



GUIDELINE

ASHRAE Guideline 39-2017R

Public Review Draft

Revision of Guideline 39-2017, Method of Test for Measuring Fractionated Compositions of Refrigerant Blends

**First Public Review (August 2024)
(Complete Draft for Full Review)**

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(This foreword is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

FOREWORD

This guideline describes a method of test (MOT) for determining the fractionated compositions of refrigerant blends for the purpose of assigning a safety classification under ANSI/ASHRAE Standard 34. It is prescriptive rather than descriptive; the user must be able to reproduce data on the reference blend R-125/600 and may use either the MOT described here or other methods or apparatus to meet the accuracy requirements.

This MOT is intended to give sufficient details to allow someone who does not routinely perform vapor liquid equilibria (VLE) experiments but is skilled in working with liquefied gases and analytical methods to be able to obtain satisfactory results.

1. PURPOSE

The purpose of this guideline is to establish test methods and procedures to obtain accurate experimentally determined fractionation (vapor and liquid) compositions of refrigerant blends under simulated isothermal leak events from containers and equipment in storage, transport, operation, and service. A fractionation analysis is undertaken to determine the worst case of fractionation for flammability (WCFF) of a refrigerant blend in order to assign flammability safety classifications under criteria established in ANSI/ASHRAE Standard 34. The WCFF, with respect to flammability and worst case of formulation (WCF) compositions of a refrigerant blend, are tested for flammability to determine the refrigerant's lower flame limit and burning velocity, which is used, along with the calculated heat of combustion, in assigning a flammability safety classification for a refrigerant blend.

2. SCOPE

This guideline defines a standardized test apparatus and procedure for experimentally conducting fractionation analyses of refrigerant blends to determine the worst case of fractionation for flammability (WCFF) composition of refrigerant blends or to validate computer simulation programs for fractionation analysis.

3. DEFINITIONS

blend: a refrigerant consisting of a mixture of two or more different chemical compounds, often used individually as refrigerants for other applications.

component: a chemical compound that is mixed with others to form a refrigerant blend.

composition: ratio of components in a blend, normally expressed as a mass percent.

equilibrium: the state in which system properties remain constant with time and, if the system is isolated from its surroundings, the properties do not change.

fractionation: a change in composition of a blend by preferential evaporation of the more volatile components or condensation of the less volatile components.

isothermal leak: a leak that occurs at a fixed temperature—i.e., under conditions such that thermal equilibrium is maintained with the surroundings at a specified fixed temperature.

liquid composition: the concentration (mass percent) of components present in the liquid phase of a refrigerant blend that is in equilibrium with its vapor phase.

liquid sample: a sample taken from the liquid phase of a refrigerant blend.

maximum permissible fill (MPF): maximum amount of refrigerant to be packaged in a shipping container for safe transportation as defined by U.S. Department of Transportation.

nominal formulation: the bulk manufactured composition of the refrigerant blend, which includes the gas and liquid phases.

vapor composition: the concentrations (mass percentages) of components present in the vapor phase of a

refrigerant blend that is in equilibrium with its liquid phase.

vapor sample: a sample taken from the vapor phase of a refrigerant blend.

worst case of formulation for flammability (WCF): the nominal formulation, including the composition tolerances, that results in the most flammable composition.

worst case of fractionation for flammability (WCFF): the composition produced during fractionation of the worst case of formulation for flammability that results in the highest concentration of flammable components as identified in ANSI/ASHRAE Standard 34 in the vapor or liquid phase.

4. APPARATUS

This guideline presents a method to experimentally measure the effect of a slow vapor leak on the composition of a refrigerant blend during storage/shipping or from equipment such as a refrigeration, air conditioning, or heat pumping system. In actuality, the leak may occur over an extended period of time (in some cases, several years), so to realistically and reproducibly simulate this situation in a lab within a reasonable time period, certain methods have been employed to accelerate the attainment of equilibrium and to obtain representative samples.

The thermodynamic consistency, reproducibility, and repeatability actually measured will determine whether the apparatus and methods used are acceptable. Also, validation of the test apparatus using R-125/600 is required. R-125/600 has been shown to be difficult to measure, likely because the less volatile component, R-600, is also the less dense material. Therefore, the top of the liquid layer is lighter and enriched in R-600. Liquid refrigerant vaporizes underneath this lighter liquid and aerosolizes the lighter R-600-rich layer. This aerosol could be carried with the leaking vapor out of the vessel, violating the requirement of only vapor-phase leakage and decrease the extent of segregation. A solution has been to agitate the liquid phase, mixing the lighter layer and not allowing it to form.

