ASHRAE®

ADDENDA

ANSI/ASHRAE Addendum a to ANSI/ASHRAE Standard 41.9-2021

Standard Methods for Refrigerant Mass Flow Measurement Using Calorimeters

Approved by ASHRAE and the American National Standards Institute on July 31, 2023.

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FOREWORD

Addendum a makes it easier for the higher-tier ASHRAE standards to adopt this standard by reference, updates the uncertainty requirements, and updates the steady-state criteria sections.

Informative Note: In this addendum, changes to the current standard are indicated in the text by underlining (for additions) and ~~strikethrough~~ (for deletions) unless the instructions specifically mention some other means of indicating the changes.

Addendum a to Standard 41.9-2021

Modify Section 3 as shown.

3. DEFINITIONS

accuracy: ~~the degree of conformity of an indicated value to the corresponding *true value*.~~ the difference between the observed value of the measurand and its corresponding true value.

post-test uncertainty: an analysis to establish the uncertainty of a test result after conducting the test.

pretest uncertainty: an analysis to establish the expected uncertainty interval for a test result before conducting the test.

steady-state criteria: the criteria that establish negligible change of refrigerant mass flow difference with time.

uncertainty: ~~a measure of the potential error in a measurement that reflects the lack of confidence in the result to a specified level.~~ the limits of error within which the true value lies.

Revise Section 5.1 as shown.

5.1 Test Plan. ~~A test plan shall include the test points, targeted set points, and corresponding operating tolerances to be performed.~~ The test plan shall be one of the following options:

a. A document provided by the person or the organization that authorized the tests and calculations to be performed
b. A method of test standard
c. A rating standard
d. A regulation or code
e. Any combination of (a) through (d)

The test plan shall specify the following:

a. The maximum allowable value for either the accuracy or the measurement uncertainty of the refrigerant mass flow rate measurement
b. The values to be determined and recorded, selected from this list: refrigerant mass flow rate, pretest refrigerant mass flow rate measurement uncertainty, post-test refrigerant mass flow rate measurement uncertainty, and lubricant circulation rate.
c. Any combination of test points and targeted set points to be performed together with operating tolerances

Revise Section 5.2 as shown to make it easier for higher-tier standards to adopt this standard by reference.

5.2 Values to Be Determined and Reported. If specified in the test plan in Section 5.1, the ~~The~~ test values to be determined and reported shall be as shown in Table 1. Use the unit of measure in the Table 1 unless otherwise specified in the test plan in Section 5.1.

Replace Section 5.4 with new Sections 5.4 and 5.5 as shown, and renumber the remaining sections.

~~**5.4 Measurement Uncertainty**. The uncertainty in each refrigerant mass flow rate measurement, kg/s (lb_m/h), shall be estimated using the methods described in Section 12 for each test point unless otherwise specified in the test plan in Section 5.1. Alternatively, the worst-case uncertainty for all test points shall be estimated and the same value reported for each test point.~~

5.4 Pretest Uncertainty Analysis. If required by the test plan in Section 5.1, perform an analysis to establish the expected uncertainty for each refrigerant mass flow rate test point prior to the conduct of that test in accordance with the pretest uncertainty analysis procedures in ASME PTC 19.1[1].

Table 5-1 Measurement Values and Units of Measure

Quantity	Units of Measure	
	SI	I-P
Refrigerant mass flow rate	kilogram per second (kg/s)	pound (avoirdupois) per hour (lb_m/h)
Uncertainty in the refrigerant mass flow rate	kilogram per second (kg/s)	pound (avoirdupois) per hour (lb_m/h)
Lubricant circulation rate	Dimensionless	Dimensionless

5.5 Post-Test Uncertainty Analysis. If required by the test plan in Section 5.1, perform an analysis to establish the refrigerant mass flow rate measurement uncertainty for each refrigerant mass flow test point in accordance with the post-test uncertainty analysis procedures in ASME PTC 19.1[1]. Alternatively, if specified in the test plan, the worst-case uncertainty for all test points shall be estimated and the same value reported for each test point.

