



**BSR/ASHRAE Standard 24-2019R**

**Public Review Draft**

# **Methods of Testing for Rating Evaporators Used for Cooling Liquids**

**First Public Review (April 2025)  
(Complete Draft for Full Review)**

This draft has been recommended for public review by the responsible project committee. To submit a comment on this proposed standard, go to the ASHRAE website at [www.ashrae.org/standards-research-technology/public-review-drafts](http://www.ashrae.org/standards-research-technology/public-review-drafts) and access the online comment database. The draft is subject to modification until it is approved for publication by the Board of Directors and ANSI. Until this time, the current edition of the standard (as modified by any published addenda on the ASHRAE website) remains in effect. The current edition of any standard may be purchased from the ASHRAE Online Store at [www.ashrae.org/bookstore](http://www.ashrae.org/bookstore) or by calling 404-636-8400 or 1-800-727-4723 (for orders in the U.S. or Canada).

The appearance of any technical data or editorial material in this public review document does not constitute endorsement, warranty, or guaranty by ASHRAE of any product, service, process, procedure, or design, and ASHARE expressly disclaims such.

© 2025 ASHRAE. This draft is covered under ASHRAE copyright. Permission to reproduce or redistribute all or any part of this document must be obtained from the ASHRAE Manager of Standards, 180 Technology Parkway, Peachtree Corners, GA 30092. Phone: 404-636-8400, Ext. 1125. Fax: 404-321-5478. E-mail: [standards.section@ashrae.org](mailto:standards.section@ashrae.org).

**ASHRAE, 180 Technology Parkway, Peachtree Corners, GA 30092**

**(This foreword is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)**

## FOREWORD

*This is a revision of ANSI/ASHRAE Standard 24-2019. This standard was prepared under the auspices of ASHRAE. It may be used, in whole or in part, by an association or government agency with due credit to ASHRAE. Adherence is strictly on a voluntary basis with the goal of having uniform standards throughout the industry.*

*The following changes were made for the 2025 revision:*

- *References were updated.*
- *Minor editorial changes were made.*

*This standard includes an Excel workbook to assist with uncertainty calculations (Appendix A). Download the workbook at ASHRAE website at [https://www.ashrae.org/24\\_2022](https://www.ashrae.org/24_2022).*

## 1. PURPOSE

This standard prescribes methods of testing the thermal performance and liquid-side pressure drop of evaporators that operate at subcritical pressures of the evaporating refrigerant.

## 2. SCOPE

This standard

- a. lists and defines the terms for rating the thermal performance and liquid-side pressure drop of evaporators used for cooling liquids;
- b. establishes the methods of test that shall be used as a basis for obtaining the thermal performance and pressure drop of evaporators that operate at subcritical pressures of the evaporating refrigerant; and
- c. applies to laboratory testing for purposes of rating evaporators within its scope. This standard is not intended for field testing of evaporators of any type.

## 3. DEFINITIONS

**evaporator:** a factory-made assembly of elements in which the heat is transferred from the liquid to the refrigerant, causing the refrigerant to evaporate and the liquid to be cooled.

**liquid:** a nearly incompressible fluid that conforms to the shape of its container but retains a nearly constant volume independent of pressure. For the purposes of this standard, operating temperatures shall be limited to being greater than the fluid's freezing/melting temperature and less than 70% of the fluid's critical temperature on an absolute temperature scale, and operating pressures shall be limited to being greater than 150% of the fluid's bubble temperature and less than 30% of the fluid's critical pressure absolute.

**net refrigeration capacity:** that portion of the total refrigeration capacity of an evaporator that produces useful cooling. This is the product of the mass flow rate of liquid and the differences in enthalpy between entering and leaving liquid expressed in energy units per unit of time. It is represented also by the total refrigeration capacity less the heat leakage rate.

**pressure drop of flowing fluids:** the difference in total pressure between two points along a flow stream.

**superheat:** the difference between the measured refrigerant temperature leaving the evaporator and the dew-point temperature of the refrigerant corresponding to the pressure of the refrigerant leaving the evaporator.

**temperature of flowing fluids:** the mixed mean stream temperature at a station perpendicular to the flow direction.

**total refrigeration capacity (of the evaporator):** the product of the mass flow rate of refrigerant and the difference in enthalpy between the leaving and entering refrigerant, expressed in energy units per unit of time.

**uncertainty:** an estimated value for the error in a measurement, which may be the result of both systematic and random error.

## 4. REQUIRED TEST RESULTS

4.1 Test results shall be expressed in the following terms:

- a. Net refrigeration capacity, kW (Btu/h)

- b. Temperature of the entering liquid, °C (°F)
- c. Temperature of leaving liquid, °C (°F)
- d. Liquid mass flow rate, kg/s (lb/h)
- e. Description of both fluid streams sufficient to obtain necessary physical properties
- f. Pressure of the liquid stream as it enters the heat exchanger, kPa (psi)
- g. Pressure drop of the liquid stream, kPa (psi)
- h. Saturation temperature of refrigerant leaving the evaporator, °C (°F)
- i. Superheat of refrigerant leaving the evaporator, °C (°F)
- j. Temperature of refrigerant entering expansion device, °C (°F)
- k. Refrigerant designation

4.2 For all measured or calculated parameters listed in Section 5.1, uncertainty shall be calculated as described in Section 7.4.