This guideline is intended to be prescriptive rather than descriptive; it identifies an approach to reproduce the accepted experimental result for R-125/600 and to obtain valid fractionation data for the blend under consideration. An apparatus and method are described as a detailed option, which may be beneficial for those with less experience in vapor liquid equilibria (VLE) determinations. The apparatus and method are intended to be robust and reliable if followed, but other means to achieve reliable data may be substituted. In any event, the apparatus must be verified at least once every five years or if any changes are made to the apparatus or procedures.

System requirements are as follows:

- a. Vessel shall be a 61.0 cu (1 L) stainless steel cylinder (see Figures 1 and 2 and Table F-1).
- b. Agitation of the liquid (stirring, shaking) by mixing it at least once per hour is required.
- c. Mass flowmeter and needle valve to measure and control the vapor flow rate (set to a mass flow of 2% or less of initial charge/hour).
- d. A sustainable liquid (e.g., isopropanol/water) or air bath to maintain the vessel at the specified temperature $\pm 5^{\circ}\text{F}$ ($\pm 3^{\circ}\text{C}$).
- e. Thermometer for measuring the temperature in the vessel by measuring the bath temperature.
- f. A port at the top of the vessel for leaking and sampling vapor without entraining liquid.
- g. Dip tube to bottom of vessel for taking representative liquid samples.

The following is optional:

- a. Pressure gage or transducer to measure the pressure in the vessel.

A detailed schematic of the experimental vessel and the sampling fixture is shown in Figure 1. An overview diagram of the experimental setup is shown in Figure 2.

The fractionation vessel is charged with the desired initial composition (i.e., worst case of formulation [WCF] to the desired initial fill, 90% or 15% of maximum permissible fill (MPF), depending on the scenario under consideration, and then leaked at a rate of 2% or less of the initial mass per hour. The vapor and liquid shall be analyzed at every 10% weight loss increment of initial charge, which is every five hours. The weight is recorded ± 0.002 lb (± 1 g) to determine the amount of refrigerant leaked and to calculate the mass balance.

It is recommended to analyze the leaking vapor more frequently (for example, every hour).

Agitate the liquid at least once per hour. The liquid is agitated to promote equilibrium.

When taking the liquid sample, the dip tube must be purged to ensure that a representative sample of the liquid phase is obtained. Liquid may be taken by flashing a small amount of the liquid phase into an isolated evacuated system with a gage. The maximum pressure of the sample is kept to less than 80% of its saturation pressure at the lower of test or ambient temperature so that only vapor is present. This sample (if necessary, spot heated to approximately 104°F [40°C] with a heat gun prior to analysis) is then analyzed.