Revise Section 5.7 as shown.

5.7 Steady-State Criteria for Refrigerant Mass Flow Rate Measurements. Refrigerant mass flow rate test data shall be recorded at steady-state test conditions ~~unless otherwise~~ if stated in the test plan in Section 5.1. Section 5.8 describes unsteady-state refrigerant mass flow rate test data recording if required by the test plan.

Revise Section 5.7.1 as shown to define the steady-state criteria requirements under laboratory and field test conditions.

5.7.1 Steady-State Criteria for Compressors that do not Incorporate Pulse-Width Modulation. Refrigerant mass flow rate test data shall be recorded at steady-state conditions ~~unless otherwise~~ if specified in the test plan in Section 5.1. ~~If the test plan requires refrigerant mass flow rate test data points to be recorded at steady-state test conditions and provides the operating condition tolerance but does not specify the steady-state criteria, then determine that steady-state test conditions have been achieved using one of the following methods:~~

~~a. Apply the steady-state criteria in Section 5.7.1.1 if the test plan provides test points for refrigerant mass flow rate measurement.~~

~~b. Apply the steady-state criteria in Section 5.7.1.2 if the test plan provides targeted set points for refrigerant mass flow rate measurement.~~

5.7.1.1 Steady-State Test Criteria for Refrigerant Mass Flow Rate Measurements Under Laboratory Test Conditions. If the test plan requires refrigerant mass flow test data points to be recorded at steady-state test conditions, and provides the operating condition tolerance but does not specify the steady-state criteria, then determine that steady-state test conditions have been achieved using one of the following methods:

a. Apply the steady-state criteria in Section 5.7.1.3 if the test plan provides test points for refrigerant mass flow rate measurement.

b. Apply the steady-state criteria in Section 5.7.1.4 if the test plan provides targeted set points for refrigerant mass flow rate measurement.

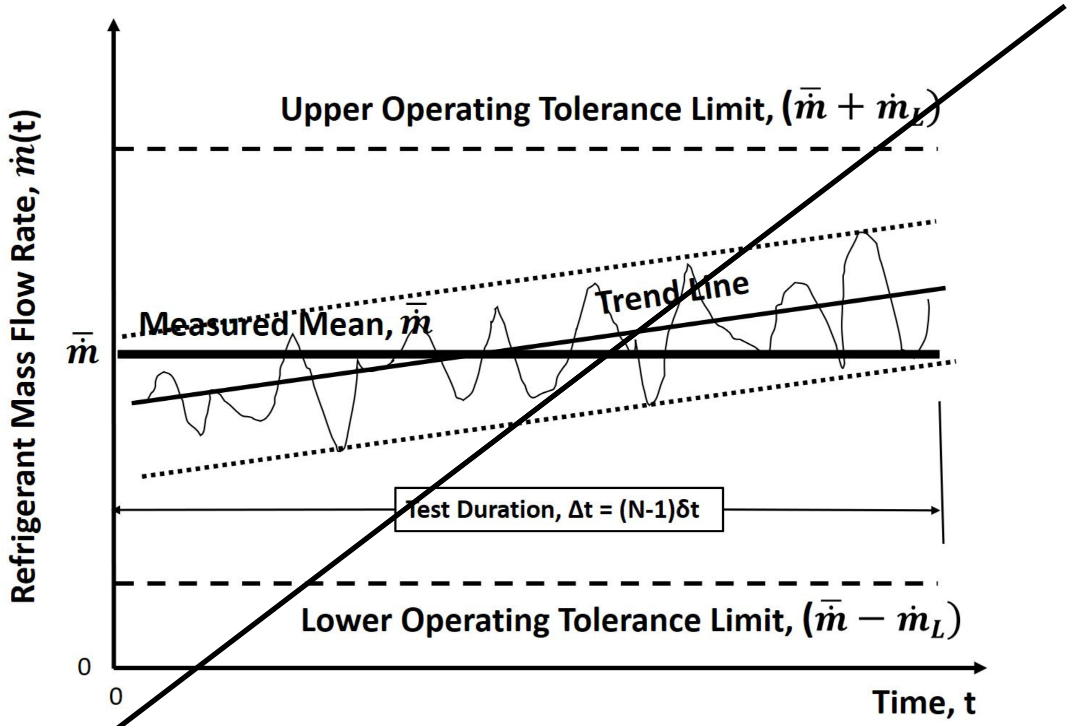
5.7.1.2 Steady-State Test Criteria for Refrigerant Mass Flow Rate Measurements Under Field Test Conditions. If the test plan requires refrigerant mass flow test data points to be recorded at steady-state test conditions, and provides the operating condition tolerance but does not specify the steady-state criteria, the methods in Section 5.7.1.1 are optional.

