BSR/ASHRAE Standard 23P

Public Review Draft

Methods for Performance Testing Positive Displacement Refrigerant Compressors and Compressor Units

Third Public Review (October 2021)
(Draft Shows Proposed Independent Substantive Changes to Previous Public Review Draft)

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 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 or by calling 404-636-8400 or 1-800-727-4723 (for orders in the U.S. or Canada).

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Background. The second 23P Independent Substantive Change (ISC) Publication Public Review (PPR) draft had 2 substantive comments. The changes in this 23P ISC PPR3 draft are a direct result of the comments on the 23P ISC PPR2 draft.

Note that in this 23P ISC PPR3 draft, changes to draft are indicated in the text by underlining for additions, and by ~~strikethroughs~~ for deletions.

A new Section 5.8 has been added.

Section 5.8. In this standard, the term "Btu" is the BtuIT[6] variant where 1 Btu = 1.055056 kJ, and the term "power" is electric power where 1 hp = 746 W[6].

The previous Section 5.8 has been renumbered as Section 5.9 and the noted changes in the new Section 5.9 are a direct result of the two comments on the 23P ISC PPR2 draft.

5.9 ~~5.8~~ Calculations

5.9.1 ~~5.8.1~~ Compressor Isentropic Efficiency. The isentropic efficiency calculations in this section apply to compressors that are tested separately and to compressors that are an integral part of condensing units.

5.9.1.1 ~~5.8.1.1~~ Isentropic Efficiency for a Single-Stage Compressor. Figure 3a and 3b shows the cycle schematic and pressure-enthalpy diagram for a single-stage compressor. The cycle on Figure 3a includes liquid injection if required for cooling. The cycle on Figure 3b includes supercritical fluid injection if required for cooling.

The isentropic efficiency for a single-stage compressor as described in Figure 3a and 3b shall be calculated using Equation 1 for SI units or using Equation 2 for I-P units.

$$\eta = \frac{[\dot{m}_1(h_{3s}-h_{2s})]}{P} \quad \text{(1)}$$ ~~$\times\ 100$~~

~~$$\eta = \frac{\dot{m}_1(h_{3s}-h_{2s})}{P} \times 0.000393 \quad \text{(2)}$$~~

$$\eta = \frac{\dot{m}_1(h_{3s}-h_{2s})}{P} \times 0.000392979 \quad \text{(2)}$$

where

η = isentropic efficiency for a single-stage stage compressor, ~~%~~ dimensionless
$\dot{m}_1$ = refrigerant mass flow rate entering the compressor, kg/s (lb_m/h)
h_{2s} = specific enthalpy of refrigerant vapor at suction pressure and temperature entering the compressor, kJ/kg (Btu/lb_m)
h_{3s} = specific enthalpy of refrigerant vapor at discharge pressure following an isentropic compression of the refrigerant from compressor suction pressure and temperature, kJ/kg (Btu/lb_m)
P = total power input to the UUT, kW (hp)

5.9.1.2 ~~5.8.1.2~~ Isentropic Efficiency for a Multi-Stage Compressor. The isentropic efficiency for a multi-stage compressor shall be calculated using Equation 3 for SI units or using Equation 4 for I-P units.

$$\eta = \frac{[\sum_{i=1}^{NS} \dot{m}_i(h_{3is}-h_{2is})]}{P} \quad \text{(3)}$$ ~~$\times\ 100$~~

~~$$\eta = \frac{[\sum_{i=1}^{NS} \dot{m}_i(h_{3is}-h_{2is})]}{P} \times 0.000393 \quad \text{(4)}$$~~

$$\eta = \frac{[\sum_{i=1}^{NS} \dot{m}_i(h_{3is} - h_{2is})]}{P} \times 0.000392979 \quad (4)$$

where

- η = isentropic efficiency for a multi-stage compressor, ~~%~~ dimensionless
- NS = number of compressor stages
- $\dot{m}_i$ = refrigerant mass flow rate entering the compressor stage i, kg/s (lb_m/h)
- h_{2is} = specific enthalpy of refrigerant vapor at suction pressure and temperature entering the compressor stage i, kJ/kg (Btu/lb_m)
- h_{3is} = specific enthalpy of refrigerant vapor at the discharge pressure for stage i following an isentropic compression of the refrigerant from compressor stage suction pressure and temperature, kJ/kg (Btu/lb_m)
- P = total power input to the UUT, kW(hp)