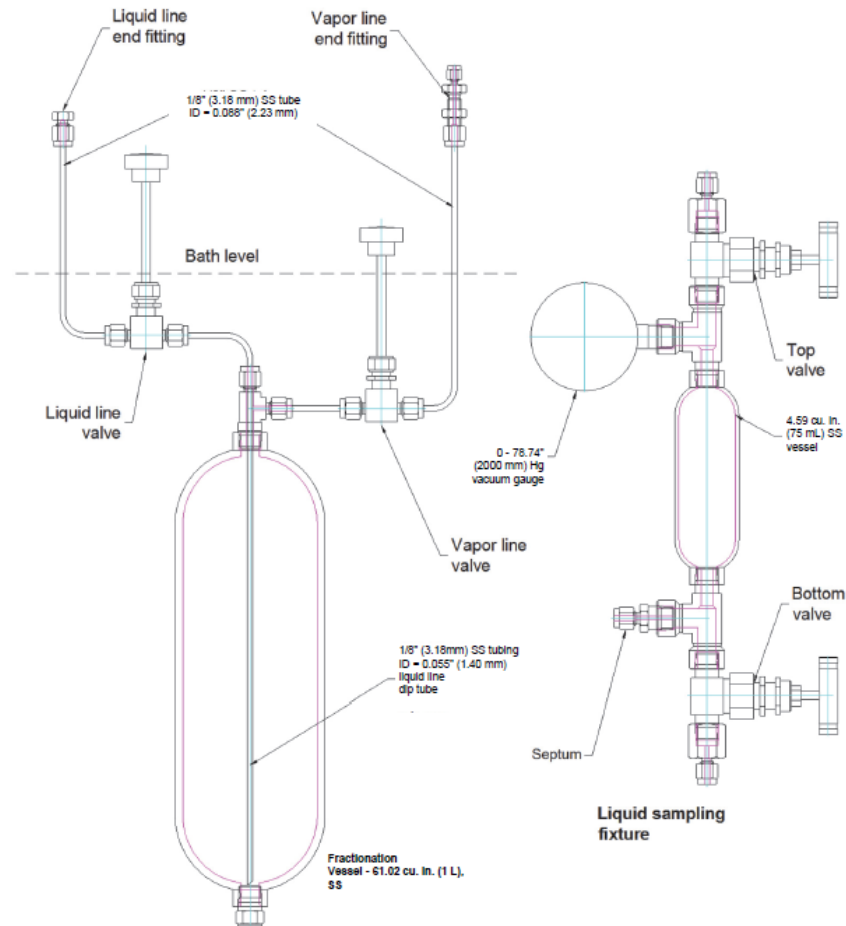


Figure 1 Experimental vessel and sampling fixture.

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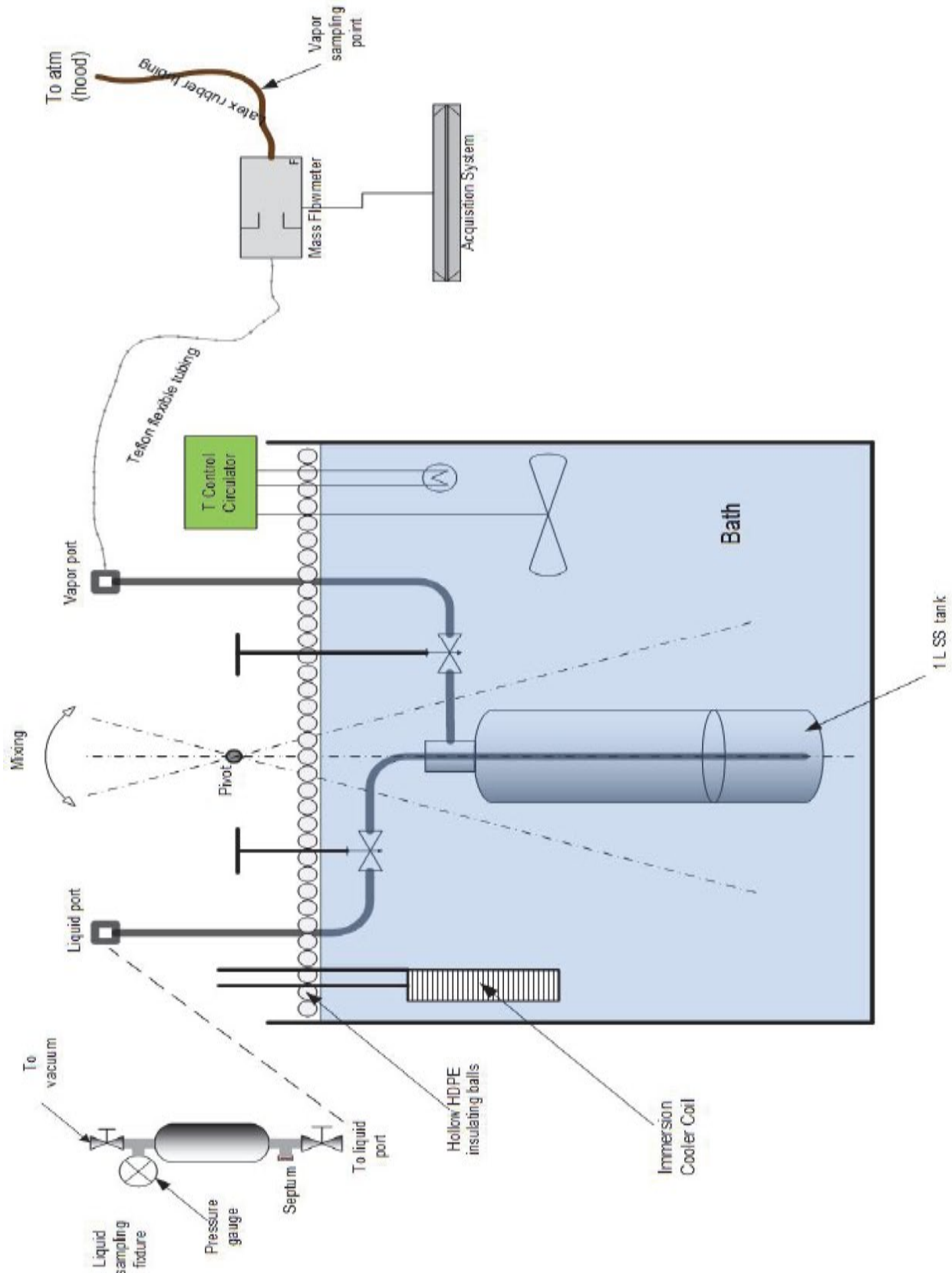


Figure 2 Experimental setup.