Informative Note: The steady-state methods in Section 5.7.1.1 are likely to be impractical under field test conditions. Under these circumstances, the user may want to select another method to determine the conditions for field test data to be recorded.)

Revise Section 5.7.1.1 as shown.

~~5.7.1.1~~ 5.7.1.3 Steady-State Refrigerant Mass Flow Rate Criteria for Test Points

[. . .]



~~**Figure 5-1 Graphical illustration of the method for determining the steady-state refrigerant mass flow rate criteria for test points.**~~

Record each sampled refrigerant mass flow rate measurement $\dot{m}_i$ and the corresponding time t_i. Apply the least-squares line method to determine the slope b of the refrigerant mass flow rate data trend line ~~illustrated in Figure 1~~ using Equation 5-2.

[. . .]

~~Determine the mean offset μ of the sampled data using Equation 5-3, and then calculate the standard deviation σ using Equation 5-4.~~

$$\cancel{\mu = \frac{1}{N}\left[\sum_{i=1}^{N}(\dot{m}_i - bt_i)\right] \qquad \text{kg/s (lb}_m\text{/h)}} \qquad \cancel{(5\text{-}3)}$$

$$\cancel{\sigma = \left[\left(\frac{1}{N-2}\right)\sum_{i=1}^{N}(\dot{m}_i - bt_i - \mu)^2\right]^{1/2} \qquad \text{kg/s (lb}_m\text{/h)}} \qquad \cancel{(5\text{-}4)}$$

The mean of the sampled refrigerant mass flow rates $\bar{\dot{m}}$ is defined by Equation ~~5-5~~5-3.

$$\cancel{\bar{\dot{m}} = \frac{1}{N}\left[\sum_{i=1}^{N}(\dot{m}_i)\right] \qquad \text{kg/s (lb}_m\text{/h)}} \qquad \cancel{(5\text{-}5)}$$

$$\bar{\dot{m}} = \frac{1}{N}\left[\sum_{i=1}^{N}(\dot{m}_i)\right] \qquad \text{kg/s (lb}_m\text{/h)} \qquad (5\text{-}3)$$

$\bar{\dot{m}}$, as determined by Equation ~~5-5~~5-3, represents the steady-state mean refrigerant mass flow rate provided that one of the following criteria is satisfied:

a. Apply Equation 5-4:

$$\dot{m}_{max} - \dot{m}_{min} \le \dot{m}_L \qquad \text{kg/s (lb}_m\text{/h)} \qquad (5\text{-}4)$$

b. Apply Equation 5-5:

$$|b \times \Delta t| \le 0.5 \times \dot{m}_L \qquad \text{kg/s (lb}_m\text{/h)} \qquad (5\text{-}5)$$

~~a. Apply Equation 5-6 if~~ $\cancel{2\sigma \geq \dot{m}_L}$~~, where~~ $\cancel{\dot{m}_L}$ ~~is the specified operating tolerance limit for refrigerant mass flow rate, and if Equation 5-6 is satisfied by not less than 95% of the sampled refrigerant mass flow rates.~~

$$\cancel{|\dot{m}_i - \mu| \leq 2\sigma \quad \text{kg/s (lb}_m\text{/h)}} \qquad \cancel{(5\text{-}6)}$$

~~b. Apply Equation 5-7 if~~ $\cancel{\dot{m}_L \geq 2\sigma}$~~, where~~ $\cancel{\dot{m}_L}$ ~~is the specified operating tolerance limit for refrigerant mass flow rate, and if Equation 5-7 is satisfied by not less than 95% of the sampled refrigerant mass flow rates.~~

$$\cancel{|\dot{m}_i - \mu| \leq \dot{m}_L \quad \text{kg/s (lb}_m\text{/h)}} \qquad \cancel{(5\text{-}7)}$$

(***Informative Note:*** For further reading about this method of determining steady-state conditions, refer to Informative Appendix A, References A1 and A2.)

