BSR/ASHRAE Standard 23.2-2014R

Public Review Draft

Methods of Test for Rating the Performance of Positive Displacement Compressors that Operate at Supercritical Pressures of the Refrigerants

First Public Review (April 2019)
(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 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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FOREWORD

ASHRAE Standard 23.2, Methods of Testing for Rating the Performance of Positive Displacement Refrigerant Compressors and Compressor Units that Operate at Subcritical Temperatures of the Refrigerant*, does not apply to the performance testing of positive displacement compressors that operate at supercritical pressures of the refrigerant (for example, compressors that operate on* CO_2*). This standard provides methods of test for rating the performance of positive displacement compressors and compressor units that operate at supercritical pressures of the refrigerant. This standard is written in compliance with ASHRAE's mandatory language requirements.*

1. PURPOSE

This standard prescribes methods for performance testing positive displacement refrigerant compressors and compressor units that operate at supercritical pressures of the refrigerant.

2. SCOPE

2.1 This standard applies to methods for performance testing single-stage and multi-stage positive displacement refrigerant compressors and condensing units that operate at discharge pressures greater than the critical pressure of the refrigerant.

2.2 This standard applies to compressors and condensing units that either (a) do not have intermediate cooling or refrigerant injection, or (b) do have intermediate cooling or refrigerant injection and the power required for intermediate cooling or refrigerant injection, if any, is included in the measured total input power to the compressor or condensing unit.

3. DEFINITIONS

The following definitions apply to the terms used in this standard.

accuracy**:** the degree of conformity of an indicated value to the corresponding true value.

bubble-point temperature: a liquid-vapor equilibrium point for a pure liquid or for a multi-component mixture of miscible, pure component liquids, in the absence of non-condensables, where the temperature of the mixture at a defined pressure is the minimum temperature required for a vapor bubble to form in the liquid.

calorimeter: a thermally insulated apparatus containing a heat exchanger that is used to determine the mass flow rate of a refrigerant by measuring the heat input/output that will result in a corresponding enthalpy change for the refrigerant.

capacity: the rate of heat removal by the refrigerant used in the compressor or compressor unit in a refrigerating system. This rate equals the product of the refrigerant mass flow rate and the difference in the specific enthalpies of the refrigerant vapor at its thermodynamic state entering the compressor or compressor unit and refrigerant liquid at the thermodynamic state entering the expansion device.

compressor: see positive displacement compressor.

compressor* or *compressor unit efficiency (isentropic efficiency): the ratio of the work absorbed for compressing a unit mass of refrigerant entering the stage of the compressor or compressor unit to the work absorbed for compressing the same unit mass of refrigerant by isentropic compression within the stage.

compressor unit: one or more positive displacement compressors and motors with ancillaries. ***Informative Note:*** Ancillaries might include fans, liquid receivers, heat exchangers, strainers, service valves, check valves, suction filters, lubricant separators, motor starters, unloaders, and variable-capacity controls, as supplied or specified by the manufacturer.

confirming test: an independent and simultaneous test performed to validate the primary test results (compare to *primary test*). Compressor or compressor unit ratings are determined from the primary test results.

cooling liquid flow rate: the total mass flow rate of liquid required for all cooling purposes in a compressor or compressor unit.

dew-point temperature: a vapor-liquid equilibrium point for a pure liquid or for a multi-component mixture of miscible, pure components, in the absence of non-condensables, where the temperature of the mixture at a defined pressure is the maximum temperature required for a liquid drop to form in the vapor.

economizer: a heat exchanger or flash tank that is used to reduce enthalpy entering the evaporator via refrigerant flow to a compressor at intermediate pressure.

energy efficiency ratio (EER): a dimensional ratio of the cooling capacity (Btu/h) to the power input (W).

error: the difference between the test result and its corresponding true value.

flowmeter: a device employing a detecting element that determines the flow rate of a refrigerant in the gaseous, liquid, or supercritical phase within a closed conduit by measuring a response of the detecting element.

hermetic compressor*:* a compressor assembly containing a motor within a gas tight housing that is permanently sealed by welding or brazing with no access for servicing internal parts in the field.

intermediate cooling: a method of using a heat exchanger to (a) cool the compressor mechanism or lubricant, or (b) cool the refrigerant to reduce discharge temperature. The heat exchanger component of the intermediate cooling means is integral to the compressor. The intermediate cooling thermal load is not taken into account in the calculations of isentropic efficiency, compressor or compressor unit capacity, or volumetric efficiency.

liquid injection: a method of (a) internally cooling the compressor mechanism or lubricant, or (b) reducing discharge temperature by introducing saturated or subcooled discharge-side liquid refrigerant into the compressor. Liquid refrigerant injection mass flow rate is not taken into account in the calculations of isentropic efficiency, compressor or compressor unit capacity, or volumetric efficiency.

lubricant circulation rate: the ratio, expressed as a percent, of the mass of lubricant circulating through a refrigerant system to the total mass of refrigerant and lubricant flowing through the system at a specified set of operating conditions.

measurement system: the instruments, signal conditioning systems, if any, and data acquisition systems, if any.

motor-compressor: a motor and an open-drive compressor mounted onto a common base but not integrated into a gas-tight housing (compare to semi-hermetic compressor).

multi-stage compressor: a compressor that has two or more compression chambers connected in series.

open compressor: a refrigerant compressor with a shaft or other moving part extending through its casing to be driven by an external source of mechanical power.

performance factor: the ratio of capacity to power input at specified operating conditions.

positive displacement refrigerant compressor: a machine that increases the pressure of a refrigerant vapor by reducing the compression chamber volume.

primary test: a test performed to determine the ratings of a compressor or compressor unit (compare to confirming test).

saturation temperature: the equilibrium temperature of a pure refrigerant or an azeotropic refrigerant in a two-phase mixture of a vapor and liquid at a given absolute pressure.

semi-hermetic compressor: a motor-compressor assembly contained within a gas-tight housing that is sealed by gasketed joints to provide access for servicing internal parts (compare to motor-compressor).

single-stage compressor: a compressor that has a single compression chamber or a compressor with two or more compression chambers connected in parallel.

subcooling: the difference between the liquid temperature entering the refrigerant control device and the bubble-point temperature at a defined pressure.

suction temperature: the temperature of the refrigerant vapor returning to the compressor or condensing unit.

superheat: the difference between the suction temperature and the dew-point temperature at a defined pressure.

test point: a specific set of test operating conditions and tolerances for recording data.

true value: the unknown, error-free value of a test result.

uncertainty: a measure of the potential error in measurement or experimental result that reflects the lack of confidence in the result to a specified level.

unit under test (UUT): a positive-displacement compressor or compressor unit.

vapor injection: a method of (a) increasing evaporator capacity using an economizer to cool refrigerant exiting the gas cooler, and (b) reducing discharge temperature. Refrigerant vapor or wet vapor that exits the economizer enters an intermediate port or an interstage port on the compressor.

volumetric efficiency: the ratio of the actual volumetric flow to the ideal volumetric flow that corresponds to the maximum geometric compressor displacement.