5. TEST PROCEDURE

- a. Prepare calibration standards covering the expected range of compositions (see Normative Appendices B and C). Calibrate the analytical method to be used (typically, gas chromatography [GC]/thermal conductivity detector [TCD]).
- b. Clean and leak test the equipment then evacuate the apparatus.
- c. Charge the apparatus and establish thermodynamic equilibrium at the test temperature $\pm 5^{\circ}\text{F}$ ($\pm 3^{\circ}\text{C}$).
- d. Establish a vapor leak of 2% or less of initial charge/hour.
- e. At a minimum, analyze the leaking vapor sample every 10% leaked, but it is recommended to analyze the vapor at least every hour. The tolerance of the analysis shall be better than $\pm 0.5\%$ on an absolute basis.
 1. Vapor sampling (the vessel is still in the bath):
 - i. Direct draw from the vapor line (past the vapor line valve and while the leak is on) using GC syringes equipped with a shut-off valve and a needle piercing the wall of rubberized tubing section of the line.
 - ii. Draw at least two samples.
- f. Sample and analyze the liquid ($\pm 0.5\%$) every five hours until any of the following events is observed: the pressure drops to atmospheric, 95% of the initial charge has leaked, or the liquid phase is exhausted. Sample acquisition procedures are as follows:
 1. Sample acquisition—Liquid sampling (the vessel is still in the bath):
 - i. Stop the vapor leak with the vapor line valve. Disconnect the vapor line tubing from the end fitting and plug the fitting. Proceed to draw the liquid samples and weigh the vessel.
 - ii. Ensure the liquid line valve is closed and remove the plug from the end fitting.
 - iii. Attach one end of the liquid sampling fixture to the end fitting on the liquid line.
 - iv. Attach vacuum line to the other end (top) of the sampling fixture.
 - v. Open both valves (top and bottom) of the sampling fixture.
 - vi. Evacuate the fixture and the section of the liquid line from the end fitting to the liquid line valve.
 - vii. Close the top valve of the sampling fixture.
 - viii. Flush the liquid sample into the sampling fixture by slowly opening the liquid line valve and observing the pressure inside the fixture (not to exceed ambient pressure 1.01 bar [760 mmHg]).
 - ix. Close the liquid line valve.
 - x. Open the fixture top valve to discard first sample and evacuate the fixture again.
 - xi. Close the top fixture valve.
 - xii. Flush the liquid sample into the sampling fixture again by slowly opening the liquid line valve and observing the pressure inside the fixture (not to exceed ambient pressure $+0.267$ bar [200 mmHg]—around 1.20 to 1.33 bar [900 to 1000 mmHg] total pressure).
 - xiii. Close the liquid line valve.
 - xiv. Close the sampling fixture bottom valve.
 - xv. Disconnect the vacuum line.
 - xvi. Disconnect the sampling fixture from the end fitting of the liquid line.
 - xvii. Plug the end fitting of the liquid line.
 - xviii. Samples of vaporized liquid are drawn from the sampling fixture through the septum fitting using GC syringes equipped with a shut-off valve.
 2. Mass loss (after vapor and liquid sampling):
 - i. Remove vessel from bath.
 - ii. Dry the vessel outer walls quickly using paper towels and compressed air.
 - iii. Weigh the vessel.
 - iv. Return the vessel to the bath.
 - v. Difference between current and previous weight reading is a measure of the blend mass loss.

The initial (prior to leakage) weight of the vessel has to be captured in the same conditions (after

submerging it in the bath and drying it off). Time spent on this procedure has to be minimized to avoid increase/decrease of tested liquid blend temperature and to minimize condensation onto the sample vessel when testing at low temperature.

- g. Record the weight ± 0.002 lb (1 g) of material remaining in the cylinder every time (every 10% leaked) alone with the liquid sample.
- h. Continue leaking until any one of the following event is observed:
 - i. one atmosphere pressure is reached in the vessel
 - ii. only vapor exists in the vessel
 - iii. more than 95% has leaked.

Informative Note: The final liquid point may need to be discarded if too little liquid is present to obtain a representative liquid phase sample.

