	0.9999
	0.8	0.9952	0.9961	0.9970	0.9974	0.9978	0.9980	0.9983	0.9984	0.9992	0.9995	0.9996	0.9997	0.9998
	1.0	0.9936	0.9948	0.9960	0.9965	0.9971	0.9974	0.9977	0.9979	0.9989	0.9993	0.9995	0.9996	0.9997
	1.5	0.9890	0.9911	0.9931	0.9940	0.9950	0.9955	0.9960	0.9963	0.9982	0.9988	0.9991	0.9993	0.9995
	2.0	0.9833	0.9865	0.9895	0.9909	0.9924	0.9931	0.9940	0.9945	0.9972	0.9981	0.9986	0.9989	0.9993
	3.0	0.9684	0.9744	0.9801	0.9826	0.9854	0.9869	0.9885	0.9894	0.9947	0.9964	0.9973	0.9979	0.9987
	5.0	0.9172	0.9317	0.9459	0.9525	0.9598	0.9635	0.9680	0.9704	0.9847	0.9897	0.9922	0.9937	0.9960
	7.0	0.8262	0.8504	0.8759	0.8884	0.9030	0.9107	0.9202	0.9255	0.9589	0.9716	0.9782	0.9823	0.9886
0.0	**0.2**	0.9993	0.9994	0.9995	0.9996	0.9997	0.9997	0.9997	0.9997	0.9999	0.9999	0.9999	0.9999	1.0000
	0.4	0.9985	0.9988	0.9990	0.9992	0.9993	0.9994	0.9994	0.9995	0.9997	0.9998	0.9999	0.9999	0.9999
	0.6	0.9977	0.9981	0.9985	0.9987	0.9989	0.9990	0.9992	0.9992	0.9996	0.9997	0.9998	0.9998	0.9999
	0.8	0.9969	0.9975	0.9980	0.9983	0.9986	0.9987	0.9989	0.9989	0.9995	0.9996	0.9997	0.9998	0.9999
	1.0	0.9961	0.9968	0.9975	0.9978	0.9982	0.9983	0.9985	0.9987	0.9993	0.9995	0.9997	0.9997	0.9998
	1.5	0.9939	0.9950	0.9961	0.9966	0.9971	0.9974	0.9977	0.9979	0.9989	0.9993	0.9995	0.9996	0.9997
	2.0	0.9915	0.9931	0.9946	0.9952	0.9960	0.9964	0.9968	0.9971	0.9985	0.9990	0.9993	0.9994	0.9996
	3.0	0.9864	0.9888	0.9911	0.9922	0.9934	0.9941	0.9948	0.9952	0.9975	0.9984	0.9988	0.9990	0.9994
	5.0	0.9734	0.9778	0.9822	0.9843	0.9867	0.9879	0.9894	0.9901	0.9949	0.9966	0.9974	0.9979	0.9987
	7.0	0.9537	0.9607	0.9681	0.9716	0.9757	0.9778	0.9803	0.9817	0.9904	0.9935	0.9951	0.9960	0.9975

Table C3. End Effect Coefficients for 3-pass Arrangement														
R	NTU max	Number of Plates												
		30	42	48	60	72	78	90	102	198	300	402	498	798
1.0	0.2	0.9986	0.9990	0.9991	0.9993	0.9994	0.9994	0.9995	0.9995	0.9997	0.9998	0.9999	0.9999	0.9999
	0.4	0.9967	0.9976	0.9978	0.9983	0.9985	0.9987	0.9988	0.9990	0.9995	0.9997	0.9997	0.9998	0.9999
	0.6	0.9941	0.9958	0.9963	0.9970	0.9976	0.9978	0.9981	0.9983	0.9992	0.9995	0.9997	0.9998	0.9998
	0.8	0.9910	0.9936	0.9944	0.9956	0.9964	0.9967	0.9972	0.9975	0.9989	0.9995	0.9997	0.9998	0.9998
	1.0	0.9874	0.9910	0.9922	0.9939	0.9950	0.9954	0.9961	0.9966	0.9986	0.9993	0.9997	0.9997	0.9997
	1.5	0.9761	0.9831	0.9853	0.9884	0.9906	0.9914	0.9927	0.9937	0.9974	0.9988	0.9995	0.9995	0.9995
	2.0	0.9622	0.9731	0.9766	0.9816	0.9849	0.9862	0.9883	0.9899	0.9957	0.9979	0.9989	0.9990	0.9991
	3.0	0.9285	0.9487	0.9551	0.9643	0.9705	0.9730	0.9769	0.9798	0.9909	0.9949	0.9969	0.9981	0.9984