## 5. TEST METHODS

### 5.1 Standard Test Methods

5.1.1 Tests shall consist of a primary test and a simultaneous confirming test at the conditions specified. The primary and confirming measurements shall be completely independent.

5.1.2 The specified conditions shall include the following:

- a. Either the net refrigeration capacity, kW (Btu/h), or the saturation temperature, °C (°F), of the refrigerant leaving the evaporator
- b. Temperature of leaving liquid, °C (°F)
- c. Liquid flow rate, kg/s (lb/h)
- d. Superheat of leaving refrigerant, °C (°F)
- e. Temperature of refrigerant entering expansion device, °C (°F)
- f. Liquid being cooled by the evaporator
- g. Refrigerant used
- h. Maximum allowable uncertainty for the reported net refrigeration capacity
- i. Maximum allowable uncertainty for the reported saturation temperature leaving the evaporator
- j. Maximum allowable uncertainty for the reported liquid pressure drop
- k. Arrangement of refrigerant and liquid connections

5.1.3 For refrigerants covered by ANSI/ASHRAE Standard 34<sup>1</sup>, the designation of the refrigerant given in ANSI/ASHRAE Standard 34 shall be specified in Section 5.1.2(g). For refrigerants not covered by ANSI/ASHRAE Standard 34, the chemical composition of the refrigerant must be specified.

5.1.4 The resulting net refrigeration capacity of the confirming test (Section 5.3) shall be within  $\pm 3.0\%$  of the primary test, but the primary test shall govern for rating purposes.

## 5.2 Primary Test Method

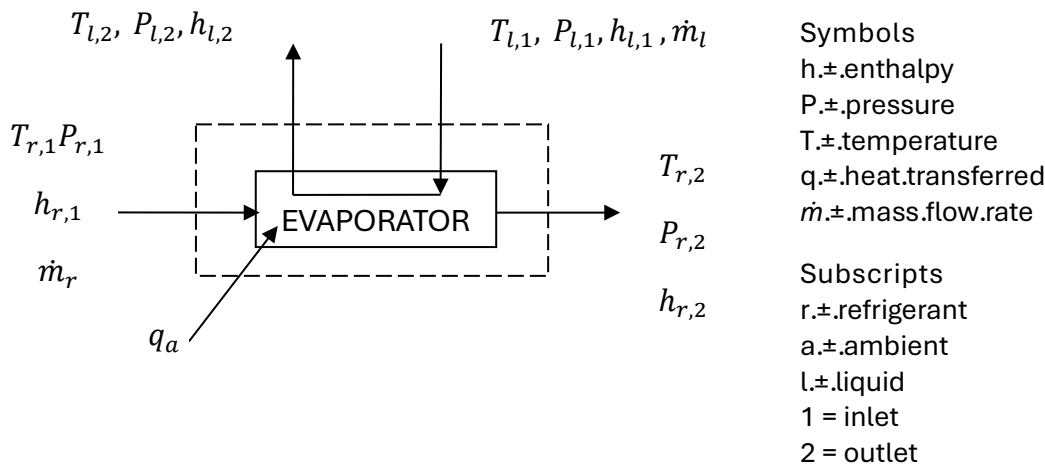


Figure 5.2.1 Primary Test Method.

**5.2.1** The primary test shall consist of a measurement of the net refrigeration capacity produced in the evaporator by measurement of the energy removed from the liquid.

**5.2.2** The net refrigeration capacity is the product of the liquid mass flow rate and the enthalpy difference of the leaving and entering liquid.

**5.2.3** Determine the liquid mass flow rate by direct mass or volume measurement, or by liquid flowmeter.

**5.2.4** Heat transfer rate between the ambient air through the external surfaces of the evaporator is the product of external surface area, the mean temperature difference between the evaporator and the ambient air, and the calculated overall heat transfer coefficient.

Determine the calculated overall heat transfer coefficient from the thermal resistance of the insulation and an ambient air film coefficient of  $10 \text{ W}/(\text{m}^2 \cdot ^\circ\text{C})$  ( $2 \text{ Btu}/[\text{h} \cdot \text{ft}^2 \cdot ^\circ\text{F}]$ ) for natural convection.

**5.2.5** The heat transfer rate between the ambient air and the evaporator shall not exceed 1.0% of the net refrigeration capacity.

**5.2.6** There shall be no visible external sweating of the evaporator or insulated covering.

**5.3 Confirming Test Method.** The confirming test shall consist of a secondary measurement of the net refrigeration capacity produced in the evaporator, using the product of the refrigerant mass flow rate and the enthalpy difference between entering and leaving refrigerant. This is the total refrigeration capacity.

## 6. INSTRUMENTS, TEST APPARATUS, AND PHYSICAL PROPERTIES

### 6.1 General

**6.1.1** Instruments and data acquisition systems shall be selected to satisfy both of the following requirements:

- a. The uncertainty requirements listed in Section 5.1.2
- b. The error limits specified in the paragraphs below

**Informative Note:** Error limits more stringent than those listed in the sections below may be required to meet the condition in Section 6.1.1(a).