5.9.1.3 ~~5.8.1.3~~ Isentropic Efficiency for a Two-Stage Compressor with Vapor Injection. Figure 4a and 4b shows the cycle schematic and pressure-enthalpy diagram for a two-stage compressor with vapor injection using a flash tank economizer. Figure 5a and 5b shows the cycle schematic and pressure-enthalpy diagram for a two-stage compressor with vapor injection using a heat exchanger economizer and liquid refrigerant that is extracted upstream of the economizer. Figure 6a and 6b shows the cycle schematic and pressure-enthalpy diagram for a two-stage compressor with vapor injection using a heat exchanger economizer and liquid refrigerant that is extracted downstream of the economizer.

The isentropic efficiency for a two-stage compressor with vapor injection using an economizer shall be calculated using Equation 5 for SI units or using Equation 6 for I-P units.

$$\eta = \frac{[\dot{m}_1(h_{3_{1s}} - h_{2_{1s}}) + \dot{m}_2(h_{3_{2s}} - h_{2_{2s}})]}{P} \; ~~\times 100~~ \quad (5)$$

~~$$\eta = \frac{[\dot{m}_1(h_{3_{1s}} - h_{2_{1s}}) + \dot{m}_2(h_{3_{2s}} - h_{2_{2s}})]}{P} \times 0.000393 \quad (6)$$~~

$$\eta = \frac{[\dot{m}_1(h_{3_{1s}} - h_{2_{1s}}) + \dot{m}_2(h_{3_{2s}} - h_{2_{2s}})]}{P} \times 0.000392979 \quad (6)$$

where

- η = isentropic efficiency for a two-stage stage compressor with vapor injection, ~~%~~ dimensionless
- $\dot{m}_1$ = refrigerant mass flow rate entering the compressor, kg/s (lb_m/h)
- $\dot{m}_2$ = refrigerant mass flow rate after mixing the injection flow and inlet flow, kg/s (lb_m/h)
- $h_{2_{1s}}$ = specific enthalpy of refrigerant vapor at suction pressure and temperature entering the compressor, kJ/kg (Btu/lb_m)
- $h_{2_{2s}}$ = specific enthalpy of refrigerant vapor after mixing the intermediate pressure flow at state point 5 with the flow at state point 3_{1s} shall be calculated using Equation 7 kJ/kg (Btu/lb_m)

$$h_{2_{2s}} = \frac{(\dot{m}_1 h_{3_{1s}} + \dot{m}_{inj} h_5)}{\dot{m}_2} \quad (7)$$

- $h_{3_{1s}}$ = specific enthalpy of refrigerant vapor at intermediate pressure following an isentropic compression of the refrigerant from compressor suction pressure and temperature, kJ/kg (Btu/lb_m)
- $h_{3_{2s}}$ = specific enthalpy of refrigerant vapor at compressor discharge pressure following an isentropic compression of the refrigerant from state point 2_{2S}, kJ/kg (Btu/lb_m)
- h_5 = specific enthalpy of refrigerant injected into compressor at intermediate pressure, shall be calculated based on pressure p_5 and temperature T_5 measured within 50 mm (2 in.) of the inlet to the compressor except where otherwise specified by the test plan in Section 5.1, kJ/kg (Btu/lb_m)
- $\dot{m}_{inj}$ = refrigerant mass flow rate injected into compressor at intermediate pressure, kg/s (lb_m/h)

a. For a flash tank economizer as shown in Figure 4a and 4b, $\dot{m}_{inj}$ shall be calculated using Equation 8 or Equation 9.
b. For a heat exchanger economizer as shown in Figure 5a and 5b, where liquid refrigerant is extracted upstream of the economizer, $\dot{m}_{inj}$ shall be measured in the liquid line at the inlet of Expansion Device 2 or calculated using Equation 10.
c. For a heat exchanger economizer as shown in Figure 6a and 6b, where liquid refrigerant is extracted downstream of the economizer, $\dot{m}_{inj}$ shall be measured in the liquid line at the inlet of Expansion Device 2 or calculated using Equation 11.

