AHRI Standard 700-2024 (SI)

Specifications for Refrigerants

AIR-CONDITIONING, HEATING,
& REFRIGERATION INSTITUTE

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IMPORTANT

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ICS Code: 71.100.45

Note:

This standard supersedes AHRI Standard 700-2019 (SI).

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Intent

This standard is intended for the guidance of the industry, including manufacturers, engineers, installers, contractors, and users.

Review and Amendment

This standard is subject to review and amendment as technology advances.

2024 Edition

This edition of AHRI Standard 700 (SI), *Specifications for Refrigerants*, was prepared by the Refrigerants/Refrigerant Recovery Standards Technical Committee. The standard was approved by the Standards Committee on 12 December 2024.

Origin and Development of AHRI Standard 700 (SI)

The initial publication was ARI Standard 700-1988 (SI), *Specifications for Fluorocarbon and Other Refrigerants*. Subsequent revisions were:

ARI Standard 700-1993 (SI), *Specifications for Fluorocarbon and Other Refrigerants*
ARI Standard 700-1995 (SI), *Specifications for Fluorocarbon and Other Refrigerants*
ARI Standard 700-1999 (SI), *Specifications for Fluorocarbon and Other Refrigerants*
ARI Standard 700-2004 (SI), *Specifications for Fluorocarbon and Other Refrigerants*
AHRI Standard 700-2006 (SI), *Specifications for Fluorocarbon Refrigerants*
AHRI Standard 700-2006 (SI) (with Addenda 1 and 2), *Specifications for Fluorocarbon Refrigerants*
AHRI Standard 700-2011 (SI), *Specifications for Fluorocarbon Refrigerants*
AHRI Standard 700-2011 (SI) (with Addendum 1), *Specifications for Fluorocarbon Refrigerants*
AHRI Standard 700-2012 (SI), *Specifications for Fluorocarbon Refrigerants*
AHRI Standard 700-2014 (SI), *Specifications for Refrigerants*
AHRI Standard 700-2014 (SI) (with Addendum 1), *Specifications for Refrigerants*
AHRI Standard 700-2015 (SI), *Specifications for Refrigerants*
AHRI Standard 700-2015 (SI) (with Addendum 1), *Specifications for Refrigerants*
AHRI Standard 700-2016 (SI), *Specifications for Refrigerants*
AHRI Standard 700-2016 (with Addendum 1) (SI), *Specifications for Refrigerants*
AHRI Standard 700-2017 (SI), *Specifications for Refrigerants*
AHRI Standard 700-2017 (SI) (with Addendum 1), *Specifications for Refrigerants*
AHRI Standard 700-2019 (SI), *Specifications for Refrigerants*

Summary of Changes

AHRI Standard 700-2024 (SI) contains the following updates to the previous edition:

- Update Refrigerants and specifications within AHRI 700
- Update sampling and test procedures
- Propose portions of the standard that can be moved to a continuous maintenance process
- Update Appendix C and Appendix D

Committee Personnel

AHRI Standard 700 Standard Work Group

Company/Organization	Participant	Voting Role
Voting Organizations		
Hudson Technologies Company	Dave Watson, Chair	Primary
A-Gas	Amber Medina	Primary
Arkema, Inc.	Kris Crosby	Primary
Carrier Corporation	Larry Burns	Primary
	Arif Rokoni	Alternate
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Koura	Sarah Kim	Primary
National Refrigerants, Inc.	Dan Wright	Primary
Trane Technologies	Steve Kujak	Primary
	Morgan Leehey	Alternate
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Greg Kalinyak		AHRI Staff Liaison

Refrigerants/Refrigerant Recovery Standards Technical Committee

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	Matt Callahan	Alternate
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	Wayne Powers	Primary
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Refrigerants/Refrigerant Recovery Standards Technical Committee (STC) Scope:

The Refrigerants/Refrigerant Recovery STC is responsible for the development and maintenance of AHRI standards and guidelines pertaining to refrigerants as defined in ASHRAE 34, and related refrigerant recovery equipment.

Out of scope for this STC are refrigerants not defined in ASHRAE 34.

Standards Committee

Company/Organization	Participant	Voting Role
Voting Organizations		
A.O. Smith Corporation	Hammam Amaireh	Primary
Bradford White Corp.	Bryan Ahee	Primary
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Jerry Yeh		AHRI Staff Liaison

These lists represent the membership at the time the Standards Technical Committee and Standards Subcommittee were balloted on the final text of this edition. Since that time, changes in the membership may have occurred. Membership on these committees shall not in and of itself constitute an endorsement by the committee members or their employers of any document developed by the committee on which the member serves.