**6.1.2** Instrument calibration shall be traceable to primary or secondary standards calibrated by the National Institute of Standards and Technology (NIST). The indicated corrections shall be applied to meet the required error limits given in subsequent paragraphs. 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 specified error limits.

**6.1.3** The source from which refrigerant and liquid thermodynamic properties are obtained shall be stated in the test report.

**Informative Note:** The preferred source is the latest version of NIST Standard Reference Database 23: Reference Fluid Thermodynamic and Transport Properties (REFPROP)<sup>2</sup> available at the time of test. Other sources include the publications distributed by refrigerant and liquid manufacturers.

## 6.2 Temperature Measurement

6.2.1 The minimum accuracy shall be within the following limits:

- a. Liquid entering and leaving the evaporator and any liquid temperatures used for indirect refrigerant mass flow rate measurement (when indirect refrigerant mass flow rate measurement is used for confirming tests):  $\pm 0.1$  K ( $\pm 0.2$  °R)
- b. All other temperatures:  $\pm 0.3$ °C ( $\pm 0.5$ °F)

6.2.2 Select, apply, and calibrate instruments in accordance with ASHRAE Standard 41.1<sup>3</sup>, noting the accuracy requirement of the measurement.

## 6.3 Pressure Measurement

6.3.1 All pressure-measuring instruments shall have a minimum accuracy within the limits of 1% of the absolute pressure readings or differential pressure readings.

6.3.2 Select, apply, and calibrate instruments in accordance with ASHRAE Standard 41.3<sup>4</sup>, noting the accuracy requirement of the measurement.

6.3.3 Measurement method for the pressure drop of the liquid being cooled, including liquid stream inlet and outlet pressure, shall follow ASHRAE Standard 30<sup>5</sup>. This includes measurement location, pressure taps, and methods for static pressure correction that account for the presence of external piping between the connections included with the primary construction of the evaporator and pressure measurement locations.

**6.4 Refrigerant Flow Measurement.** Refrigerant flow measurements shall be made using either direct flow or indirect flow methods.

6.4.1 Direct flow measurements shall be made with one or more of the following instruments:

- a. Liquid refrigerant mass rate meter
- b. Liquid refrigerant volume rate meter
- c. Gaseous refrigerant flowmeter

6.4.2 Instruments for direct flow measurement in Section 6.4.1 shall be selected, applied, and calibrated in accordance with ASHRAE Standard 41.10<sup>6</sup>, noting the accuracy requirement for the measurement.

6.4.3 Indirect flow measurements shall be made per ASHRAE Standard 41.9<sup>7</sup>, Section 10.

6.4.4 The minimum accuracy shall be within  $\pm 1\%$  of the range of flows measured.

## 6.5 Liquid Flow Rate Measurement

6.5.1 Flow measurements shall be made with one or more of the following instruments or apparatus:

- a. Liquid flowmeter in accordance with ASHRAE Standard 41.8<sup>8</sup>
- b. Weight tank, scale, and timer

6.5.2 The minimum accuracy of flow rate measurements shall be within  $\pm 1\%$  of the range of flow rate measured.

**6.6 Time Measurements.** Time measurements shall be made with an apparatus whose minimum accuracy is within  $\pm 0.1\%$  of the elapsed time.

**6.7 Weight Measurements.** Weight measurements shall be made with an apparatus whose minimum accuracy is within  $\pm 0.5\%$  of the quantity measured.

## 7. TEST PROCEDURE

### 7.1 General

7.1.1 The evaporator, the selected instruments, and test apparatus shall be assembled, connected, functionally tested, leak tested, dehydrated, evacuated, and charged with the amount of refrigerant necessary to obtain the conditions specified in Section 5.1.2. If necessary, refrigerant subcoolers, superheaters, or heat exchangers shall be used to ensure accuracy of measurements and to obtain specified conditions. If designed and included as a specific part of the evaporator assembly, any such superheater, subcooler, or heat exchanger shall be considered a part of the evaporator.

7.1.2 Gases shall be purged from the liquid being cooled. Open liquid loops shall be designed to prevent air entrainment in the liquid.

7.1.3 The liquid being cooled must be kept in the liquid state as it passes through the evaporator at all times during the test.

### 7.2 Operation and Limits

**7.2.1** Start the system and obtain and maintain the specified conditions. After establishment of steady-state conditions, the following conditions shall be met:

- a. The test shall be conducted for a minimum of 30 minutes.
- b. A minimum of 30 data points shall be taken.
- c. The stability of all readings must be sufficient to satisfy the uncertainty requirements listed in Section 5.1.2.

**7.2.2** The test record shall include the date, names of the observers, essential identifying physical data of the evaporator tested, refrigerant and liquid used, all test readings, reference to instrument calibrations and computations, and the determined results.