$$\dot{m}_{inj} = \frac{\dot{m}_1 \times x_{vapor}}{(1-x_{vapor})} \quad (8)$$

$$m_{inj} = \dot{m}_2 - \dot{m}_1 \quad (9)$$

$$\dot{m}_{inj} = \frac{\dot{m}_1(h_{4_2}-h_{4_1})}{(h_5-h_{4_2})} \quad (10)$$

$$\dot{m}_{inj} = \frac{\dot{m}_2(h_{4_2}-h_{4_1})}{(h_5-h_{4_1})} \quad (11)$$

where

h_{4_2} = specific enthalpy of subcritical liquid refrigerant or specific enthalpy of supercritical refrigerant fluid entering economizer, kJ/kg (Btu/lb$_m$)
h_{4_1} = specific enthalpy of liquid refrigerant leaving economizer, kJ/kg (Btu/lb$_m$)
x_{vapor} = quality of refrigerant in economizer based on h_{4_2} and pressure p_5, ~~%~~ dimensionless
P = total power input to the UUT, kW (hp)

5.9.1.4 ~~5.8.1.4~~ Isentropic Efficiency for Compressors Connected in Series with Vapor Injection. Figure 7a and 7b shows the cycle schematic and pressure-enthalpy diagram for compressors connected in series with vapor injection using a flash tank economizer. Figure 8a and 8b shows the cycle schematic and pressure-enthalpy diagram for compressors connected in series with vapor injection using a heat exchanger economizer and liquid refrigerant that is extracted upstream of the economizer. Figure 9a and 9b shows the cycle schematic and pressure-enthalpy diagram for compressors connected in series with vapor injection using a heat exchanger economizer and liquid refrigerant that is extracted downstream of the economizer. The isentropic efficiency for compressors connected in series with vapor injection using an economizer shall be calculated using Equation 12 for SI units or using Equation 13 for I-P units.

$$\eta = \frac{[\dot{m}_1(h_{3_{1s}}-h_{2_{1s}})+\dot{m}_2(h_{3_{2s}}-h_{2_{2s}})]}{P} ~~\times 100~~ \quad (12)$$

~~$$\eta = \frac{[\dot{m}_1(h_{3_{1s}}-h_{2_{1s}})+\dot{m}_2(h_{3_{2s}}-h_{2_{2s}})]}{P} \times 0.000393 \quad (13)$$~~

$$\eta = \frac{[\dot{m}_1(h_{3_{1s}}-h_{2_{1s}})+\dot{m}_2(h_{3_{2s}}-h_{2_{2s}})]}{P} \times 0.000392979 \quad (13)$$

where

η = isentropic efficiency for compressors connected in series with vapor injection, ~~%~~ dimensionless
$\dot{m}_1$ = refrigerant mass flow rate entering the first compressor, kg/s (lb$_m$/h)
$\dot{m}_2$ = refrigerant mass flow rate after mixing the injection flow rate and inlet flow to the first compressor, kg/s (lb$_m$/h)
$h_{2_{1s}}$ = specific enthalpy of refrigerant vapor entering the first compressor, kJ/kg (Btu/lb$_m$)
$h_{2_{2s}}$ = specific enthalpy of refrigerant vapor after mixing the intermediate pressure flow at state point 5 with the flow at state point 3_{1s} shall be calculated using Equation 14, kJ/kg (Btu/lb$_m$)

$$h_{2_{2s}} = \frac{(\dot{m}_1 h_{3_{1s}} + \dot{m}_{inj} h_5)}{\dot{m}_2} \tag{14}$$

$h_{3_{1s}}$ = specific enthalpy of refrigerant vapor at intermediate pressure following an isentropic compression of the refrigerant from compressor suction pressure and temperature, kJ/kg (Btu/lb_m)

$h_{3_{2s}}$ = specific enthalpy of refrigerant vapor at compressor discharge pressure following an isentropic compression of the refrigerant from state point 2_{2S}, kJ/kg (Btu/lb_m)

h_5 = specific enthalpy of refrigerant injected into compressor at intermediate pressure, shall be calculated based on pressure p_5 and temperature T_5 measured within 50 mm (2 in.) of the inlet to the compressor except where otherwise specified by the test plan in Section 5.1, kJ/kg (Btu/lb_m)