Revise Section 5.7.1.2 as shown.

~~5.7.1.2~~5.7.1.4 Steady-State Refrigerant Mass Flow Rate Criteria for Targeted Set Points

[. . .]

Record each sampled refrigerant mass flow rate measurement $\dot{m}_i$ and the corresponding time t_i. Apply the least-squares line method to determine the slope b of the refrigerant mass flow rate data trend line illustrated in Figure 5-2 using Equation ~~5-9~~5-7.

$$\cancel{b = \left\{ \frac{[N(\sum_{i=1}^{N} t_i \dot{m}_i) - (\sum_{i=1}^{N} t_i)(\sum_{i=1}^{N} \dot{m}_i)]}{[N(\sum_{i=1}^{N} t_i^2) - (\sum_{i=1}^{N} t_i)^2]} \right\}} \qquad \cancel{(5\text{-}9)}$$

$$\underline{b = \left\{ \frac{[N(\sum_{i=1}^{N} t_i \dot{m}_i) - (\sum_{i=1}^{N} t_i)(\sum_{i=1}^{N} \dot{m}_i)]}{[N(\sum_{i=1}^{N} t_i^2) - (\sum_{i=1}^{N} t_i)^2]} \right\}} \qquad \underline{(5\text{-}7)}$$

(***Informative Note:*** It should be noted that the units for the slope in Equation ~~5-9~~5-7 are refrigerant mass flow rate, kg/s [lb_m/h], divided by the units that the user has selected for time.)

~~Determine the mean offset μ of the sampled data using Equation 5-10, and calculate the standard deviation σ using Equation 5-11.~~

$$\cancel{\mu = \frac{1}{N}[\sum_{i=1}^{N} (\dot{m}_i - bt_i)] \quad \text{kg/s (lb}_m\text{/h)}} \qquad \cancel{(5\text{-}10)}$$

$$\cancel{\sigma = \left[\left(\frac{1}{N-2}\right)\sum_{i=1}^{N} (\dot{m}_i - bt_i - \mu)^2\right]^{1/2} \quad \text{kg/s (lb}_m\text{/h)}} \qquad \cancel{(5\text{-}11)}$$

The mean of the sampled refrigerant mass flow rates $\bar{\dot{m}}$ is defined by Equation ~~5-12~~5-8.

$$\cancel{\bar{\dot{m}} = \frac{1}{N}[\sum_{i=1}^{N} (\dot{m}_i)] \quad \text{kg/s (lb}_m\text{/h)}} \qquad \cancel{(5\text{-}12)}$$

$$\underline{\bar{\dot{m}} = \frac{1}{N}[\sum_{i=1}^{N} (\dot{m}_i)] \quad \text{kg/s (lb}_m\text{/h)}} \qquad \underline{(5\text{-}8)}$$