### 7.3 Computation of Results

**7.3.1** From the primary test, calculate the net refrigeration capacity  $q_l$  by using the energy removed from the liquid as shown in Equation 1.

$$q_l = \dot{m}_l (h_{l,1} - h_{l,2}) \quad (1)$$

where

$\dot{m}_l$  = liquid mass flow rate, kg/s (lb/h)

$h_{l,1}$  = enthalpy of liquid entering evaporator, kJ/kg (Btu/lb)

$h_{l,2}$  = enthalpy of liquid leaving evaporator, kJ/kg (Btu/lb)

**7.3.2** From the confirming test, the total refrigeration capacity  $q_r$  is equal to the product of the mass flow rate of refrigerant and the enthalpy difference between the refrigerant entering and leaving the evaporator as shown in Equation 2.

$$q_r = \dot{m}_r (h_{r,2} - h_{r,1}) \quad (2)$$

where

$\dot{m}_r$  = refrigerant mass flow rate, kg/s (lb/h)

$h_{r,2}$  = enthalpy of the refrigerant leaving evaporator, kJ/kg (Btu/lb)

$h_{r,1}$  = enthalpy of the refrigerant entering evaporator, kJ/kg (Btu/lb)

**7.3.3** The dimensionless difference between the results of the primary and confirming tests

$$\Delta q_w = (q_r - q_l) / q_l \quad (3)$$

shall not be greater than  $\pm 0.03$ .

**7.3.4** The heat transferred through the external surfaces to the ambient air shall be determined by

$$q_a = U_s A_s (T_a - T_e) \quad (4)$$

where

$q_a$  = heat transferred through external surfaces, kW (Btu/h)

$$U_s = \frac{1}{(x/k + 1/h_s)} \quad (5)$$

$x/k = 0$  if insulation is not used

$x$  = insulation thickness, m (ft)

$k$  = thermal conductivity of insulation, W/(m·K) (Btu/[h·ft·°F])

$h_s$  = film coefficient of ambient air, W/(m<sup>2</sup>·K) (Btu/[h·ft<sup>2</sup>·°F]); for natural convection, use 10 W/(m<sup>2</sup>·K) (2.0 Btu/[h·ft<sup>2</sup>·°F])

$A_s$  = exposed external surface through which heat is lost, m<sup>2</sup> (ft<sup>2</sup>)

$T_e$  = refrigerant dew-point temperature at evaporator outlet if the refrigerant is in contact with the external surface of the evaporator, or the arithmetic average of the entering and leaving liquid temperatures if the liquid is in contact with the external surface of the evaporator, °C (°F)

$T_a$  = average ambient air temperature, °C (°F)

#### 7.4 Uncertainty Analysis

**7.4.1** As specified in Section 4.2, the uncertainty for all parameters in Section 4.1 shall be specified. Uncertainty calculations (also referred to as error analysis) shall be performed in accordance with ASME PTC 19.1, *Test Uncertainty*<sup>9</sup>. Informative Appendix A provides an example of one method for determining the uncertainty of the parameters in Section 4.1.

**7.4.2** The method used for calculating the uncertainty for each parameter in Section 4.1 shall be reported.

**7.4.3** The uncertainties calculated for the parameters in Section 4.1 shall not exceed the values specified in Section 5.1.2.

**7.4.4** The uncertainties calculated for the parameters in Section 4.1 shall be stated at the 95% confidence interval.

#### 8. REFERENCES

1. ASHRAE. 2022. ANSI/ASHRAE Standard 34, *Designation and Safety Classification of Refrigerants*. Atlanta: ASHRAE.
2. Lemmon, E.W., Bell, I.H., Huber, M.L., McLinden, M.O. NIST Standard Reference Database 23: Reference Fluid Thermodynamic and Transport Properties-REFPROP, Version 10.0, National Institute of Standards and Technology, Standard Reference Data Program, Gaithersburg, 2018. doi: <https://doi.org/10.18434/T4/15025283>. ASHRAE.
2024. ANSI/ASHRAE Standard 41.1, *Standard Methods for Temperature Measurement*. Atlanta: ASHRAE.
4. ASHRAE. 2022. ASHRAE Standard 41.3, *Standard Methods for Pressure Measurement*. Atlanta: ASHRAE.
5. ASHRAE. 2019. ANSI/ASHRAE Standard 30, *Method of Testing Liquid Chillers*. Atlanta: ASHRAE.
6. ASHRAE. 2024. ANSI/ASHRAE Standard 41.10, *Standard Methods for Refrigerant Volumetric or Mass Flow Measurement Using Flowmeters*. Atlanta: ASHRAE.
7. ASHRAE. 2021. ANSI/ASHRAE Standard 41.9, *Standard Methods for Refrigerant Mass Flow Measurements Using Calorimeters*. Atlanta: ASHRAE.
8. ASHRAE. 2023. ANSI/ASHRAE Standard 41.8, *Standard Methods for Liquid Flow Measurement*. Atlanta: ASHRAE.
9. ASME. 2018. PTC 19.1 *Test Uncertainty*. Manhattan. ASME.

**(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)**

## INFORMATIVE APPENDIX A UNCERTAINTY ANALYSIS

### A1. DEFINITIONS

**error:** the difference between the true value of the quantity measured and the observed value. All errors in experimental data can be classified as one of two types: systematic (fixed) errors or random (precision) errors. The terms “accuracy” and “precision” are often used to distinguish between systematic and random errors. A measurement with small systematic errors is said to be unbiased. A measurement with small random errors is said to have high precision. A measurement that is unbiased and precise is said to be accurate. (See *random error* and *systematic error*.)