4. CLASSIFICATIONS

4.1 Compressor Types. Positive-displacement compressors that are within the scope of this standard are classified as one of the following types:

4.1.1 Open compressor.

4.1.2 Hermetic compressor.

4.1.3 Semihermetic compressor.

4.1.4 Motor-compressor.

4.2 Calorimeter Types. Calorimeters that are within the scope of this standard are classified either as evaporator calorimeters or as condenser calorimeters.

4.2.1 Evaporator calorimeters:

a. Secondary refrigerant calorimeter
b. Secondary fluid calorimeter
c. Primary refrigerant calorimeter.

4.2.2 Condenser calorimeter.

4.3 Flowmeter Types. Flowmeters that are within the scope of this standard are classified as one of the following types:

4.3.1 Gaseous refrigerant flowmeter

4.3.2 Liquid refrigerant flowmeter.

5. REQUIREMENTS

5.1 Test Plan. A test plan shall specify the test points and the calculations to be performed. The test plan shall be one of the following:

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.

5.2 Primary and Confirming Refrigerant Mass Flow Rate Measurements. Each test data point shall consist of a primary test and a simultaneous, independent confirming test at a specified set of operating conditions. To be independent:

a. the confirming test measurement systems shall be separate from the corresponding measurement systems in the primary test, and
b. the fluid flows and heat transfers in the confirming test shall neither share nor influence the fluid flows or heat transfers in the primary method.

Compressor or condensing unit ratings shall be determined from refrigerant mass flow rates obtained by the primary method of test. The refrigerant mass flow rates obtained from the primary test are valid only if the corresponding measured refrigerant mass flow rate from the confirming test is within ±3% of the primary test measurement.

Table 1 lists the test method alternatives for measuring refrigerant mass flow rates. The user shall select one of these six test methods to be the primary test method and one of these six test methods to be the confirming test method.

TABLE 1 Alternative test methods for measuring refrigerant mass flow rates

List of Test Methods (Column A)	Measurement Standard	Primary Test Method (Column B)	Confirming Test Method (Column C)
Secondary Refrigerant Calorimeter	ASHRAE 41.9[1]	Select any test method listed in Column A.	Select any test method from Column A provided that the primary and confirming test methods are independent and performed simultaneously.
Secondary Fluid Calorimeter			
Primary Refrigerant Calorimeter			
Condenser Calorimeter			
Gaseous Refrigerant Flowmeter	ASHRAE 41.10[2]		
Liquid Refrigerant Flowmeter			

5.3 Intermediate Cooling and Supercritical Fluid Injection. If intermediate cooling or supercritical fluid injection is included in the UUT:

a. Intermediate cooling shall be performed according to the manufacturer's instructions with respect to the parameters needed to operate the selected method of intermediate cooling. Figure 1 shows the cycle schematic and pressure-enthalpy diagram for a two-stage compressor with intermediate cooling, and Figure 2 shows the cycle schematic and pressure-enthalpy diagram for compressors in series with intermediate cooling. Use Equation 5-6a or 5-6b to calculate the isentropic efficiency for the compressors shown in Figures 5-1 and 5-2.
b. Supercritical fluid injection shall be performed according to the manufacturer's instructions with respect to pressure, temperature, quality, and refrigerant mass flow rate at the injection location.

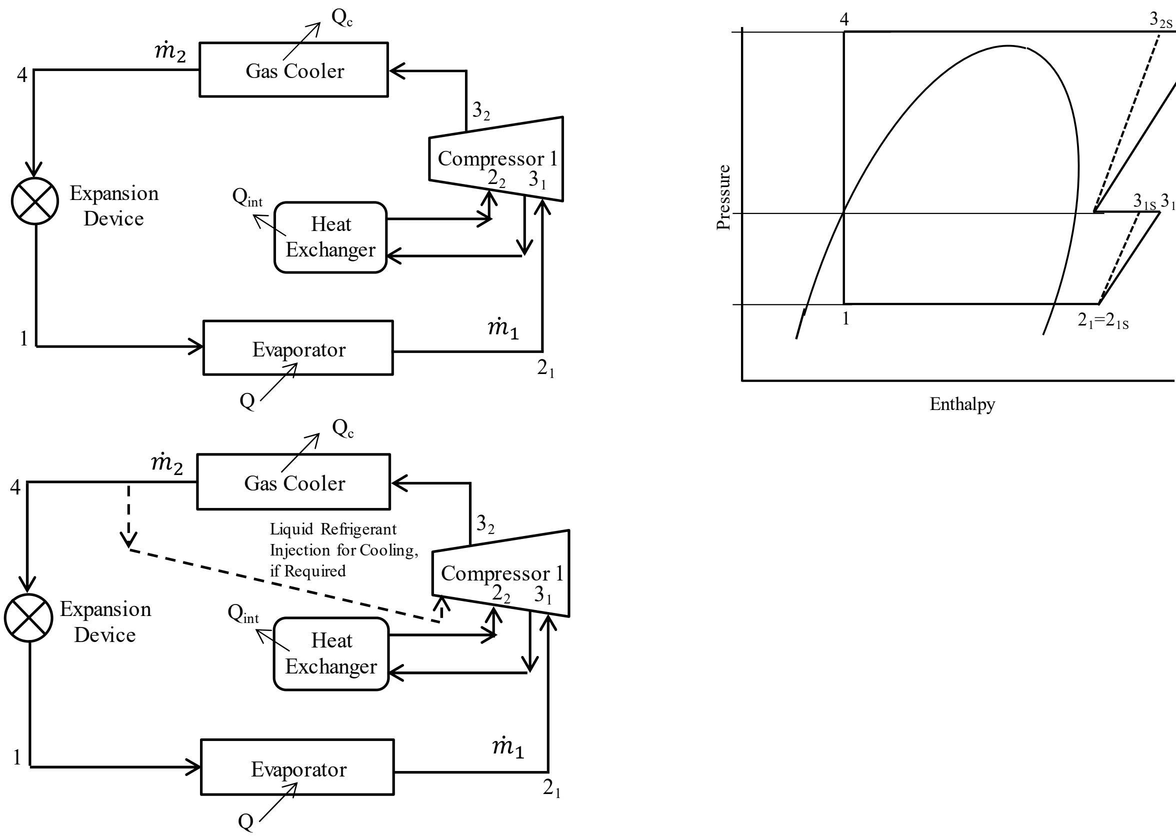


FIGURE 1 Cycle schematic and pressure-enthalpy diagram for a two-stage compressor with intermediate cooling