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SPECIFICATIONS FOR REFRIGERANTS

Section 1. Purpose

This standard establishes purity specifications to verify composition, and to specify the associated methods of testing for acceptability of the refrigerants listed in Section 2 regardless of source (new, reclaimed, or repackaged, or all three) for use in new and existing refrigeration and air-conditioning products within the scope of AHRI.

Section 2. Scope

This standard specifies levels of contaminants (purity requirements) for fluorocarbon, hydrocarbon, and carbon dioxide refrigerants regardless of source and lists test methods. These refrigerants are as referenced in ASHRAE 34 and in ISO 817:

2.1 Single Component Fluorocarbon Refrigerants

R-11; R-12; R-13; R-22; R-23; R-32; R-113; R-114; R-115; R-116; R-123; R-124; R-125; R-134a; R-141b; R-142b; R-143a; R-152a; R-218; R-227ea; R-236fa; R-245fa; R-1224yd(Z); R-1233zd(E); R-1234yf; R-1234ze(E); R-1336mzz(Z); and R-1336mzz(E).-

2.2 Single Component Hydrocarbon Refrigerants

R-50; R-170; R-E170; R-290; R-600; R-600a; R-601; R-601a; R-610; R-1150; and R-1270.

2.3 Carbon Dioxide Refrigerant

R-744

2.4 Zeotropic Blend Refrigerants

R-401A; R-401B; R-402A; R-402B; R-403A; R-403B; R-404A; R-405A; R-406A; R-407A; R-407B; R-407C; R-407D; R-407E; R-407F; R-407G; R-407H; R-407I; R-408A; R-409A; R-409B; R-410A; R-410B; R-411A; R-411B; R-412A; R-413A; R-414A; R-414B; R-415A; R-415B; R-416A; R-417A; R-417B; R-417C; R-418A; R-419A; R-419B; R-420A; R-421A; R-421B; R-422A; R-422B; R-422C; R-422D; R-422E; R-423A; R-424A; R-425A; R-426A; R-427A; R-428A; R-429A; R-430A; R-431A; R-434A; R-435A; R-437A; R-438A; R-439A; R-440A; R-442A; R-444A; R-444B; R-445A; R-446A; R-447A; R-447B; R-448A;; R-449A; R-449B; R-449C; R-450A; R-451A; R-451B; R-452A; R-452B; R-452C; R-453A; R-454A; R-454B; R-454C; R-454D; R-455A; R-455B; R-455C; R-456A; R-457A; R-457B; R-457C; R-457D; R-459B; R-460A; R-460B; R-460C; R-461A; R-462A; R-463A; R-464A; R-465A; R-466A; R-467A; R-468A; R-468B; R-468C; R-469A; R-470A; R-470B; R-471A; R-472A; R-472B; R-473A; R-475A; R-476A; R-477A; R-477B; and R-478A.

2.5 Zeotropic Hydrocarbon Blend Refrigerants

R-432A; R-433A; R-433B; R-433C; R-436A; R-436B; R-441A; and R-443A.

2.6 Azeotropic Blend Refrigerants

R-500; R-502; R-503; R-507A; R-508A; R-508B; R-509A; R-510A; R-511A; R-512A; R-513A; R-513B; R-514A; R-515A; R-515B; and R-516A.

Section 3. Definitions

All terms in this document follow the standard industry definitions in the ASHRAE *Terminology* website unless otherwise defined in Section 3.2. These standard-specific defined terms are italicized throughout the standard.

3.1 Expression of Provisions

Terms that provide clear distinctions between requirements, recommendations, permissions, options, and capabilities.

3.1.1 "Can" or "cannot"

Express an option or capability.

3.1.2 “May”

Signifies a permission expressed by the document.

3.1.3 “Must”

Indication of unavoidable situations and does not mean that an external constraint referred to is a requirement of the document.

3.1.4 “Shall” or “shall not”

Indication of mandatory requirements to strictly conform to the standard and where deviation is not permitted.

3.1.5 “Should” or “should not”

Indication of recommendations rather than requirements. In the negative form, a recommendation is the expression of potential choices or courses of action that is not preferred but not prohibited.

3.2 Standard-specific Definitions

3.2.1 Boiling Point

Temperature at which the vapor pressure of a liquid equals the absolute external pressure at the liquid vapor interface.

3.2.2 Boiling Point Range

The temperature range involved in the distillation of oil, from the start to the time when the oil evaporates.

3.2.3 Bubble Point

Refrigerant liquid saturation temperature at a specified pressure.

3.2.4 Critical Temperatures

The temperature at and above where vapor of the substance cannot be liquefied, no matter how much pressure is applied.