	5.0	0.8508	0.8900	0.9029	0.9216	0.9344	0.9394	0.9475	0.9538	0.9773	0.9861	0.9905	0.9929	0.9959
	7.0	0.7727	0.8280	0.8468	0.8743	0.8936	0.9012	0.9136	0.9234	0.9603	0.9744	0.9814	0.9855	0.9919
0.8	0.2	0.9988	0.9991	0.9992	0.9994	0.9994	0.9995	0.9995	0.9996	0.9998	0.9998	0.9999	0.9999	0.9999
	0.4	0.9971	0.9979	0.9981	0.9985	0.9987	0.9988	0.9989	0.9991	0.9995	0.9997	0.9997	0.9998	0.9998
	0.6	0.9949	0.9963	0.9967	0.9974	0.9978	0.9980	0.9982	0.9985	0.9992	0.9995	0.9996	0.9997	0.9998
	0.8	0.9922	0.9944	0.9951	0.9961	0.9967	0.9970	0.9974	0.9977	0.9989	0.9993	0.9996	0.9997	0.9998
	1.0	0.9891	0.9922	0.9932	0.9945	0.9955	0.9958	0.9964	0.9969	0.9985	0.9991	0.9994	0.9996	0.9997
	1.5	0.9794	0.9852	0.9871	0.9897	0.9915	0.9922	0.9933	0.9941	0.9972	0.9984	0.9989	0.9992	0.9993
	2.0	0.9672	0.9764	0.9793	0.9834	0.9862	0.9873	0.9891	0.9904	0.9953	0.9971	0.9980	0.9985	0.9989
	3.0	0.9371	0.9542	0.9596	0.9674	0.9726	0.9747	0.9779	0.9804	0.9897	0.9931	0.9948	0.9957	0.9972
	5.0	0.8644	0.8982	0.9093	0.9252	0.9361	0.9403	0.9472	0.9525	0.9723	0.9797	0.9833	0.9854	0.9887
	7.0	0.7881	0.8363	0.8525	0.8761	0.8925	0.8990	0.9096	0.9178	0.9489	0.9607	0.9665	0.9699	0.9752
0.6	0.2	0.9990	0.9992	0.9993	0.9994	0.9995	0.9996	0.9996	0.9996	0.9998	0.9999	0.9999	0.9999	0.9999
	0.4	0.9975	0.9982	0.9984	0.9987	0.9989	0.9990	0.9991	0.9992	0.9995	0.9997	0.9997	0.9998	0.9998
	0.6	0.9957	0.9969	0.9972	0.9977	0.9981	0.9982	0.9985	0.9986	0.9993	0.9995	0.9996	0.9997	0.9998
	0.8	0.9935	0.9953	0.9958	0.9966	0.9972	0.9974	0.9977	0.9980	0.9990	0.9993	0.9995	0.9996	0.9997
	1.0	0.9910	0.9934	0.9942	0.9953	0.9961	0.9964	0.9969	0.9972	0.9986	0.9991	0.9993	0.9994	0.9997
	1.5	0.9830	0.9876	0.9891	0.9912	0.9926	0.9932	0.9941	0.9948	0.9973	0.9982	0.9986	0.9989	0.9993
	2.0	0.9728	0.9802	0.9825	0.9858	0.9881	0.9889	0.9903	0.9914	0.9954	0.9968	0.9975	0.9979	0.9986
	3.0	0.9468	0.9607	0.9651	0.9714	0.9756	0.9773	0.9799	0.9819	0.9894	0.9921	0.9935	0.9943	0.9955
	5.0	0.8788	0.9070	0.9162	0.9294	0.9384	0.9419	0.9475	0.9519	0.9682	0.9742	0.9772	0.9789	0.9816
	7.0	0.8013	0.8418	0.8553	0.8751	0.8887	0.8941	0.9029	0.9097	0.9354	0.9451	0.9500	0.9527	0.9571
0.4	0.2	0.9992	0.9994	0.9994	0.9995	0.9996	0.9996	0.9997	0.9997	0.9998	0.9999	0.9999	0.9999	0.9999
	0.4	0.9980	0.9985	0.9987	0.9989	0.9991	0.9991	0.9992	0.9993	0.9996	0.9997	0.9998	0.9998	0.9999
	0.6	0.9966	0.9975	0.9978	0.9982	0.9985	0.9986	0.9987	0.9989	0.9994	0.9996	0.9996	0.9997	0.9998
	0.8	0.9949	0.9963	0.9967	0.9973	0.9977	0.9979	0.9981	0.9983	0.9991	0.9994	0.9995	0.9996	0.9997
	1.0	0.9930	0.9948	0.9954	0.9963	0.9969	0.9971	0.9975	0.9977	0.9988	0.9991	0.9993	0.9994	0.9996
	1.5	0.9870	0.9904	0.9915	0.9931	0.9942	0.9946	0.9953	0.9958	0.9977	0.9984	0.9987	0.9989	0.9992