6. TEST REPORT

The reports shall contain the following information:

- a. Description of the apparatus used.
- b. Description of the procedures used.
- c. Description of analysis method.
- d. Calibration results showing deviation from fit.
- e. Description of any variances from the unit and procedures in this method of test.
- f. Validation results from the well-known binary system, i.e., R-125/600 at -33.9°F (-36.6°C) and 130°F (54.4°C).
- g. Test temperature.
- h. Initial composition by gravimetric and GC analysis.
- i. Temperature and composition of the liquid and vapor phases after 2% and at each 10% increment of amount leaked.
- j. Plots of vapor and liquid composition versus amount leaked. Include model results if validating a model.
- k. Plot vapor versus liquid phase composition for test run.

7. DATA CONSISTENCY (DATA QUALITY) CHECKS

Inspection of the data obtained will indicate the quality of the experimental results. Some aspects to look for are as follows:

- a. The plots of composition versus leak quantity are smooth to less than 0.5% of compositions.
- b. Fifteen percent and 90% of maximum permissible fill (MPF) leaked data should follow similar trends, including depletion of the most volatile component—i.e., the one with the lowest boiling point.
- c. For vapor leaks, blend components with a higher concentration in the vapor phase than in the liquid phase should be decreasing in concentration as the leak progresses and vice versa.
- d. Plots of the most flammable compositions obtained versus temperature should be continuous but could show a discontinuity of the slope when the end-of-leak criteria for changes—for example, if the leak ends because of reaching 1 atm rather than 95% leaked.
- e. Plotting the vapor vs. liquid composition results in a smooth curve for each temperature tested.

8. EXPECTED REPRODUCIBILITY OF RESULTS

The composition error is expected to be less than or equal to $\pm 0.5\%$ absolute (± 0.005 mass fraction) at any leaked fraction from a smooth polynomial fit of the data.

Bias can be determined from the difference in analysis of the initial composition from the weights used versus the GC analysis. Further, the validation runs (with the well-known binary system R-125/600) also show bias if it exists. The bias in the data shall be less than $\pm 0.5\%$ absolute.

9. SIGNIFICANCE OF RESULTS

The WCFF, with respect to flammability, is one of two compositions of a refrigerant blend that is tested for flammability to determine the refrigerant's lower flame limit and burning velocity. These values, along with heat of combustion, are used to assign a refrigerant blend's flammability safety classification and quantity limits for use. The results of the test may be used for experimental verification of the fractionation model used to determine the WCFF.

(This appendix is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE APPENDIX A—FRACTIONATION CONDITIONS SUMMARY TABLE

Table A-1 Fractionation Leak Test and Analysis Required by Standard 34

Configuration	Initial Fill	Vapor Leak Rate	Sampling and Analysis Intervals	End of Test	Temperatures
Storage/shipping container ASHRAE Standard 34 (B2.4.1)	90% of maximum permissible fill (MPF) Composition WCF	2% of initial mass per hour	After leaking 2% of initial mass, then at 10%, every 10% to 90% (95% if liquid remains at 90%)	Pressure falls to atmospheric or no liquid remains or 95% of initial mass has been leaked	<ul style="list-style-type: none"> • 130°F (54.4°C) • -40°F (-40°C) or BP + 18°F (10°C) • Intermediate temperature resulting in WCFF or 73°F (23°C)
Leaks from equipment ASHRAE Standard 34 (B2.4.2)	15% of MPF Composition WCF	2% of initial mass per hour	After leaking 2% of initial mass, then at 10%, every 10% to 90% (95% if liquid remains at 90%)	Pressure falls to atmospheric or no liquid remains or 95% of initial mass has been leaked	<ul style="list-style-type: none"> • 140°F (60°C) • -40°F (-40°C) or BP + 18°F (10°C) • Intermediate temperature resulting in WCFF or 73°F (23°C)
Charge leak–recharge ASHRAE Standard 34 (B2.5)	15% of MPF for initial fill, then 15% full for recharges Composition WCF	2% of initial mass per hour	After leaking 20% of initial mass, for each of 5 leak-recharge cycles	When 20% of mas has been leaked after the fourth cycle of 20% leak/20% recharge with WCF	

(This is a normative appendix and is part of this guideline.)

NORMATIVE APPENDIX B—GAS CHROMATOGRAPHY (GC) ANALYSIS

B1. ASHRAE GPC 39P: GC CALIBRATION FUNCTION

Presented here is a summary of the results and procedures for the laboratories participating in the ASHRAE Guideline 39P round-robin tests for GC reproducibility and composition analysis as they relate to the calibration of gas chromatographs. The key results are that (a) calibration on a molar composition basis is more reliable than calibration on a mass basis and (b) inclusion of the (0, 0) and (100, 100) data points in the fit of the calibration curve increases the reliability.