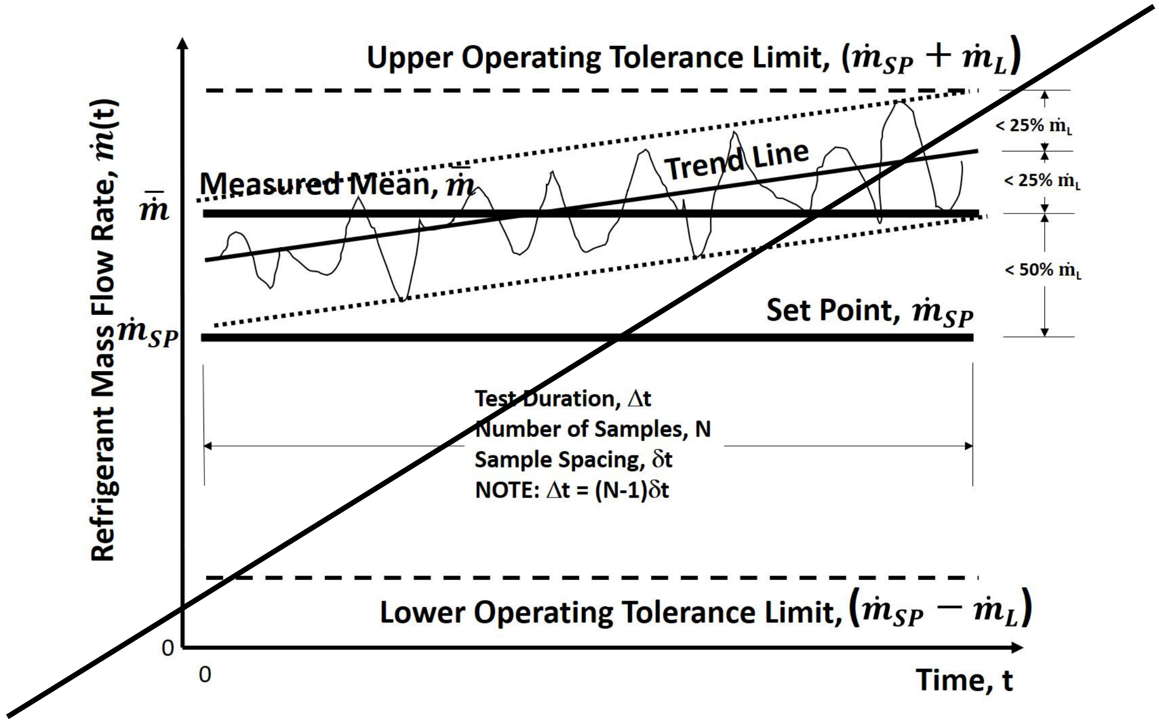
<u>$\bar{\dot{m}}$, as determined by Equation 5-5, represents the steady-state mean refrigerant mass flow rate provided that one of the following criteria is satisfied:</u>

<u>a. Apply Equation 5-8:</u>

$$\underline{\dot{m}_{max} - \dot{m}_{min} \leq \dot{m}_L \quad \text{kg/s (lb}_m\text{/h)}} \qquad \underline{(5\text{-}9)}$$

<u>b. Apply Equation 5-9:</u>

$$\underline{|b \times \Delta t| \leq 0.5 \times \dot{m}_L \quad \text{kg/s (lb}_m\text{/h)}} \qquad \underline{(5\text{-}10)}$$



~~**Figure 5-2 Graphical illustration of the method for determining the steady-state refrigerant mass flow rate criteria for targeted set points.**~~

~~A tolerance on the fluctuations about the trend line represents a limit on the fluctuation level relative to the trend line of the sampled data. If the tolerance of fluctuations about the trend line is not specified in the test plan, the bounds for a 95% confidence limit for the fluctuations about the trend line shall then be determined according to Equation 5-13.~~

$$\cancel{\left|\bar{\dot{m}} - \dot{m}_{SP}\right| + |b\Delta t| + 2\sigma \le \dot{m}_L \quad \text{kg/s (lb}_m\text{/h)}} \qquad \cancel{(5\text{-}13)}$$

~~The steady-state condition of the set-point refrigerant mass flow rate~~ $\cancel{\dot{m}_{SP}}$ ~~exists~~

~~a. where Equation 5-14 is satisfied by not less than 95% of the sampled refrigerant mass flow rates, where~~ $\cancel{\dot{m}_L}$ ~~is the operating tolerance limit for refrigerant mass flow rate:~~

$$\cancel{(\dot{m}_{SP} - \dot{m}_L) \le \dot{m}_i \le (\dot{m}_{SP} + \dot{m}_L) \quad \text{kg/s (lb}_m\text{/h)}} \qquad \cancel{(5\text{-}14)}$$