**fixed error:** see *systematic error*.

**precision error:** see *random error*.

**random error:** an error that causes readings to take random values on either side of a mean value. The random error is quantified based on how well an instrument can reproduce subsequent readings for an unchanging input. Random errors cannot be corrected through calibration.

**systematic error:** an error that persists and cannot be considered as due entirely to chance. Systematic error can be corrected through calibration.

**uncertainty:** an estimated value for the error in a measurement, which may be the result of both systematic and random error.

### A2. METHODOLOGY FOR UNCERTAINTY ANALYSIS

Uncertainty analysis (also referred to as “error analysis”) is outlined in Coleman and Steele’s *Experimentation, Validation, and Uncertainty Analysis for Engineers*<sup>A-1</sup>. Additional details on uncertainty analysis can be found in ASME PTC 19.1 *Test Uncertainty*<sup>A-2</sup>. The goal of the uncertainty analysis is to bound the reported test results such that, with 95% confidence, the true values lie within the range. The uncertainty of the reported results is found by propagation of error sources from in the measurement system.

The types of data obtained and the nature of the experiment affect the type of uncertainty analysis used and the statistical techniques applied. One approach is to use multiple laboratories and measurement systems and then average the results to find the true cooling capacity of the evaporator. In this approach, it is assumed that all random and bias errors are encompassed in the measurements from the different systems. While this approach is ideal, it is not feasible for most applications. Thus, the error analysis applied in this standard is intended for steady-state measurements taken from a single system over a long enough time period to encompass all system variations. The first step is to assign the uncertainty in each of the measured variables.

$$U_{\bar{X}} = \sqrt{B_{\bar{X}}^2 + (tS_{\bar{X}})^2} \quad (\text{A-1})$$

where

$U_{\bar{X}}$  = overall uncertainty in variable  $X$

$B_{\bar{X}}$  = sum of the fixed errors associated with this variable

$S_{\bar{X}}$  = the standard deviation of the measured experimental variable

$t$  =  $t$ -value from statistical reference at the 95% confidence level for the appropriate degrees of freedom (1.96 if more than 30 points taken)

For data taken from one test system, the fixed error can’t be ignored and must be represented in the uncertainty analysis. The fixed errors are errors that do not vary randomly during operation of the facility. For example, errors introduced during calibration are considered fossilized into the system and do not vary randomly (see Coleman and Steele) and should thus be included as fixed errors. As a general practice, calibration against a known standard using the instrument, data acquisition system, and a calibration equation is the best way to estimate fixed errors. If this type of calibration is not possible, at a minimum, the manufacturer’s specifications of uncertainty on instruments and data acquisition system shall be used. In this case, the final fixed error is estimated from



$$B_X^2 = B_{X,1}^2 + B_{X,2}^2 + \dots + B_{X,i}^2 \quad (\text{A.2})$$

where  $B_{x,i}$  is the uncertainty associated with each error source.

It is important to note that the standard deviation in Equation A-1 is most meaningful if data are taken on a time scale longer than any naturally occurring variations in the system. To this end, measurements taken for this standard prescribe that a minimum of 30 data points be taken at evenly spaced intervals over a minimum time period of 30 minutes. The average and standard deviation for each measured variable is calculated from

$$\bar{X} = \frac{1}{N} \sum_{i=1}^N X_i \quad (\text{A.3})$$

$$S_{\bar{X}} = \left[ \frac{1}{N(N-1)} \sum_{i=1}^N (X_i - \bar{X})^2 \right]^{1/2} \quad (\text{A.4})$$

A Taylor Series propagation of error can then be used to determine the effect of fixed and random errors on the reported net refrigerating capacity for the evaporator. In general, the Taylor Series propagation of error is estimated from a data analysis equation that calculates  $r$  from measured variables  $X$ .

$$r = r(\bar{X}_1, \bar{X}_2, \dots, \bar{X}_j) \quad (\text{A.5})$$

The uncertainty can then be estimated from

$$U_r = \left[ \left( \frac{\partial r}{\partial \bar{X}_1} U_{\bar{X}_1} \right)^2 + \left( \frac{\partial r}{\partial \bar{X}_2} U_{\bar{X}_2} \right)^2 + \dots + \left( \frac{\partial r}{\partial \bar{X}_j} U_{\bar{X}_j} \right)^2 \right]^{1/2} \quad (\text{A.6})$$

where the  $U_{\bar{x}}$  must be defined as a 95% confidence interval and calculated according to Equation A-1 for each input variable.

The partial derivatives shown in Equation A-6 can, in general, be difficult to evaluate. In an effort to streamline these calculations, the following Taylor Series equations have been derived for the test results to report.