Note: Because we are analyzing refrigerants that are fully vaporized, and the sample injected into the GC is a fixed volume at a fixed pressure, the moles injected are nearly constant. Therefore, the molar composition basis is more appropriate.

The raw data from a GC analysis is typically in terms of area counts for each component in a mixture. These are converted to area percentages:

$$A_i = \frac{c_i}{\sum_{k=1,n} c_k} \quad (\text{B-1})$$

where A_i is the area percentage for component i of the n component mixture, and the c_i are the raw area counts for each component.

One or more standard mixture is analyzed using the same column, temperature program, etc., as the unknowns to generate A_i at known compositions x_i . In addition to these calibration data, it must be the case that a mixture having no component i must yield an area percentage of zero—i.e., $A_i = 0$ for $x_i = 0$. Likewise, a mixture that is 100% component i must yield $A_i = 100$ for $x_i = 100$. The (0, 0) and (100, 100) data points are fitted together with the calibration data to a simple function, such as a polynomial:

$$x_i = b_0 + b_1 A_i + b_2 A_i^2 \quad (\text{B-2})$$

where x_i is composition and the b_i are the coefficients from the fit. Knowing the b_i , the composition of an unknown sample is then easily determined from Equation B-2.

A key result from the GPC 39P round-robin tests is that compositions should be on a molar basis rather than a mass basis. This is illustrated in Figure B-1, which shows results from a round-robin test on R-125/600 mixtures. Note that the calibration function on a molar basis is nearly a straight line, while that on a mass basis shows considerable curvature. The molar function also has a larger correlation coefficient.

These conclusions are based on tests carried out on R-125/600 mixtures by five laboratories participating in the ASHRAE GPC 39P round-robin tests. Initially, the labs used a variety of calibration methods. Other calibration functions, including those based on relative response factor, and a single-point calibration based on a standard close to the composition of the unknown, proved to be less reliable in the round-robin testing. Note that this method is based on tests carried out using thermal conductivity detectors; this method was not applicable to the single lab that used a flame ionization detector (FID).