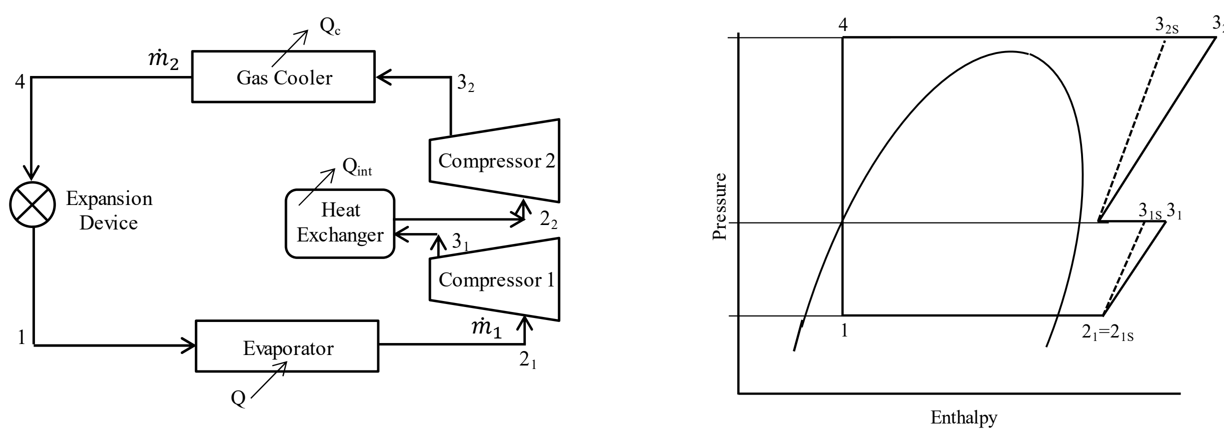


FIGURE 2 Cycle schematic and pressure-enthalpy diagram for compressors in series with intermediate cooling

Informative Note: For example, where testing compressors that use supercritical fluid injection for cooling and include a test method that measures total refrigerant mass flow rate on the supercritical discharge side of the UUT, the supercritical fluid injection mass flow rate may be measured by one of the methods listed in Table 1 and then subtracted from the total refrigerant mass flow rate to determine the refrigerant mass flow rate entering the UUT. The resulting refrigerant mass flow rate is used in the calculations in Section 5.8.

5.4 Input Power. In the primary test method, the total input power, W (hp), to the UUT shall be measured at each test point in accordance with ASHRAE 41.11[3].

5.5 Measurement Uncertainty. The uncertainty in each refrigerant mass flow rate measurement and power input measurement shall be estimated at each test point using the methods prescribed in ASHRAE 41.9[1] or ASHRAE 41.10[2] at 95% probability, unless otherwise specified by the test plan. Alternatively, the worst-case uncertainty for all test points shall be estimated and reported for every test point.

5.6 Refrigerant Data. The primary source of refrigerant properties shall be NIST Thermodynamic Properties of Refrigerants and Refrigerant Mixtures Database (REFPROP)[4]. Refrigerant properties for refrigerants that are not included in REFPROP shall be obtained from the refrigerant supplier. The source of refrigerant properties shall be stated in the test report.

5.7 Refrigerant Numbers. The ASHRAE refrigerant number[A1] for the refrigerant used during these tests shall be stated in the test report.

5.8 Calculations

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.

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

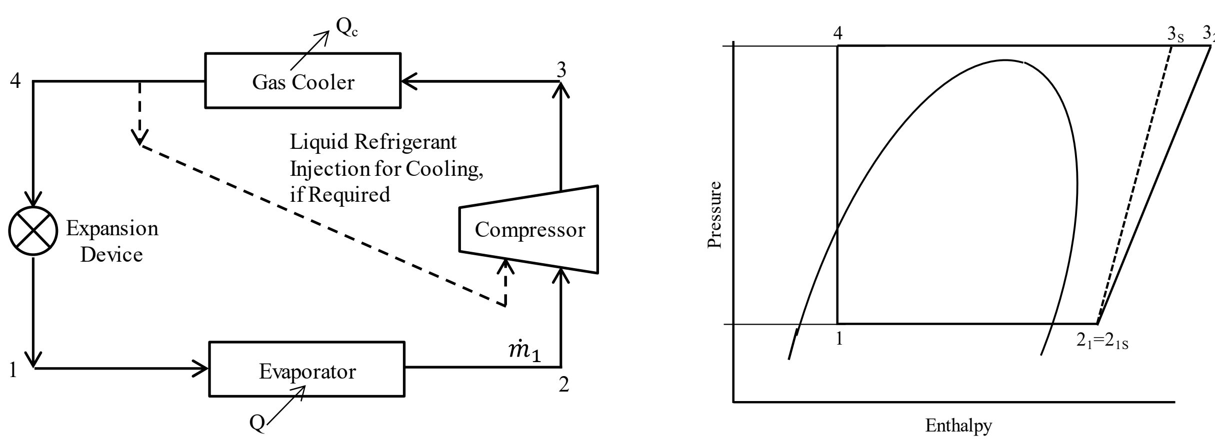


FIGURE 3 Cycle schematic and pressure-enthalpy diagram for a single-stage compressor

The isentropic efficiency for a single-stage compressor as described in Figure 3 shall be calculated using Equation 5-5a for SI units or using Equation 5-5b for I-P units.

$$\eta = \frac{[\dot{m}_1(h_{3s} - h_2)]}{P} \times 100 \qquad (5\text{-}5a)$$

$$\eta = \frac{[(h_{3s} - h_2)]}{P} \times 0.02931 \qquad (5\text{-}5b)$$

where

η = isentropic efficiency, % (%), for a single-stage stage compressor

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

h_2 = 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 (kW)

5.8.1.2 Isentropic Efficiency for a Multi-Stage Compressor. The isentropic efficiency for a multi-stage compressor shall be calculated using Equation 5-6a for SI units or using Equation 5-6b for I-P units.

$$\eta = \frac{[\sum_{i=1}^{NS} \dot{m}_i(h_{3is} - h_{2is})]}{P} \times 100 \qquad (5\text{-}6a)$$

$$\eta = \frac{[\sum_{i=1}^{NS} \dot{m}_i(h_{3is} - h_{2is})]}{P} \times 0.02931 \qquad (5\text{-}6b)$$

where

η = isentropic efficiency, % (%), for a multi-stage compressor

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 (kW)

5.8.1.3 Isentropic Efficiency for a Two-Stage Compressor with Vapor Injection. Figure 4 shows the cycle schematic and pressure-enthalpy diagram for a two-stage compressor with vapor injection using a flash tank economizer. Figure 5 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 6 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.