$\dot{m}_{inj}$ = refrigerant mass flow rate injected into compressor at intermediate pressure, kg/s (lb_m/h).

a. For a flash tank economizer as shown in Figure 7a and 7b, $\dot{m}_{inj}$ shall be calculated using Equation 15 or Equation16.
b. For a heat exchanger economizer as shown in Figure 8a and 8b, where liquid refrigerant is extracted upstream of the economizer, $\dot{m}_{inj}$ shall be measured in the liquid line at the inlet of Expansion Device 2 or calculated using Equation 17.
c. For a heat exchanger economizer as shown in Figure 9a and 9b, where liquid refrigerant is extracted downstream of the economizer, $\dot{m}_{inj}$ shall be measured in the liquid line at the inlet of Expansion Device 2 or calculated using Equation 18.

$$\dot{m}_{inj} = \frac{\dot{m}_1 (x_{vapor})}{(1 - x_{vapor})} \tag{15}$$

$$\dot{m}_{inj} = \dot{m}_2 - \dot{m}_1 \tag{16}$$

$$\dot{m}_{inj} = \frac{\dot{m}_1 (h_{4_2} - h_{4_1})}{(h_5 - h_{4_2})} \tag{17}$$

$$\dot{m}_{inj} = \frac{\dot{m}_2 (h_{4_2} - h_{4_1})}{(h_5 - h_{4_1})} \tag{18}$$

where

h_{4_2} = specific enthalpy of liquid refrigerant or supercritical refrigerant fluid entering economizer, kJ/kg (Btu/lb_m)

h_{4_1} = specific enthalpy of liquid refrigerant leaving economizer, kJ/kg (Btu/lb_m)

x_{vapor} = quality of refrigerant in economizer based on h_{4_2} and pressure p5, ~~%~~ dimensionless

P = total power input to the UUT, kW (hp)

Renumber Sections 5.8.2, 5.8.2.1, and 5.8.2.2 as 5.9.2, 5.9.2.1, and 5.9.2.2 respectively.

5.9.2 ~~5.8.2~~ Capacity. The capacity of a UUT, if required by the test plan in Section 5.1, shall be calculated as described in Section 5.9.2.1 ~~5.7.2.1~~ or 5.9.2.2 ~~5.7.2.2~~.

5.9.2.1 ~~5.8.2.1~~ The capacity of a UUT without vapor injection shall be calculated using Equation 19.

$$Q = \dot{m}_1 (h_2 - h_1) \tag{19}$$

where

Q = capacity of a UUT at the specified operating conditions, kW (Btu/h)

$\dot{m}_1$ = refrigerant mass flow rate entering the evaporator, kg/s (lb_m/h)

h_1 = specific enthalpy of refrigerant entering the evaporator, kJ/kg (Btu/lb_m)
h_2 = specific enthalpy of refrigerant entering the compressor from the evaporator, kJ/kg (Btu/lb_m)

5.9.2.2 ~~5.8.2.2~~ The capacity of a UUT with vapor injection shall be calculated using Equation 20.

$$Q = \dot{m}_1(h_{2_1} - h_{1_1}) \tag{20}$$

where
Q = capacity of a UUT at the specified operating conditions, kW (Btu/h);
$\dot{m}_1$ = refrigerant mass flow rate, entering the evaporator kg/s (lb_m/h);
h_{1_1} = specific enthalpy of refrigerant entering the evaporator, kJ/kg (Btu/lb_m);
h_{2_1} = specific enthalpy of refrigerant entering the compressor from the evaporator, kJ/kg (Btu/lb_m)

Renumber Section 5.8.3 to 5.9.3.