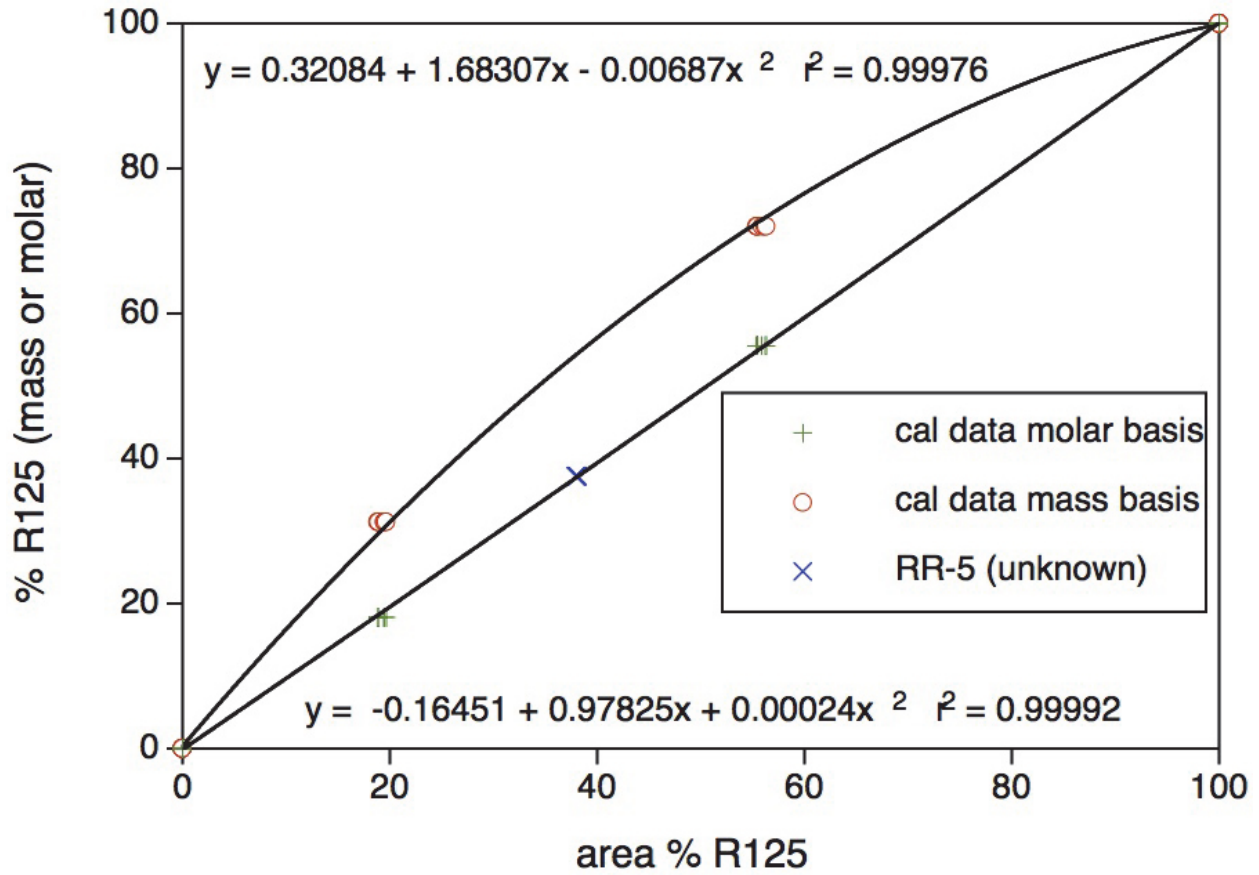


Figure B-1 Comparison of calibration functions on mass and molar bases for R-125/600 mixtures. Note that calibration data from several labs have been combined in this figure.

(This is a normative appendix and is part of this guideline.)

NORMATIVE APPENDIX C—CALIBRATIONS STANDARDS

C1. GAS CALIBRATION BLEND

Gas blends needed for calibrating the gas chromatograph (GC) shall be made where the weight of each component is to be known to an accuracy of at least 0.1%. The standard shall be made in a 50# (23 kg) WC cylinder (20 lb [9.1 kg] propane grill jugs or refrigerant recycling jugs) and containing only vapor. To avoid condensation of a blend component, the partial pressure of each component in the blend shall be less than 80% of its saturation pressure at 68°F (20°C).

As an example, the following directions are offered to prepare a 50%/50% by mass blend of R-125/600 in a 50# (23 kg) WC cylinder with a volume of 0.800 ft³ (22.7 L).

For this blend and these conditions, 0.198 lb (89.8 g) of each component will be needed. If these are known to an accuracy of better than ±0.007 oz (0.2 g), we will have a standard good to ±0.1%. The 50# (23 kg) WC cylinder has a tare weight of approximately 28.6 lb (13 kg). To weight 28.6 lb (13 kg) to an accuracy of ±0.007 oz (0.2 g), great care must be taken, and the process can be expensive.

To avoid this expense, a lighter/smaller cylinder can be used for weighing and then the sample flashed into the 50# (23 kg) WC cylinder. Use of a balance capable of weighing 4 kg to ±0.0004 oz (0.01 g) and a cylinder with a smaller volume (ignoring the small buoyancy correction) also reduces the expense considerably. This method allows the liquid refrigerant blend to be made with accurately known weights and then totally vaporized into the larger cylinder for analysis. As the final sample is only vapor, many issues with liquid sampling and vaporizing are avoided.

Evacuate an 18.3 in.³ (300 cc) cylinder and record the weight and volume. Record weights of clean, dry room-temperature cylinders with nothing attached that can alter the weight—e.g., transfer lines, paper tags, etc. These weights are to be taken before and after the addition of each component. First, add n-butane (3.17 oz [89.8 g]), then add R-125 (3.17 oz [89.8 g]) taking a clean, dry unhindered cylinder weight before addition, between additions, and when finished. Mix the liquids in the cylinder by inverting the cylinder several times. This will give a blend of approximately 50/50 wt% R-125/n-butane. Flash this liquid phase into the 50# (23 kg) WC evacuated cylinder. Allow the cylinder to warm and mix by rolling or spot warming. From the weights, calculate the composition obtained.

This cylinder shall be maintained and stored at temperatures greater than 68°F (20°C).

(This appendix is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE APPENDIX D—R-125/600 FRACTIONATION DATA

Compare experimental fractionation results from REFPROP modeled results. The objective is to obtain data that agrees with the REFPROP results to within $\pm 0.5\%$ in composition at any leak fraction. The expected compositions, as calculated by REFPROP, are given in Tables D-1 and D-2.