3.2.5 Dew Point

Refrigerant vapor saturation temperature at a specified pressure.

3.2.6 Effective Carbon Number (ECN)

The instrumental response factor calculated based on functional groups (or descriptors) present in molecular structure of a volatile organic compound.

3.2.7 Effective Carbon Number Method (ECN Method)

Method to external calibration method by applying *ECN* for quantitative analysis of compounds.

3.2.8 High Boiling Residue (HBR)

Non-volatile material remaining in the Goetz bulb upon completion of the analysis.

Note: Can be called non-volatile residue.

3.2.9 Non-condensable Gas (NCG)

Any gas that does not condense to liquid phase in a system.

Section 4. Test Requirements

4.1 Referee Test

Detailed test procedures are included in Appendix C. If alternative test methods are employed, the user shall be able to demonstrate that the results are at least equal to the specified referee test method.

4.2 Refrigerant Sampling

4.2.1 Sampling Precautions

Representative samples shall be obtained for analysis. Sampling shall be done by qualified personnel following accepted sampling and safety procedures. Refrigerants with *critical temperatures* at or less than the ambient temperature cannot be reliably sampled for both a liquid phase and a vapor phase without special handling. Refrigerants that are ASHRAE 34 Class 2L, Class 2, or Class 3 are flammable.

4.2.2 Cylinder Preparation

Place a clean, empty sample cylinder with the valve open in an oven at 110°C for one hour. Remove the sample cylinder from the oven while hot, immediately connect the sample cylinder to an evacuation system, and evacuate the cylinder to less than 56 kPa. Close the valve and let the cylinder cool. Weigh the empty cylinder.

4.2.3 Vapor Phase Sampling

A vapor phase sample shall be obtained for determining the non-condensables. The source temperature shall be measured and recorded at the time the sample is taken.

4.2.3.1 Special Handling for Low Critical Temperature Refrigerant

A vapor phase sample is required to determine non-condensables and volatile impurities, including other refrigerants. The vapor phase sample is obtained by regulating the sample container temperature to 5K or more above the refrigerant *critical temperature*.

4.2.3.2 Handling for Liquid Refrigerants with Boiling Points At or Above Room Temperature

Since R-11, R-113, R-123, R-141b, R-245fa, R-514A, R-1233zd(E), R-1336mzz(Z), and R-1336mzz(E) have *boiling points* at or above room temperature, non-condensable determination is not required for these refrigerants.

Note: If present, *NCG* concentrate in the vapor phase of the refrigerant. The introduction of either air or liquid phase refrigerant during the sample transfer should be eliminated.

4.2.4 Liquid Phase Sampling

A liquid phase sample shall be used for all tests listed in this standard except the test for non-condensables.

4.2.4.1 Liquid Sampling

The sample cylinder, at ambient temperature, shall be filled to at least 60% by volume but not greater than 80%. This can be accomplished by weighing the empty cylinder and then the cylinder with refrigerant. When the required amount of refrigerant is collected, close the valve(s) and immediately disconnect the sample cylinder.

For low pressure refrigerants not requiring *NCG*, submitted samples shall be in either metal cylinders or in glass or plastic bottles such that the containers are at least 80% liquid full.

Note: All connections and transfer lines should be dry and evacuated to prevent contaminating the sample.

Note: Low *critical temperature* refrigerants can have extremely high pressure at the sampling vessel.

Note: Expansion of refrigerant under transportation conditions should be considered.

All connections and transfer lines shall be designed to handle high pressures.

4.2.4.2 Special Handling for Low Critical Temperature Refrigerant

A liquid phase sample shall be used for all testing except volatile impurities, including other refrigerants. The liquid phase sample is obtained by regulating the sample cylinder temperature to 2°C less than the *critical temperature* of the refrigerant.

Note: If free water is present in the sample, cooling to less than 0°C can result in the formation of ice. Clathrates can form at temperatures greater than 0°C with fluorocarbon refrigerants.

4.2.4.3 Record Weight

Check the sample cylinder for leaks and record the gross weight.

4.3 Refrigerant Identification

The required method shall be gas chromatography as described in Appendix C with the corresponding gas chromatogram figures as illustrated in Appendix D. The chromatogram of the sample shall be compared to known standards.

4.4 Water Content

4.4.1 Method

The coulometric Karl Fischer (KF) titration, as described in Appendix C, shall be used for determining the water content of refrigerants. This method can be used for refrigerants that are either a liquid or a gas at room temperature. For all refrigerants, the sample for water analysis shall be taken from the liquid phase of the container to be tested.