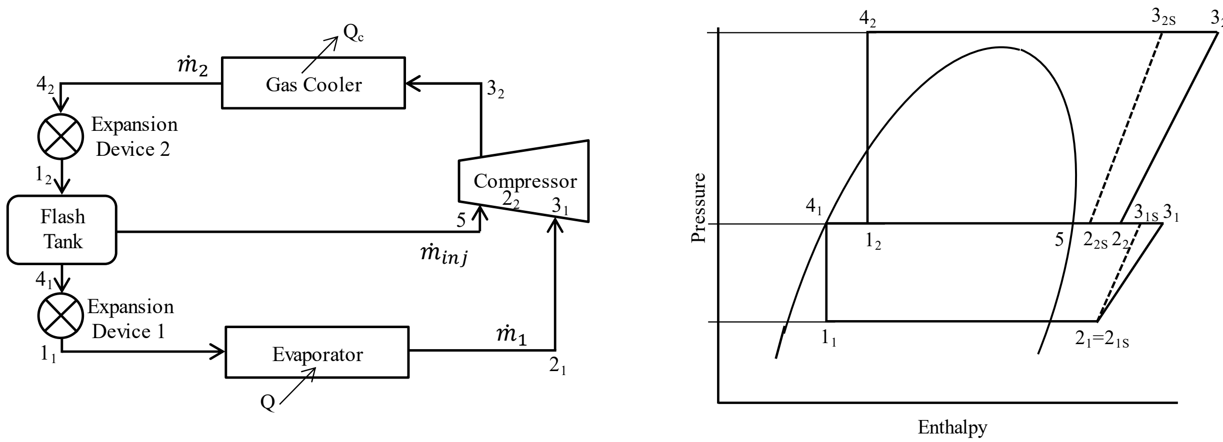


FIGURE 4 Cycle schematic and pressure-enthalpy diagram for a two-stage compressor with vapor injection using a flash tank economizer

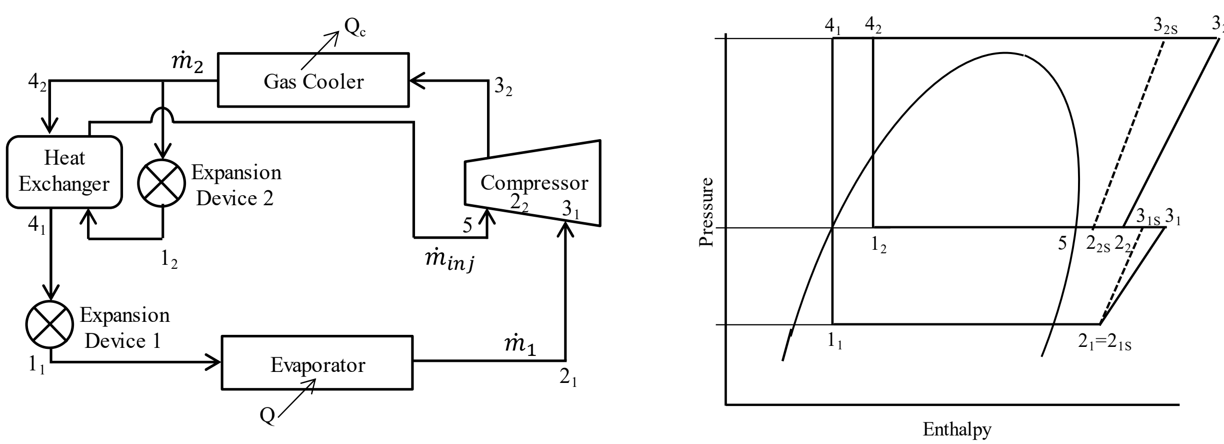


FIGURE 5 Cycle schematic and pressure-enthalpy diagram for a two-stage compressor with vapor injection using a heat exchanger economizer and liquid refrigerant that is extracted upstream of the economizer

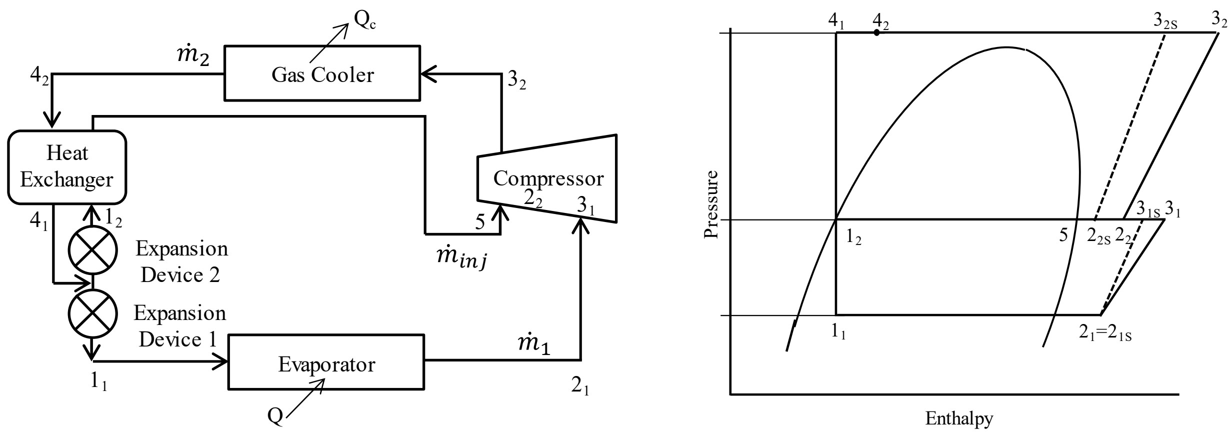


FIGURE 6 Cycle schematic and pressure-enthalpy diagram for a two-stage compressor with vapor injection using a heat exchanger economizer and liquid refrigerant that is extracted downstream of the economizer

The isentropic efficiency for a two-stage compressor with vapor injection using an economizer shall be calculated using Equation 5-7a for SI units or using Equation 5-7b for I-P units.

$$\eta = \frac{[\dot{m}_1(h_{3_{1S}} - h_{2_{1S}}) + \dot{m}_2(h_{3_{2S}} - h_{2_{2S}})]}{P} \times 100 \quad (5\text{-}7a)$$

$$\eta = \frac{[\dot{m}_1(h_{3_{1S}} - h_{2_{1S}}) + \dot{m}_2(h_{3_{2S}} - h_{2_{2S}})]}{P} \times 0.02931 \quad (5\text{-}7b)$$

where

η = isentropic efficiency, % (%), for a two-stage stage compressor with vapor injection

$\dot{m}_1$ = 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 5-8, kJ/kg (Btu/lb_m)

$$h_{2_{2s}} = \frac{(\dot{m}_1 h_{3_{1S}} + \dot{m}_{inj} h_5)}{\dot{m}_2} \quad (5\text{-}8)$$

$h_{3_{1s}}$ = 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 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 2, $\dot{m}_{inj}$ shall be calculated using Equation 5-9a or Equation 5-9b.
b. For a heat exchanger economizer as shown in Figure 3, 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 5-10a.
c. For a heat exchanger economizer as shown in Figure 4, 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 5-10b.

$$\dot{m}_{inj} = \frac{\dot{m}_1 \times x_{vapor}}{(1 - x_{vapor})} \quad (5\text{-}9a)$$

$$m_{inj} = \dot{m}_2 - \dot{m}_1 \quad (5\text{-}9b)$$

$$\dot{m}_{inj} = \frac{\dot{m}_1 (h_{4_2} - h_{4_1})}{(h_5 - h_{4_2})} \quad (5\text{-}10a)$$

$$\dot{m}_{inj} = \frac{\dot{m}_2 (h_{4_2} - h_{4_1})}{(h_5 - h_{4_1})} \quad (5\text{-}10b)$$

where

h_{4_2} = 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, % (%)

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

5.8.1.4 Isentropic Efficiency for Compressors Connected in Series with Vapor Injection. Figure 7 shows the cycle schematic and pressure-enthalpy diagram for compressors connected in series with vapor injection using a flash tank economizer. Figure 8 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 9 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.