~~b. where~~

$$\cancel{-0.50\dot{m}_L \le (\bar{\dot{m}} - \dot{m}_{SP}) \le 0.50\dot{m}_L \quad \text{kg/s (lb}_m\text{/h)}} \qquad \cancel{(5\text{-}15)}$$

~~c. and where~~

$$\cancel{b\Delta t \le 0.50\dot{m}_L \quad \text{kg/s (lb}_m\text{/h)}} \qquad \cancel{(5\text{-}16)}$$

~~(***Informative Note:*** For further reading about this method of determining steady-state conditions, refer to Informative Appendix A, References A1 and A2.)~~

Revise Section 11.1 as shown.

11.1 Symbols. Table 2 defines the symbols used in Section 11.

Table 11-1 Symbols Used in Section 11

Symbol	Description	SI Units	I-P Units
C_c	Lubricant circulation rate through the calorimeter~~, %~~	Dimensionless	
C_s	Lubricant circulation rate through the lubricant separator~~, %~~	Dimensionless	
C_{suut}	Lubricant circulation rate through the UUT~~, %~~	Dimensionless	
$\dot{m}_{lc}$	Lubricant mass flow rate through the calorimeter	kg/s	lb_m/h
$\dot{m}_{ls}$	Lubricant mass flow rate through the auxiliary separator	kg/s	lb_m/h
$\dot{m}_{lt}$	Total lubricant mass flow rate	kg/s	lb_m/h
$\dot{m}_{rc}$	Refrigerant mass flow rate through the calorimeter	kg/s	lb_m/h
$\dot{m}_{rs}$	Refrigerant mass flow rate through the auxiliary separator	kg/s	lb_m/h
$\dot{m}_{rt}$	Total refrigerant mass flow rate	kg/s	lb_m/h
$\dot{m}_{rls}$	Total refrigerant/lubricant mass flow rate through the auxiliary separator	kg/s	lb_m/h

Revise Equations 11-1, 11-2, 11-12, and 11-13 as shown.

$$\cancel{C_c = \frac{\dot{m}_{lc}}{\dot{m}_{rc} + \dot{m}_{lc}} \times 100\%} \qquad \cancel{(11\text{-}1)}$$

$$\underline{C_c = \frac{\dot{m}_{lc}}{(\dot{m}_{rc} + \dot{m}_{lc})}, \text{ dimensionless}} \qquad \underline{(11\text{-}1)}$$

$$\cancel{C_s = \frac{\dot{m}_{ls}}{(\dot{m}_{rs} + \dot{m}_{ls})} \times 100\%} \qquad \cancel{(11\text{-}2)}$$

$$\underline{C_s = \frac{\dot{m}_{ls}}{(\dot{m}_{rs} + \dot{m}_{ls})}, \text{ dimensionless}} \qquad \underline{(11\text{-}2)}$$

$$\cancel{C_{suut} = \frac{\dot{m}_{lt}}{(\dot{m}_{rt} + \dot{m}_{lt})} \times 100\%} \qquad \cancel{(11\text{-}12)}$$

$$\underline{C_{suut} = \frac{\dot{m}_{lt}}{(\dot{m}_{rt} + \dot{m}_{lt})}, \text{ dimensionless}} \qquad \underline{(11\text{-}12)}$$

$$\cancel{C_{suut} = \left\{ \frac{\dot{m}_{rc}\left(\frac{C_c}{1 - C_c}\right) + C_s \dot{m}_{rls}}{\dot{m}_{rc}\left[1 + \left(\frac{C_c}{1 - C_c}\right)\right] + \dot{m}_{rls}} \right\} \times 100\%} \qquad \cancel{(11\text{-}13)}$$

$$\underline{C_{suut} = \left\{ \frac{\dot{m}_{rc}\left(\frac{C_c}{1 - C_c}\right) + C_s \dot{m}_{rls}}{\dot{m}_{rc}\left[1 + \left(\frac{C_c}{1 - C_c}\right)\right] + \dot{m}_{rls}} \right\}, \text{ dimensionless}} \qquad \underline{(11\text{-}13)}$$

Revise Section 12.1 as shown.