4.4.2 Limits

The value for water content shall be expressed in parts per million (ppm) by weight and shall not exceed the maximum specified in Table 1 through Table 23. When considering compliance, uncertainty has been taken into account with Table 1 through Table 23.

4.5 Conductivity (Alternative to Chloride and Acidity Tests)

4.5.1 Method

A refrigerant can be tested for conductivity as an indication of the presence of acids, metal chlorides, and any compound that ionizes in water. This alternative procedure is intended for use with new or reclaimed refrigerants; however, oil can interfere with the test results.

4.5.2 Limits

The value for conductivity shall be converted to and expressed in ppm by weight calculated as hydrochloric acid (HCl) and shall be compared with the maximum acidity value specified (see in Table 1 through Table 23). If the conductivity is greater than this amount, then the chloride and acidity tests shall be conducted. If the conductivity is not greater than this amount, then the chloride and acidity tests can be omitted.

4.6 Chloride

4.6.1 Method

The refrigerant shall be tested for chloride as an indication of the presence of hydrochloric acid or metal chlorides, or both. The referee procedure is intended for use with new or reclaimed halogenated refrigerants; however, *HBR* greater than the amounts in Table 1 through Table 23 can interfere with the test results.

The test method shall be that as described in Appendix C. The test shall show turbidity at chloride levels of 3 ppm or greater by weight.

4.6.2 Limits

The results of the test shall not exhibit any sign of turbidity. Record the results as either “Pass” or “Fail.”

4.7 Acidity

4.7.1 Method

The acidity test uses the titration principle to detect any compound that is soluble in water and ionizes as an acid. The test method shall be that as described in Appendix C. This test shall not be used for determination of high molecular weight organic acids. However, these acids are found in the *HBR* test outlined in Section 4.8. The test shall have a fifty-gram to sixty-gram sample and a detection limit (DL) of 0.1 ppm by weight calculated as HCl.

4.7.2 Limits

The value for acidity shall be expressed in ppm by weight as HCl and shall not exceed the limits in Table 1 through Table 4 and Table 6 through Table 23.

4.8 High Boiling Residue

4.8.1 Method

HBR shall be determined by either volume or weight. The volume method measures the residue from a standard volume of refrigerant after evaporation. The gravimetric method is described in Appendix C. Oils or organic acids, or both shall be captured by these methods.

4.8.2 Limits

The value for *HBR* shall be expressed as a percentage by volume or weight and shall not exceed the maximum percent specified in Table 1 through Table 23.

4.9 Particulates and Solids

4.9.1 Method

The measured amount of sample shall be placed in a Goetz bulb under controlled temperature conditions. The particulates/solids shall be determined by visual examination of the Goetz bulb prior to the evaporation of refrigerant. For details of this test method, refer to Section C.3.

R-744 partially sublimates when measuring a known amount of liquid sample into the Goetz bulb and the solid R-744 interferes with the visual examination of particulates/solids. Determining the particulates/solids shall be completed by visual examination of the Goetz bulb after the evaporation of the refrigerant.

4.9.2 Limits

Visual presence of dirt, rust or other particulate contamination is a failed test.

4.10 Non-condensables

4.10.1 Method

A vapor phase sample shall be used for determination of non-condensables. *NCGs* consist primarily of air accumulated in the vapor phase of refrigerants where the solubility of air in the refrigerant liquid phase is extremely low and air is extremely low as a liquid phase contaminant. The presence of *NCGs* can reflect poor quality control in transferring refrigerants to storage tanks and cylinders.

The test method shall be gas chromatography with a thermal conductivity detector (TCD) as described in Appendix C.

4.10.2 Limits

The maximum level of non-condensables in the vapor phase of a test sample shall not exceed the maximum at 25.0°C as shown in Table 1 through Table 23.

4.11 All Other Volatile Impurities and Other Refrigerants

4.11.1 Method

The amount of volatile impurities including other refrigerants in the subject refrigerant shall be determined by gas chromatography as described in Appendix C.

4.11.2 Limits

The test sample shall not contain more than 0.5% by weight of volatile impurities including other refrigerants and unsaturates.

4.11.2.1 Individual Listed Volatile Impurities

Table 1 through Table 23 list specific volatile impurities and their maximum allowable concentrations in percent (%) by weight.

4.11.2.2 R-40 Impurities

Refrigerant shall not contain more than 300 ppm of R-40.

4.12 Total C_3, C_4, and C_5 Polyolefins in Hydrocarbon Refrigerants

4.12.1 Method

The amount of polyolefin impurities in the hydrocarbon shall be determined by gas chromatography as described in GPA 2177.