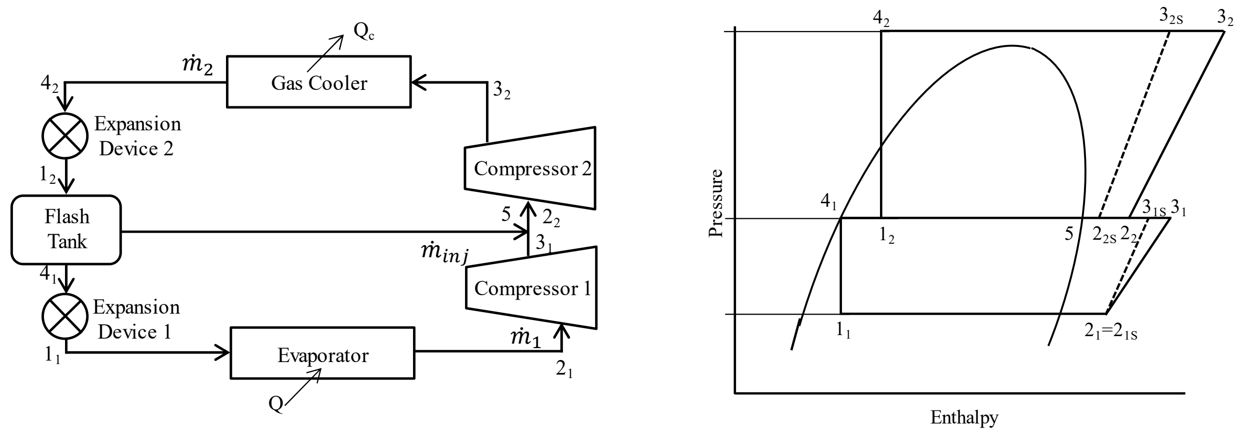


FIGURE 7 Cycle schematic and pressure-enthalpy diagram for compressors connected in series with vapor injection using a flash tank economizer

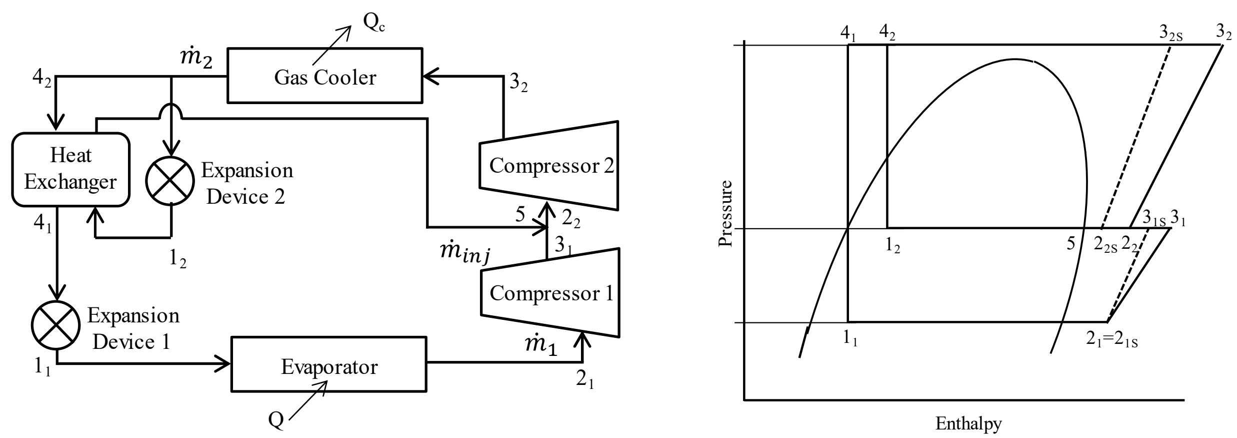


FIGURE 8 Cycle schematic and pressure-enthalpy diagram for compressors connected in series with vapor injection using a heat exchanger economizer and liquid refrigerant that is extracted upstream of the economizer

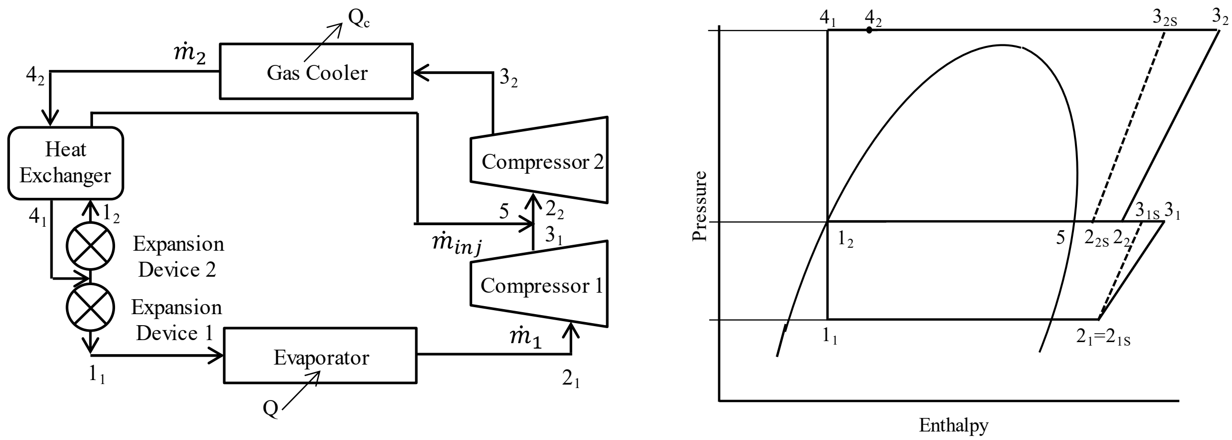


FIGURE 9 Cycle schematic and pressure-enthalpy diagram for compressors connected in series with vapor injection using a heat exchanger economizer and liquid refrigerant that is extracted downstream of the economizer

The isentropic efficiency for compressors connected in series with vapor injection using an economizer shall be calculated using Equation 5-11a for SI units or using Equation 5-11b for I-P units.

$$\eta = \frac{[\dot{m}_1(h_{3_{1s}} - h_{2_{1s}}) + \dot{m}_2(h_{3_{2s}} - h_{2_{2s}})]}{P} \times 100 \qquad (5\text{-}11a)$$

$$\eta = \frac{[\dot{m}_1(h_{3_{1s}} - h_{2_{1s}}) + \dot{m}_2(h_{3_{2s}} - h_{2_{2s}})]}{P} \times 0.02931 \qquad (5\text{-}11b)$$

where

η = isentropic efficiency, % (%), for compressors connected in series with vapor injection