### A3. DEVELOPMENT OF UNCERTAINTY CALCULATIONS FOR EVAPORATOR TESTING

Equation 1 gives the net refrigerating capacity:

$$q_l = \dot{m}_l (h_{l,1} - h_{l,2}) \quad (\text{A.7})$$

The parameters in Equation A-7 not directly measured are related to the measured parameters by the following relationships:

$$h_{l,1} = f(T_{l,1}, P_{l,1}) \quad (\text{A.8a})$$

$$h_{l,2} = f(T_{l,2}, P_{l,2}) \quad (\text{A.8b})$$

Incorporating the relationships of Equations A-8a and A-8b into Equation A-7 yields the following equation for the uncertainty in the net refrigerating capacity:

$$U_{q_w} = \left[ \left( \frac{\partial q_l}{\partial P_{l,1}} U_{P_{l,1}} \right)^2 + \left( \frac{\partial q_l}{\partial P_{l,2}} U_{P_{l,2}} \right)^2 + \left( \frac{\partial q_l}{\partial T_{l,1}} U_{T_{l,1}} \right)^2 + \left( \frac{\partial q_l}{\partial T_{l,2}} U_{T_{l,2}} \right)^2 + \left( \frac{\partial q_l}{\partial \dot{m}_l} U_{\dot{m}_l} \right)^2 \right]^{1/2} \quad (\text{A.9})$$

where

$$\frac{\partial q_l}{\partial P_{l,1}} = \dot{m}_l \left( \frac{\partial h_{l,1}}{\partial P_{l,1}} \right) \quad (\text{A.10a})$$

$$\frac{\partial q_l}{\partial P_{l,2}} = -\dot{m}_l \left( \frac{\partial h_{l,2}}{\partial P_{l,2}} \right) \quad (\text{A.10b})$$

$$\frac{\partial q_l}{\partial T_{l,1}} = \dot{m}_l \left( \frac{\partial h_{l,1}}{\partial T_{l,1}} \right) \quad (\text{A.10c})$$

$$\frac{\partial q_l}{\partial T_{l,2}} = -\dot{m}_l \left( \frac{\partial h_{l,2}}{\partial T_{l,2}} \right) \quad (\text{A.10d})$$

$$\frac{\partial q_l}{\partial \dot{m}_l} = h_{l,1} - h_{l,2} \quad (\text{A.10e})$$

The partial derivatives for enthalpy with respect to temperature and pressure can be calculated from property equations of state, or they can be estimated using finite difference methods applied to tabular property data. REFPROP can calculate these partial derivatives for a number of refrigerants and cooling liquids.

For the saturation temperature of the refrigerant leaving the evaporator  $T_e$ , where  $T_e$  is derived from a pressure measurement at the outlet of the evaporator, the uncertainty is given as

$$U_{T_e} = \left[ \left( \frac{\partial T_e}{\partial P_{r,sat}} U_{P_{r,sat}} \right)^2 \right]^{\frac{1}{2}} \quad (\text{A.11})$$

The partial derivative for saturation temperature with respect to saturation pressure can be calculated from property equations of state, obtained from REFPROP, or estimated using finite difference methods applied to tabular property data.

For the superheat, which is typically measured by taking the difference between the measured outlet refrigerant temperature and the outlet saturation pressure,

$$T_{sh} = T_{r,out} - T_e \quad (\text{A.12})$$

the uncertainty is given by

$$U_{T_{sh}} = \left[ \left( \frac{\partial T_{sh}}{\partial T_{r,out}} U_{T_{r,out}} \right)^2 + \left( \frac{\partial T_{sh}}{\partial T_e} U_{T_e} \right)^2 \right]^{\frac{1}{2}} \quad (\text{A.13})$$

where

$$\frac{\partial T_{sh}}{\partial T_{r,out}} = 1 \quad (\text{A14a})$$

$$\frac{\partial T_{sh}}{\partial T_e} = -1 \quad (\text{A14b})$$

For the liquid pressure drop, if the pressure drop is measured by a differential pressure device, the uncertainty is given by Equation A-1. If the cooling liquid pressure drop is measured by taking the difference between the measured inlet and outlet liquid pressure,

$$\Delta P_l = P_{l,1} - P_{l,2} \quad (\text{A.15})$$

the uncertainty is given by

$$U_{\Delta P_l} = \left[ \left( \frac{\partial \Delta P_l}{\partial P_{l,1}} U_{P_{l,1}} \right)^2 + \left( \frac{\partial \Delta P_l}{\partial P_{l,2}} U_{P_{l,2}} \right)^2 \right]^{\frac{1}{2}} \quad (\text{A.16})$$

where

$$\frac{\partial \Delta P_l}{\partial P_{l,1}} = 1 \quad (\text{A17a})$$

$$\frac{\partial \Delta P_l}{\partial P_{l,2}} = -1 \quad (\text{A17b})$$

The uncertainty for all other measured test results is given by Equation A-1.

As the uncertainties are directly affected by the accuracy of the measurements being taken, it is strongly recommended that the reported uncertainties be simulated before the actual rating test is conducted in order to ensure that the instrumentation is accurate enough to obtain the desired uncertainty. This simulation can be completed by using expected values and expected standard deviations for the measured variables. The simulation can also be used to determine the maximum allowable reading standard deviations for the given instrumentation that will still achieve the desired uncertainty. Knowledge of the maximum standard deviations can be used during test time to check for problems.

The above methodology has been incorporated into an Excel workbook to assist with uncertainty calculations. Download the workbook at ASHRAE website at [https://www.ashrae.org/24\\_2019](https://www.ashrae.org/24_2019).