5.9.3 ~~**5.8.3**~~ **Performance Factor.** The performance factor shall be calculated based on the capacity and power input at specified operating conditions. The alternative forms of the *performance factor* are the coefficient of performance (COP) as defined in Equation 21, the energy efficiency ratio (EER) as defined in Equation 22, and ratio of power input to capacity as defined in Equation 23.

$$COP = \frac{Capacity,\ W}{Power\ Input,\ W} \tag{21}$$

$$EER = \frac{Capacity,\ Btu/h}{Power\ Input,\ W} \tag{22}$$

$$\frac{bhp}{ton} = \frac{Power\ Input,\ bhp}{Capacity,\ ton} \tag{23}$$

Renumber Sections 5.8.4, 5.8.4.1, and 5.8.4.2 as 5.9.4, 5.9.4.1, and 5.9.4.2 respectively and make corrections as shown below.

5.9.4 ~~**5.8.4**~~ **Volumetric Efficiency.** For multi-stage compressors, the volumetric efficiency shall be calculated for the first stage only.

5.9.4.1 ~~5.8.4.1~~ **Volumetric Efficiency for Compressor Types except Linear Compressors.** Volumetric efficiency, if required in the test plan, shall be calculated using Equation 24 for SI units or Equation 25 for I-P units:

$$\eta_v = \frac{(\dot{m})(v)}{(V)(N)} \cancel{\times 100} \tag{24}$$

$$\eta_v = \frac{(\dot{m})(v)}{(V)(N)} \times 2880 \tag{25}$$

where

η_v = volumetric efficiency, ~~%~~ dimensionless
$\dot{m}$ = refrigerant mass flow rate entering the compressor, kg/s (lb_m/h)
v = specific volume of the refrigerant vapor entering the compressor, m^3/kg (ft^3/lb_m)
V = geometric displacement of the compressor, m^3/rev (in^3/rev)

N = compressor shaft rotational speed, rev/s (rpm)

5.9.4.2 ~~5.8.4.2~~ Volumetric Efficiency for Linear Compressors. Volumetric efficiency, if required in the test plan, shall be calculated using Equation 26 for SI units or Equation 27 for I-P units:

$$\eta_v = \frac{(\dot{m})(v)}{(V_{max})(f)} \cancel{\times 100} \tag{26}$$

$$\eta_v = \frac{(\dot{m})(v)}{(V_{max})(f)} \times 0.48 \tag{27}$$

where

η_v = volumetric efficiency, ~~%~~ dimensionless
$\dot{m}$ = refrigerant mass flow rate entering the compressor, kg/s (lb_m/h)
v = specific volume of the refrigerant vapor entering the compressor, m^3/kg (ft^3/lb_m)
V_{max} = geometric displacement of the compressor at maximum stroke, m^3/cycle (in^3/cycle)
f = compressor operating frequency, Hz

In Section 10, Normative Reference 5 has been updated and Normative Reference 6 has been added.

10. REFERENCES

[1]ASHRAE. ~~2018~~ 2021. ANSI/ASHRAE Standard 41.9, *Calorimeter Test Methods for Mass Flow Measurements of Refrigerants*. Atlanta: ASHRAE.

[2]ASHRAE. ~~2013~~ 2020. ANSI/ASHRAE Standard 41.10, *Flowmeter Test Methods for Mass Flow Measurement of Refrigerants*. Atlanta: ASHRAE.

[3]ASHRAE. ~~2014~~ 2020. ANSI/ASHRAE Standard 41.11, *Standard Methods for Power Measurements*. Atlanta: ASHRAE.

[4]NIST. 2013. Reference Fluid Thermodynamic and Transport Properties ~~Thermodynamic Properties of Refrigerants and Refrigerant Mixtures~~ Database (REFPROP). NIST Standard Reference Database 23, Version 10, National Institute of Standards and Technology, Gaithersburg, MD.

[5]ASHRAE. 2014. ANSI/ASHRAE Standard 41.6, *Standard Method for Humidity Measurement*. Atlanta: ASHRAE.

[6] NIST Special Publication 1038, *The International System of Units (SI) – Conversion Factors for General Use, 2006.* National Institute of Standards and Technology, Gaithersburg, MD.

Notes:

1. Reference 1 is only required if a selected primary or secondary test method is a calorimeter method.
2. Reference 2 is only required if a selected primary or secondary test method is a flowmeter method.
3. Reference 5 is only required if the compressor unit is evaporatively-cooled.