$\dot{m}_1$ = 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 5-12, kJ/kg (Btu/lb_m)

$$h_{2_{2s}} = \frac{(\dot{m}_1 h_{3_{1s}} + \dot{m}_{inj} h_5)}{\dot{m}_2} \tag{5-12}$$

$h_{3_{1s}}$ = 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 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 5, $\dot{m}_{inj}$ shall be calculated using Equation 5-14a or Equation 5-14b.
b. For a heat exchanger economizer as shown in Figure 6, 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 5-14a.
c. For a heat exchanger economizer as shown in Figure 7, 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 5-14b.

$$\dot{m}_{inj} = \frac{\dot{m}_1 (x_{vapor})}{(1 - x_{vapor})} \tag{5-13a}$$

$$\dot{m}_{inj} = \dot{m}_2 - \dot{m}_1 \tag{5-13b}$$

$$\dot{m}_{inj} = \frac{\dot{m}_1 (h_{4_2} - h_{4_1})}{(h_5 - h_{4_2})} \tag{5-14a}$$

$$\dot{m}_{inj} = \frac{\dot{m}_2 (h_{4_2} - h_{4_1})}{(h_5 - h_{4_1})} \tag{5-14b}$$

where

h_{4_2} = 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, % (%)

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

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 5.7.2.1 or 5.7.2.2.

5.8.2.1 The capacity of a UUT without vapor injection shall be calculated using Equation 5-15.

$$Q = \dot{m}_1(h_2 - h_1) \quad (5\text{-}15)$$

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)

5.8.2.2 The capacity of a UUT with vapor injection shall be calculated using Equation 5-16.

$$Q = \dot{m}_1(h_{2_1} - h_{1_1}) \quad (5\text{-}16)$$

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)

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 5-17, the energy efficiency ratio (EER) as defined in Equation 5-18, and ratio of power input to capacity as defined in Equation 5-19.

$$COP = \frac{Capacity,\ W}{Power\ Input,\ W} \tag{5-17}$$

$$EER = \frac{Capacity,\ Btu/h}{Power\ Input,\ W} \tag{5-18}$$

$$\frac{bhp}{ton} = \frac{Power\ Input,\ bhp}{Capacity,\ ton} \tag{5-19}$$

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

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 5-20a for SI units or Equation 5-20b for I-P units:

$$\eta_v = \frac{(\dot{m})(v)}{(V)(N)} \times 100 \tag{5-20a}$$

$$\eta_v = \frac{(\dot{m})(v)}{(V)(N)} \times 2880 \tag{5-20b}$$

where

η_v = volumetric efficiency, %

$\dot{m}$ = 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)

5.8.4.2 Volumetric Efficiency for Linear Compressors. Volumetric efficiency, if required in the test plan, shall be calculated using Equation 5-21a for SI units or Equation 5-21b for I-P units:

$$\eta_v = \frac{(\dot{m})(v)}{(V_{max})(f)} \times 100 \tag{5-21a}$$

$$\eta_v = \frac{(\dot{m})(v)}{(V_{max})(f)} \times 48 \tag{5-21b}$$

where

η_v = volumetric efficiency, %

$\dot{m}$ = 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 (Hz)

6. INSTRUMENTS

6.1 Instruments and data acquisition systems shall be selected to meet the accuracy limits specified in the paragraphs below.

6.2 Measurements from the instruments shall be traceable to primary or secondary standards calibrated by the National Institute of Standards and Technology (NIST) or to the Bureau International des Poids et Mesures (BIPM) if a National Metrology Institute (NMI) other than NIST is used. In either case, the indicated corrections shall be applied to meet the uncertainty stated in subsequent sections. Instruments shall be recalibrated on regular intervals that do not exceed the intervals prescribed by the instrument manufacturer, and calibration records shall be maintained. Instruments shall be installed in accordance with the instrument manufacturer's requirements or the manufacturer's accuracy does not apply.

6.3 Instruments shall be installed and applied in accordance with:

a. Refrigerant mass flow rate: ASHRAE 41.9[1] if a calorimeter method is a selected primary or secondary test method.
b. Refrigerant mass flow rate: ASHRAE 41.10[2] if a flowmeter method is a selected primary or secondary test method.
c. Input power: ASHRAE 41.11[3].

Informative Note: Measurement instrument test condition tolerances are included in ASHRAE 41.9 and 41.10.

6.4 Flowmeter Installation and Accuracy. If ASHRAE 41.10 is a selected primary or secondary test method, the flowmeter measurement system accuracy shall be within ±1.0% of the quantity measured unless otherwise specified in the test plan in Section 5.1.

6.5 Input Power Measurement Accuracy. Input power measurement system accuracy shall be within ±1.0% of the quantity measured unless otherwise specified in the test plan in Section 5.1.

7. COMPRESSOR TEST REPORT

7.1 Test Identification

a. Date, place, time, and duration of test.
b. Operator's name.

7.2 Unit Under Test Description

a. Unit under test (UUT) model number and serial number.
b. Refrigerant identification.[A4]
c. Source of refrigerant thermodynamic property data.
d. Lubricant identification.

7.3 Primary Method Equipment Description

a. Identify the calorimeter or flowmeter test method selected.
b. Test apparatus description, model number, serial number, and date of calibration.

7.4 Confirming Method Equipment Description

a. Identify the calorimeter or flowmeter test method selected.
b. Test apparatus description, model number, serial number, and date of calibration.

7.5 Test Conditions and Limits

7.5.1 Where power input is determined by electrical power measurement, set and maintain the voltage for each phase at the motor terminal within ±1% of the voltage specified in the test plan in Section 5.1.

7.5.2 Where power input is determined by shaft power measurement, set and maintain the shaft speed within ±1% of the speed specified in the test plan.

7.5.3 Where power input is determined by the load setting on a variable-speed compressor or on a pulse-width modulated compressor, set and maintain the load within ±1% of the load specified in the test plan.

7.5.4 Set and maintain the compressor ambient air temperature within ±4ºC (±7ºF) of the value specified in the test plan.

7.5.5 Unless otherwise specified in the test plan or required for ambient air temperature control in Section 8.5.4, airflow from a fan shall not be directed onto the compressor.

Informative Note: Air circulation specifications in the test plan may include volumetric airflow rate, air velocity, temperature, or airflow orientation with respect to the compressor.

7.5.6 Set and maintain the compressor suction pressure within ±1% of the absolute compressor suction pressure specified in the test plan.

7.5.7 Set and maintain the suction superheat within ±1 K (±1.8ºR) of the superheat specified in the test plan.

7.5.8 Vapor or liquid injection shall be performed according to the manufacturer's instructions with respect to pressure, temperature, quality, and refrigerant mass flow rate at the injection location.

7.5.9 Set and maintain the compressor discharge pressure within ±1% of the absolute compressor discharge pressure specified in the test plan.

7.5.10 The UUT manufacturer's requirements for the compressor break in procedure shall be performed prior to any test data recording unless otherwise specified in the test plan.