#### A4. REFERENCES

- A-1. Coleman, H.W., and W.G. Steele. 2009. *Experimentation, Validation, and Uncertainty Analysis for Engineers*, Third edition. Hoboken, NJ: John Wiley & Sons.
- A-2. ASME. 2018. *PTC 19.1 Test Uncertainty*. Manhattan. ASME.

**(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)**

### INFORMATIVE APPENDIX B METHOD TO COMPUTE THE ENTHALPY DIFFERENCE OF A LIQUID STREAM WHEN AN EOS-BASED FUNCTION IS NOT AVAILABLE<sup>B-1</sup>

#### B1. OVERVIEW

In ASHRAE Standard 24, Section 5.2.2 calls for using the enthalpy of the liquid being cooled when computing the heat transfer rate,

$$q_l = \dot{m}_l(h_{l,out} - h_{l,in}) = \dot{m}_l(h_{l,2} - h_{l,1}) \quad (\text{B.1})$$

In many cases, this is simplified to

$$q_l = \dot{m}_l c_{P,l}(T_{l,out} - T_{l,in}) = \dot{m}_l c_{P,l}(T_{l,2} - T_{l,1}) \quad (\text{B.2})$$

However, the enthalpy of a liquid is also a function of pressure and, therefore, the heat transfer rate also depends on the pressure drop of the liquid as it goes through the heat exchanger, in addition to the change in temperature.

It can be shown for certain cases, especially those where there is a large pressure drop in conjunction with a small temperature difference, that the error in the computed heat transfer rate becomes significant when the pressure drop is ignored. For this reason, this standard now requires that pressure be included in the determination of enthalpy or enthalpy difference.

It is preferred that the enthalpy of a liquid be determined from a function based on an equation of state that includes both temperature and pressure as inputs. For example, REFPROP<sup>B-2</sup> returns enthalpy values for liquids as a function of temperature and pressure, including for water and a number of higher-boiling-temperature hydrocarbons.

Because such a function might not exist for all liquids that could be used when executing this method of test (e.g., glycol and brine solutions), this appendix outlines a method for computing an estimate of the change in enthalpy from other known information.

#### B2. DERIVATION OF AN ESTIMATE FOR ENTHALPY DIFFERENCE

The basis for this derivation can be found in any textbook on classical thermodynamics<sup>B-3,B-4</sup>. The differential change in enthalpy can be expanded as follows,

$$dh = \left(\frac{\partial h}{\partial T}\right)_P dT + \left(\frac{\partial h}{\partial P}\right)_T dP \quad (\text{B.3})$$

Substitution of the Gibbs relation and a Maxwell relation along with the definition of specific heat results in the following equation,

$$dh = c_p dT + \left[ v - T \left(\frac{\partial v}{\partial T}\right)_P \right] dP = c_p dT + v \left[ 1 - \frac{T}{v} \left(\frac{\partial v}{\partial T}\right)_P \right] dP = c_p dT + v[1 - T\alpha_p]dP \quad (\text{B.4})$$

where  $\alpha_p = (1/v)(\partial v/\partial T)_P = -(1/\rho)(\partial \rho/\partial T)_P$  is the “volume expansivity” or “coefficient of thermal expansion” of the liquid.

Assuming that the coefficients of  $dT$  and  $dP$  can be considered to be constant over the relatively small changes in temperature and pressure typically encountered in HVAC&R equipment, integration of Equation B-4 gives the following:

$$h_{l,2} - h_{l,1} = c_{p,l}(\bar{T}) \cdot (T_{l,2} - T_{l,1}) + \frac{1 - \bar{T} \alpha_p(\bar{T})}{\rho_l(\bar{T})} \cdot (P_{l,2} - P_{l,1}) \cdot \Upsilon \quad (\text{B.5})$$

where the properties are evaluated at the average of the inlet and outlet temperatures,  $\bar{T} = (T_{l,1} + T_{l,2})/2$  and  $\Upsilon$  accounts for the necessary unit conversions.  $\alpha_p$  is determined as either an analytical or numerical derivative of the density function. The volume expansivity of water as a function of temperature is shown in Figure B-1. Values of  $\alpha_p$  for glycols are similar.

Equation B-5 can be rearranged into the following form:

$$h_{l,2} - h_{l,1} = c_{p,l}(\bar{T}) \cdot (T_{l,2} - T_{l,1})(1 + Q_{\Delta P}) \quad \text{where} \quad Q_{\Delta P} = \frac{1 - \bar{T} \alpha_p(\bar{T})}{c_{p,l}(\bar{T}) \rho_l(\bar{T})} \left( \frac{P_{l,2} - P_{l,1}}{T_{l,2} - T_{l,1}} \right) \cdot \Upsilon \quad (\text{B.6})$$

$Q_{\Delta P}$  is the change in enthalpy or heat transfer rate due to the change in pressure relative to the change in temperature. It can also be considered as the error in enthalpy difference if the change in pressure is ignored,  $Q_{error}$ . Example magnitudes of this error as a function of temperature and pressure differences are shown in Figure B-2.