12.1 Post-Test Uncertainty ~~Estimate~~ Analysis. If required by the test plan in Section 5.1, a post-test analysis ~~An estimate~~ of the measurement uncertainty, performed in accordance with ASME PTC 19.1[~~8~~1], shall accompany each refrigerant mass flow measurement.

[...]

Revise Section 13.6 as shown.

13.6 Test Results. If specified in the test plan in Section 5.1, report the following test results:

a. Refrigerant mass flow rate, kg/s (lb_m/h)
b. Compressor input power, W (W)~~, if required by the test plan in Section 5.1~~
c. Pretest uncertainty ~~Uncertainty~~ in refrigerant mass flow rate, kg/s (lb_m/h)
d. Post-test uncertainty ~~Uncertainty~~ in refrigerant mass flow rate, kg/s (lb_m/h)
e. Lubricant circulation rate through the calorimeter, percent by mass

Renumber Section 14 as shown.

1. ASME PTC 19.1-2018, *Test Uncertainty.* ASME, New York, NY.
2. NIST Standard Reference Database 23: *NIST Reference Fluid Thermodynamic and Transport Properties Database (REFPROP) Version 10.* National Institute of Standards and Technology, Gaithersburg, MD.
3. ANSI/ASHRAE Standard 41.11-2020, *Standard Methods for Power Measurement.* Atlanta: ASHRAE. See Note 1.
4. ANSI/ASHRAE Standard 15-2019, *Safety Standard for Refrigeration Systems and Addenda*. Atlanta: ASHRAE.
5. ANSI/ASHRAE *Standard* 41.1-2020, *Standard Methods for Temperature Measurement*. Atlanta: ASHRAE.
6. ANSI/ASHRAE *Standard* 41.3-2014, *Standard Methods for Pressure Measurement*. Atlanta: ASHRAE.
7. ANSI/ASHRAE Standard 41.4-2015, *Standard Methods for Measurement of Proportion for Lubricant in Liquid Refrigerant*, Atlanta: ASHRAE. See Note 2.
8. ANSI/ASHRAE Standard 41.8-2015 (R2018), *Standard Methods for Liquid Flow Measurement*. Atlanta: ASHRAE. See Note 3.
9. ~~ASME PTC 19.1-2018, *Test Uncertainty.* ASME, New York, NY.~~

Informative Notes:

1. Reference ~~2~~3 is only required if compressor input power measurements are required in the test plan in Section 5.1
2. Reference ~~6~~7 is only required if lubricant concentration measurements are required.
3. Reference ~~7~~8 is only required (a) if liquid coolant mass flow rate measurements are required by the test plan, or (b) if an auxiliary lubricant separator is used.

Revise Informative Appendix B as shown.

This example uses ASME PTC 19.1[~~8~~1] to establish a framework for estimating the systematic standard uncertainty b_r of the refrigerant mass flow for a primary refrigerant calorimeter that uses an electrical heat source, and for a secondary fluid calorimeter that uses a liquid or vapor heat source, where the result R is a function of independent parameters. For this example, $b_r = \Delta m$ and $R = \dot{m}$. The parameter descriptions for this example are shown in Table B-1. Note that, in general, using a commercial equation solver software, such as MATLAB or EES significantly reduces the time and effort required to complete an uncertainty analysis.

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Through its *Handbook*, appropriate chapters will contain up-to-date Standards and design considerations as the material is systematically revised.

ASHRAE will take the lead with respect to dissemination of environmental information of its primary interest and will seek out and disseminate information from other responsible organizations that is pertinent, as guides to updating Standards and Guidelines.

The effects of the design and selection of equipment and systems will be considered within the scope of the system's intended use and expected misuse. The disposal of hazardous materials, if any, will also be considered.

ASHRAE's primary concern for environmental impact will be at the site where equipment within ASHRAE's scope operates. However, energy source selection and the possible environmental impact due to the energy source and energy transportation will be considered where possible. Recommendations concerning energy source selection should be made by its members.

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