7.6 Measured Compressor Test Results

a. Ambient air temperature, °C (°F).
b. Specifics regarding ambient circulation over the UUT if required by the test plan.
c. Barometric pressure if a pressure sensing device is referenced to atmospheric pressure.
d. Electrical data if required by the test plan:
    1. Voltage, V.
    2. Frequency, Hz.
    3. Current, A:
        i. Single phase current, A.
        ii. Three phase current, A, for all 3 legs.
    4. Power factor.
    5. Power input, W.
e. Compressor speed if required by the test plan:
    1. Shaft rotational speed, rev/s (rpm).
    2. Shaft input frequency, Hz, for linear compressors or membrane compressors.
f. Suction pressure, kPa (psia).
g. Suction temperature, °C (°F).
h. Discharge pressure, kPa (psia).
i. Discharge temperature, °C (°F).
j. Refrigerant temperature, °C (°F), entering the injection points if vapor injection is included.
k. Refrigerant pressure, kPa (psia), entering the injection points if vapor injection is included.
l. Refrigerant pressure, kPa (psia), entering the calorimeter or flowmeter for the primary test method.
m. Refrigerant temperature, °C (°F), entering the calorimeter or flowmeter for the primary test method.
n. Refrigerant pressure, kPa (psia), leaving the calorimeter or flowmeter for the primary test method.

o. Refrigerant temperature, °C (°F), leaving the calorimeter or flowmeter for the primary test method.
p. Refrigerant pressure, kPa (psia), entering the calorimeter or flowmeter for the confirming test method.
q. Refrigerant temperature, °C (°F), entering the calorimeter or flowmeter for the confirming test method.
r. Refrigerant pressure, kPa (psia), leaving the calorimeter or flowmeter for the confirming test method.
s. Refrigerant temperature, °C (°F), leaving the calorimeter or flowmeter for the confirming test method.
t. Lubricant circulation rate, % by mass, for the primary test.
u. Refrigerant mass flow rates:
    1. If supercritical fluid or vapor injection is not included, or if injection is included and the injected refrigerant mass flow rate is calculated using Equation 5-9, 5-10, 5-13, or 5-14, then either of the following may be selected for the primary and confirming tests:
        i. Total refrigerant mass flow rate entering the compressor, kg/s (lb_m/h),
        ii. Total refrigerant mass flow rate leaving the compressor, kg/s (lb_m/h).
    2. If supercritical fluid or vapor injection is included and the injected refrigerant mass flow rate is not calculated using Equation 5-9, 5-10, 5-13, or 5-14, then select one of the methods below:
        i. Total refrigerant mass flow rate kg/s (lbm/h), measured at each of the following locations, entering the compressor, leaving the compressor, and entering the injection points.
        ii. Total refrigerant mass flow rate kg/s (lbm/h), measured at any two locations, with confirming measurements at both locations.
v. Compressor torque, N-m (ft-lb_f), if required by the test plan.
w. Power input to compressor including ancillaries, W (hp).

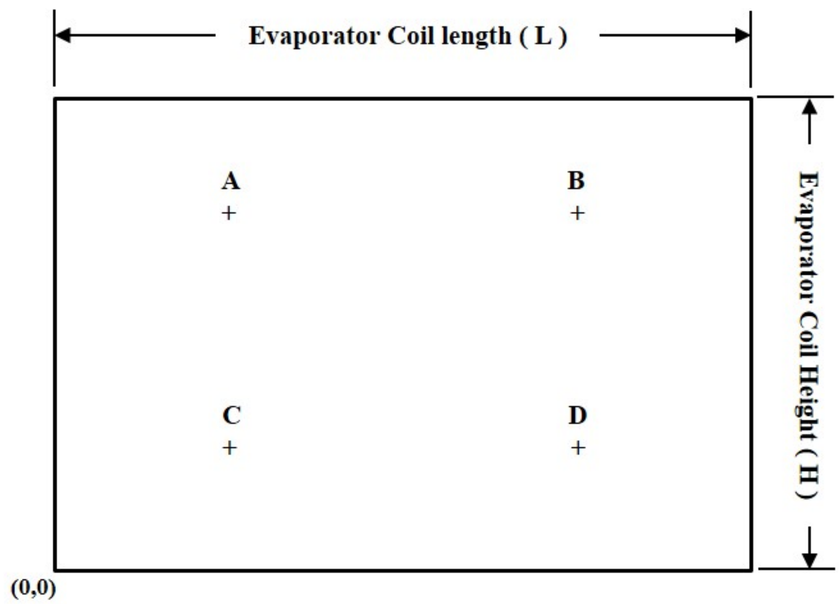
7.7 Calculated Compressor Test Results

a. Uncertainty in refrigerant mass flow rate, kg/s (lb_m/h).
b. Uncertainty in power input, W (hp).
c. Compressor isentropic efficiency, %
d. Performance factor, not less than one of the following:
    1. Coefficient of performance (COP), W/W
    2. Energy efficiency ratio (EER), (Btu/W-h)
    3. Ratio of power input to capacity, bhp/ton
e. Capacity, W (Btu/h), if required by the test plan.
f. Volumetric efficiency, % (if required)

8. COMPRESSOR UNIT OPERATING CONDITIONS

8.1 Liquid-Cooled Gas Coolers

a. No forced ambient air circulation over the unit under test (UUT) is permitted unless otherwise specified in the test plan.
b. The test chamber ambient temperature shall be maintained by forced air circulation.
c. The cooling liquid temperature flowing into and out of the gas cooler shall be set to within ±0.3ºC (0.5ºF) of the cooling inlet and outlet temperatures specified in the test plan.



Dry bulb temperature sensor A coordinates: ([0.25×L ± 3 mm (0.1 in)], [0.75×H ± 3 mm (0.1)(in)])
Dry bulb temperature sensor B coordinates: ([0.75×L ± 3 mm (0.1 in)], [0.75×H ± 3 mm (0.1)(in)])
Dry bulb temperature sensor C coordinates: ([0.25×L ± 3 mm (0.1 in)], [0.25×H ± 3 mm (0.1)(in)])
Dry bulb temperature sensor D coordinates: ([0.75×L ± 3 mm (0.1 in)], [0.25×H ± 3 mm (0.1)(in)])

FIGURE 10 Temperature Sensor Locations

8.2 Air-Cooled Gas Coolers

a. No forced ambient air circulation over the UUT is permitted unless otherwise specified in the test plan.
b. The test chamber ambient temperature shall be maintained by forced air circulation.
c. Four (4) dry-bulb air inlet temperature sensors shall be attached to the gas cooler where specified in Figure 10.
d. The average dry-bulb air inlet temperature shall be set within ±1ºC (±2ºF) of the value specified in the test plan.