Note that the impact of pressure drop on enthalpy change across a heat exchanger can be additive or subtractive, depending on the direction of change in temperature. If State 2 represents the outlet state and State 1 the inlet state, then  $P_{l,2} - P_{l,1} < 0$ . In an evaporator,  $T_{l,2} - T_{l,1} < 0$  also, so the error term is greater than zero (additive). In a condenser,  $P_{l,2} - P_{l,1} > 0$ , so the error term is less than zero (subtractive).

### B3. EXAMPLE

Let’s consider an example where a 30%vol propylene glycol/water solution is being cooled by an evaporator at the conditions shown in Table B-1. The values in bold represent the inputs, or measurements.

Let’s assume that the density and specific heat of the liquid are described by the values listed in the 2017 *ASHRAE Handbook—Fundamentals* (I-P), Chapter 31, Tables 10 and 11, respectively. Portions of those tables are reproduced in Figures B-3 and B-4, along with curve fits as functions of temperature obtained using Microsoft Excel’s LINEST function (or similar). Figure B-3 shows how to calculate  $\alpha_p$ , the volume expansivity, from the equation for density.

The various intermediate and final computed quantities are listed in Table B-1. Equation B-6 was used to compute the heat transfer rate. Note that, in this case, the pressure drop contributes only a small 0.6% increase to the heat transfer rate relative to the temperature difference. Although this might seem negligible, it is 1/5th the allowed tolerance between the heat

transfer rates computed from the primary and confirming test methods as given in Section 5.1.4 of the standard. If the pressure drop were increased to 20 psid, the error in the heat transfer rate would be 1.1%.

Further description and discussion of this method is given in the paper “Method to Compute the Enthalpy Difference of a Liquid Stream in the Absence of an EoS-Based Function<sup>B-1</sup>.” The calculations used for this example have been included as a worksheet in the Excel uncertainty workbook discussed in Informative Appendix A.

#### B4. RECOMMENDATIONS

It is preferred that the enthalpy of a liquid be determined from a function based on an equation of state that includes both temperature and pressure as inputs; for example, the REFPROP function that calculates enthalpy.

For liquids where such an enthalpy function does not exist or is not readily available, Equation B-5 can be used to compute the enthalpy difference across the heat exchanger. The key assumptions behind Equation B-5 are that the specific heat is approximately linear between  $T_{l,1}$  and  $T_{l,2}$  and that the liquid can be considered incompressible between  $P_{l,1}$  and  $P_{l,2}$ .

Table B-1 shows example values for a condenser cooled by a propylene glycol solution.

Equation B-6 can be used to determine the magnitude of the impact of pressure drop on the heat transfer rate. If  $Q_{error}$  is sufficiently small (depends on context), then use of Equation B-2 to compute the heat transfer rate is permissible.

#### B5. REFERENCES

- B-1. Schultz, K.J. 2013. Method to compute the enthalpy difference of a liquid stream when an EOS-based function is not available. *ASHRAE Transactions* 119(2).
- B-2. Lemmon, E.W., Bell, I.H., Huber, M.L., McLinden, M.O. NIST Standard Reference Database 23: Reference Fluid Thermodynamic and Transport Properties-REFPROP, Version 10.0, National Institute of Standards and Technology, Standard Reference Data Program, Gaithersburg, 2018. doi: <https://doi.org/10.18434/T4/1502528>
- B-3. Van Wylen, G.J., and R.E. Sonntag. 1973. *Fundamentals of Classical Thermodynamics*, Second Edition, Chapter 10. John Wiley and Sons.
- B-4. ASHRAE. 2021. *ASHRAE Handbook—Fundamentals*, Chapter 2, “Calculating Thermodynamic Properties,” pp 2.4–2.5.

**Table B-1 Example Values for a Condenser Cooled by a Propylene Glycol Solution**

Liquid:	Propylene Glycol/Water Solution	
Concentration:	30%vol	
$\dot{V}_l$	50 gpm	3.15 L/s
$T_{l,in} = T_{l,1}$	50 °F	10.0 °C
$T_{l,out} = T_{l,2}$	45 °F	7.2 °C
$\Delta T = T_{l,2} - T_{l,1}$	5 °F	-2.8 °C
$T_{l,ave} = \bar{T}$	47.5 °F	8.6 °C
	507.17 R	281.76 K
$\rho_l(T_{l,1})$	64.53 lb/ft <sup>3</sup>	1034.10 kg/m <sup>3</sup>
$w_l$	25,881 lb/h	11,737 kg/h
$\Delta P = P_{l,2} - P_{l,1}$	-10 psid	-68.9 kPa
	-23.1 ftwc	-7.04 mAq
$c_{p,l}(\bar{T})$	0.912 Btu/lb·R	3.816 kJ/kg·K

$\rho_l(\bar{T})$	64.57 lb/ft <sup>3</sup>	1034.10 kg/m <sup>3</sup>
$\alpha_p(\bar{T})$	0.000207 1/R	0.000372 1/K
$\bar{T}\alpha_p(\bar{T})$	0.105 []	0.105 []
$Q_{\Delta P}$	0.006 []	0.006 []
$q_l(\Delta T \text{ only})$	-118,020 Btu/h	-34.559 kW
$q_l$ (gross)	-118,684 Btu/h -9.89 tons	-34.754 kW

*Note:* The values in bold represent the measurements.