	2.0	0.9793	0.9847	0.9865	0.9890	0.9906	0.9913	0.9923	0.9931	0.9961	0.9972	0.9977	0.9980	0.9985
	3.0	0.9589	0.9694	0.9727	0.9774	0.9806	0.9819	0.9839	0.9854	0.9911	0.9931	0.9942	0.9947	0.9957
	5.0	0.9005	0.9230	0.9303	0.9408	0.9480	0.9508	0.9553	0.9588	0.9717	0.9764	0.9788	0.9801	0.9823
	7.0	0.8257	0.8597	0.8711	0.8877	0.8993	0.9038	0.9112	0.9170	0.9388	0.9471	0.9512	0.9536	0.9573
0.2	0.2	0.9993	0.9995	0.9996	0.9996	0.9997	0.9997	0.9997	0.9998	0.9999	0.9999	0.9999	0.9999	1.0000
	0.4	0.9985	0.9989	0.9990	0.9992	0.9993	0.9994	0.9994	0.9995	0.9997	0.9998	0.9998	0.9999	0.9999
	0.6	0.9975	0.9982	0.9984	0.9987	0.9989	0.9989	0.9991	0.9992	0.9995	0.9997	0.9997	0.9998	0.9998
	0.8	0.9964	0.9973	0.9976	0.9981	0.9984	0.9985	0.9987	0.9988	0.9993	0.9995	0.9996	0.9997	0.9998
	1.0	0.9952	0.9964	0.9968	0.9974	0.9978	0.9980	0.9982	0.9984	0.9991	0.9994	0.9995	0.9996	0.9997
	1.5	0.9914	0.9936	0.9944	0.9954	0.9961	0.9964	0.9968	0.9972	0.9984	0.9989	0.9991	0.9992	0.9994
	2.0	0.9867	0.9901	0.9913	0.9929	0.9939	0.9944	0.9950	0.9956	0.9975	0.9982	0.9985	0.9987	0.9991
	3.0	0.9742	0.9808	0.9829	0.9859	0.9880	0.9888	0.9901	0.9911	0.9947	0.9961	0.9967	0.9971	0.9977
	5.0	0.9353	0.9509	0.9560	0.9633	0.9682	0.9701	0.9733	0.9757	0.9846	0.9879	0.9896	0.9905	0.9920
	7.0	0.8767	0.9038	0.9128	0.9261	0.9353	0.9390	0.9449	0.9496	0.9672	0.9739	0.9773	0.9792	0.9823
0.0	0.2	0.9995	0.9996	0.9997	0.9997	0.9998	0.9998	0.9998	0.9998	0.9999	0.9999	1.0000	1.0000	1.0000
	0.4	0.9990	0.9993	0.9993	0.9995	0.9995	0.9996	0.9996	0.9997	0.9998	0.9999	0.9999	0.9999	1.0000
	0.6	0.9985	0.9989	0.9990	0.9992	0.9993	0.9994	0.9994	0.9995	0.9997	0.9998	0.9999	0.9999	0.9999
	0.8	0.9980	0.9985	0.9987	0.9989	0.9991	0.9991	0.9993	0.9993	0.9996	0.9998	0.9998	0.9999	0.9999
	1.0	0.9975	0.9981	0.9983	0.9986	0.9988	0.9989	0.9991	0.9992	0.9996	0.9997	0.9998	0.9998	0.9999
	1.5	0.9961	0.9971	0.9974	0.9979	0.9982	0.9983	0.9985	0.9987	0.9993	0.9995	0.9997	0.9997	0.9998
	2.0	0.9947	0.9960	0.9964	0.9971	0.9975	0.9977	0.9980	0.9982	0.9991	0.9994	0.9995	0.9996	0.9998
	3.0	0.9918	0.9937	0.9944	0.9954	0.9961	0.9963	0.9968	0.9972	0.9985	0.9990	0.9992	0.9994	0.9996
	5.0	0.9849	0.9883	0.9895	0.9913	0.9926	0.9931	0.9939	0.9946	0.9971	0.9981	0.9985	0.9988	0.9993
	7.0	0.9761	0.9813	0.9831	0.9859	0.9880	0.9888	0.9901	0.9911	0.9952	0.9968	0.9976	0.9980	0.9988

Note: The tables were created with the method described in: "Multipass Plate Heat Exchangers - Effectiveness-NTU Results and Guidelines for Selecting Pass Arrangements", Journal of Heat Transfer, May 1989, Vol. 111, pp. 300-313. by Kandlikar, S. G. and Shah, R. K.