8.3 Evaporatively-Cooled Gas Coolers

a. No forced ambient air circulation over the UUT is permitted unless otherwise specified in the test plan.
b. The test chamber ambient temperature shall be maintained by forced air circulation.
c. The wet-bulb inlet temperature shall be set to within ±0.3ºC (0.5ºF) of the value specified in the test plan using wet-bulb temperature measurement methods prescribed by ASHRAE 41.6.[4]
d. Four (4) dry-bulb air inlet temperature sensors shall be attached to the gas cooler where specified in Figure 8-1.
e. The average dry-bulb air inlet temperature shall be set within ±1ºC (±2ºF) of the value specified in the test plan.

9. COMPRESSOR UNIT TEST REPORT

9.1 Test Identification

a. Date, place, time, and duration of test.
b. Operator's name.

9.2 Unit Under Test Description

a. Unit under-test model number and serial number.
b. Refrigerant identification.[A4]
c. Source of refrigerant thermodynamic property data.
d. Lubricant identification.

9.3 Primary Method Equipment Description

a. Identify the calorimeter or flowmeter test method selected.
b. Test apparatus description, model number, serial number, and date of calibration.

9.4 Confirming Method Equipment Description

a. Identify the calorimeter or flowmeter test method selected
b. Test apparatus description, model number, serial number, and date of calibration.

9.5 Test Conditions and Limits

9.5.1 Where power input is determined by electrical power measurement, set and maintain the voltage for each phase at the motor terminal within ±1% of the voltage specified in the test plan in Section 5.1.

9.5.2 Where power input is determined by shaft power measurement, set and maintain the shaft speed within ±1% of the speed specified in the test plan.

9.5.3 Where power input is determined by the load setting on a variable-speed compressor or on a pulse-width modulated compressor, set and maintain the load within ±1% of the load specified in the test plan.

9.5.4 Set and maintain the compressor ambient air temperature within ±4ºC (±7ºF) of the value specified in the test plan.

9.5.5 Unless otherwise specified in the test plan or required for ambient air temperature control in Section 10.5.4, airflow from a fan that is not integral to the UUT shall not be directed onto the compressor.

Informative Note: Air circulation specifications in the test plan may include volumetric airflow rate, air velocity, temperature, or airflow orientation with respect to the compressor.

9.5.6 Set and maintain the compressor suction pressure within ±1% of the absolute compressor suction pressure specified in the test plan.

9.5.7 Set and maintain the superheat within ±1 K (±1.8ºR) of the superheat specified in the test plan.

9.5.8 Vapor or liquid injection shall be performed according to the manufacturer's instructions with respect to pressure, temperature, quality, and refrigerant mass flow rate at the injection location.

9.5.9 Set and maintain the compressor discharge pressure within ±1% of the absolute compressor discharge pressure specified in the test plan.

9.5.10 The UUT manufacturer's requirements for the compressor break in procedure shall be performed prior to any test data recording unless otherwise specified in the test plan.

9.6 Measured Compressor Unit Test Results

a. Average gas cooler inlet dry-bulb air temperature, °C (°F), if the gas cooler is air-cooled or evaporatively-cooled.
b. Average gas cooler inlet wet-bulb air temperature, °C (°F), if the gas cooler is evaporatively-cooled.
c. Liquid-cooled gas cooler inlet temperature, °C (°F), if the gas cooler is liquid-cooled.
d. Liquid-cooled gas cooler outlet temperature, °C (°F), if the gas cooler is liquid-cooled.
e. Ambient air temperature, °C (°F).
f. Specifics regarding ambient airflow circulation over the UUT if required by the test plan.
g. Barometric pressure if a pressure sensing device is referenced to atmospheric pressure.
h. Electrical data if required by the test plan:
    1. Voltage, V.
    2. Frequency, Hz.
    3. Current, A:

        i. Single phase current, A.
        ii. Three phase current, A, for all 3 legs.
    4. Power factor.
    5. Power input, W.

i. Compressor speed if required by the test plan:
    1. Shaft rotational speed, rev/s (rpm).
    2. Shaft input frequency, Hz, for linear compressors or membrane compressors.

j. Suction pressure, kPa (psia).
k. Suction temperature, °C (°F).
l. Discharge pressure, kPa (psia).
m. Discharge temperature, °C (°F).
n. Refrigerant temperature, °C (°F), entering the injection points if vapor injection is included.
o. Refrigerant pressure, kPa (psia), entering the injection points if vapor injection is included.
p. Refrigerant pressure, kPa (psia), entering the calorimeter or flowmeter for the primary test method.
q. Refrigerant temperature, °C (°F), entering the calorimeter or flowmeter for the primary test method.
r. Refrigerant pressure, kPa (psia), leaving the calorimeter or flowmeter for the primary test method.
s. Refrigerant temperature, °C (°F), leaving the calorimeter or flowmeter for the primary test method.
t. Refrigerant pressure, kPa (psia), entering the calorimeter or flowmeter for the confirming test method.
u. Refrigerant temperature, °C (°F), entering the calorimeter or flowmeter for the confirming test method.
v. Refrigerant pressure, kPa (psia), leaving the calorimeter or flowmeter for the confirming test method.
w. Refrigerant temperature, °C (°F), leaving the calorimeter or flowmeter for the confirming test method.
x. Lubricant circulation rate, % by mass, for the primary test.
y. Refrigerant mass flow rates:
    1. If supercritical fluid or vapor injection is not included, or if injection is included and the injected refrigerant mass flow rate is calculated using Equation 5-9, 5-10, 5-13, or 5-14, then select one of the following:
        i. Total refrigerant mass flow rate entering the compressor unit, kg/s (lb_m/h), obtained by a primary and confirming test.
        ii. Total refrigerant mass flow rate leaving the compressor unit, kg/s (lb_m/h), obtained by a primary and confirming test.
    2. If supercritical fluid or vapor injection is included and the injected refrigerant mass flow rate is not calculated using Equation 5-9, 5-10, 5-13, or 5-14, then select one of the methods below:
        i. Total refrigerant mass flow rate kg/s (lbm/h), measured at each of the following locations, entering the compressor, leaving the compressor, and entering the injection points.

ii. Total refrigerant mass flow rate kg/s (lbm/h), measured at any two locations, with confirming measurements at both locations.

z. Compressor torque, N-m (ft·lb_f), if required by the test plan.
aa. Power input to compressor including ancillaries, W (hp).

9.7 Calculated Compressor Unit Test Results

a. Uncertainty in refrigerant mass flow rate, kg/s (lb_m/h).
b. Uncertainty in power input, W (hp).
c. Compressor isentropic efficiency, %
d. Performance factor, not less than one of the following:
    1. Coefficient of performance (COP), W/W.
    2. Energy efficiency ratio (EER), (Btu/W-h).
    3. Ratio of power input to capacity, bhp/ton.
e. Capacity, W (Btu/h), if required by the test plan.
f. Volumetric efficiency, %, if required by the test plan.

10. REFERENCES

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

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

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

[4]NIST. 2013. *Thermodynamic Properties of Refrigerants and Refrigerant Mixtures Database (REFPROP)*. NIST Standard Reference Database 23, Version 9.1, National Institute of Standards and Technology, Gaithersburg, MD.

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

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INFORMATIVE ANNEX A – BIBLIOGRAPHY

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