Table D-1 REFPROP Simulation of Leak at 90% Initial Fill, Starting Composition R-125/600 (50/50), Vapor Leak at -33.9°F (-36.6°C)

% Loss	Liquid, wt%		Vapor, wt%	
	R-125	R-600	R-125	R-600
2.0	49.2	50.8	93.9	6.1
10.0	45.2	54.8	93.8	6.2
20.0	39.2	60.8	93.4	6.6
30.0	31.5	68.5	92.6	7.4
40.0	21.0	79.0	90.5	9.5
50.0	8.0	92.0	80.7	19.3
60.0	0.0	100.0	0.3	99.7
70.0	0.0	100.0	0.0	100.0
80.0	0.0	100.0	0.0	100.0

Table D-2 REFPROP Simulation of Leak at 90% Initial Fill, Starting Composition R-125/600 (50/50), Vapor Leak at 130°F (-54.4°C)

% Loss	Liquid, wt%		Vapor, wt%	
	R-125	R-600	R-125	R-600
2.0	48.7	51.3	81.5	18.5
10.0	45.5	54.5	80.6	19.4
20.0	40.7	59.3	79.2	20.8
30.0	34.9	65.1	77.0	23.0
40.0	27.9	72.1	73.5	26.5
50.0	19.6	80.4	66.9	33.1
60.0	10.6	89.4	53.2	46.8
70.0	3.2	96.8	25.8	74.2
80.0	0.3	99.7	3.7	96.3
90.0	0.0	100.0	0.2	99.8
95.0	0.0	100.0	0.0	100.0

(This appendix is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE APPENDIX E—BIBLIOGRAPHY

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INFORMATIVE APPENDIX F—SUGGESTED PARTS LIST

Table F-1 Example Bill of Lading for Fractionation Apparatus

Supplier ^a	Part No.	Plumbing Description	Quantity	Functional Description	Critical Part Specifications
Swagelok	304L-HDF4-1000	1 L SS cylinder double-ended ¼ in. mNPT	1	1 L (0.035 ft ³) vessel	
Swagelok	SS-4-P	¼ in. (6.35 mm) SS pipe plug	1	Bottom plug for vessel	
Swagelok	SS-400-3-4TMT	Male run tee, ¼ in. (6.35 mm)	1	Vessel top fitting	
Swagelok	SS-200-R-4BT	Bored-through reducer, 1/8 × ¼ in. (3.18 mm × 6.35 mm)	1	Liquid sampling tube feed through	
Swagelok	SS-1RS4	SS integral bonnet needle valve, 0.37 Cv, ¼ in. (6.35 mm)	1	Vapor sampling valve	
Swagelok	SS-0RS2	SS integral bonnet needle valve, 0.09 Cv, 1/8 in. (3.18 mm)	1	Liquid sampling valve	
Swagelok	SS-4F-2	SS inline filter ¼ in. 2 um pore (6.35 mm)	1	Filter to prevent particles from effecting flow in control valve	2 micron
Swagelok	SS-SS4	SS low-flow metering valve, ¼ in. (6.35 mm)	1	Vapor flow control needle valve Cv = 0.0004 (no off service)	Cv = 0.0004 or less
Omega part	#FMA1814	Mass flow meter	1	Mass flow meter	Mass flow 20 g/h
Omega part	FMA178PW	Socket plug supply for 115Vac	1		
Swagelok	304L-HDF2-40-PD	304 L SS double-ended cylinder, 1/8 in. (3.18 mm) FNPT, 40 cm ³ (0.0014 ft ³), 130 bar (1885 psig)	10	40 cc (0.0014 ft ³) sampling cylinders	
Swagelok	SS-OVF2	SS integral bonnet needle valve, 0.09 Cv, 1/8 in. (3.18 mm) FNPT, vee stem	20	Valve for sampling cylinder 2, one for each end	
Swagelok	SS-2-HN	SS pipe fitting, hex nipple, 1/8 in. (3.18 mm) male NPT	20	Valve to cylinder	
Swagelok	SS-200-1-2	Male connect 1/8 in. (3.18 mm)	20	Valve to tubing	
Swagelok	SS-2-ST	SS pipe street tree, 1/8 in. (3.18 mm)	10	Pipe tee for each cylinder	
Swagelok	SS-400-1-2	SS Swagelok tube fitting, male connector, ¼ in. tube OD × 1/8 in. male NPT (6.35 mm × 3.18 mm)	10	Septum adapter	
			1	Pressure gage for sampling cylinder	
				Septum	
				Vacuum system	
				Isothermal chamber or bath and auxiliary equipment—i.e., chiller, controller, stirrer	
				Scale 4 kg, ±0.02 g (8.82 lb, ±0.0007 oz)	
		Gas chromatography / thermal conductivity detector		GC/TCD	

a. Certain trade names and products are given to adequately document the experimental equipment and procedures. This does not constitute a recommendation or endorsement of these products by ASHRAE, nor does it imply that the products are necessarily the best available for the purpose.