4.12.2 Limits

The test sample shall not contain more than 0.05 % by weight in the hydrocarbon sample as shown in Table 4 and Table 21. Record the results as either "Pass" or "Fail."

4.13 Sulfur Odor in Hydrocarbon Refrigerants

4.13.1 Method

The amount of sulfur-containing compounds or other compounds with an odor shall be determined in accordance with ASTM D1296.

4.13.2 Limits

The test sample paper shall not emit a residual sulfur odor as shown in Table 4 and Table 21.

Section 5. Rating Requirements

This standard does not have any applicable rating requirements.

Section 6. Minimum Data Requirements for Published Ratings

This standard does not establish requirements for published ratings.

Section 7. Conformance Conditions

While conformance with this standard is voluntary, conformance shall not be claimed or implied for products or equipment within the standard's Purpose (Section 1) and Scope (Section 2) unless such product claims meet all of the requirements of the standard and all of the testing and rating requirements are in complete compliance with the standard. Any product that has not met all the requirements of the standard cannot reference, state, or acknowledge conformance to the standard in any written, oral, or electronic communication.

Table 1 Single Component Fluorocarbon Refrigerants Characteristics and Allowable Levels of Contaminants (R-11 through R-116)

	Reporting Units	Reference Section	R-11	R-12	R-13	R-22	R-23	R-32	R-113	R-114	R-115	R-116
Characteristics												
Boiling Point[1]	°C at 101.3 kPa	N/A	23.7	-29.8	-81.5	-40.8	-82	-51.7	47.6	3.6	-38.9	-78.2
Boiling Point Range[1]	K	N/A	± 0.3	± 0.3	± 0.5	± 0.3	± 0.5	± 0.3	± 0.3	± 0.3	± 0.3	± 0.3
Critical Temperature[1]	°C	N/A	198	112	28.9	96.2	26.1	78.1	214.1	145.7	80	19.9
Isomer(s)	—	N/A	N/A	N/A	N/A	N/A	N/A	N/A	R-113a	R-114a	N/A	N/A
Quantity of Isomer(s)	% by weight	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0-1	0-30	N/A	N/A
Vapor Phase Contaminants												
Air and Other Non-condensables, Maximum	% by volume at 25.0°C	4.10	N/A[2]	1.5	1.5	1.5	1.5	1.5	N/A[2]	1.5	1.5	1.5
Liquid Phase Contaminants												
Water, Maximum	ppm by weight	4.4	20	10	10	10	10	10	20	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

	Reporting Units	**Reference Section**	**R-11**	**R-12**	**R-13**	**R-22**	**R-23**	**R-32**	**R-113**	**R-114**	**R-115**	**R-116**
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	1	1	1	1	1	1	1
Chloride[3]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	Visually clean	Visually clean

Notes:

1. *Boiling points*, boiling ranges, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Because R-11, R-113, R-123, R-141b, R-245fa, R-1233zd(E), R-1366mzz(E) and R-1336mzz(Z) have *boiling points* equal to or greater than the room temperature, testing for non-condensables is not required for these refrigerants.
3. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable; — = Intentionally left blank

Table 2 Single Component Fluorocarbon Refrigerants Characteristics and Allowable Levels of Contaminants
(R-123 through R-227ea)

	Reporting Units	Reference Section	R-123	R-124	R-125	R-134a	R-141b	R-142b	R-143a	R-152a	R-218	R-227ea
Characteristics												
Boiling Point[1]	°C at 101.3 kPa	N/A	27.8	-12	-48.1	-26.1	32	-9.2	-47.2	-24	-36.8	-16.5
Boiling Point Range[1]	K	N/A	±0.3	±0.3	±0.3	±0.3	±0.3	N/A	±0.3	±0.3	±0.3	N/A
Critical Temperature[1]	°C	N/A	183.7	122.3	66	101.1	206.8	137.1	72.7	113.3	72	101.7
Isomer(s)	—	N/A	R-123a R-123b	R-124a	N/A	R-134	R-141 R-141a	R-142 R-142a	R-143	N/A	N/A	N/A
Quantity of Isomer	% by weight	N/A	0-8 of each	0-5	N/A	0-0.5	0-0.1 of each	0-0.1 of each	0-0.01	N/A	N/A	N/A
Vapor Phase Contaminants												
Air and Other Non-condensables, Maximum	% by volume at 25.0 °C	4.10	N/A[2]	1.5	1.5	1.5	N/A[2]	2	1.5	1.5	1.5	1.5
Liquid Phase Contaminants												
Water, Maximum	ppm by weight	4.4	20	10	10	10	100	15	10	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.9	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean

	Reporting Units	**Reference Section**	**R-123**	**R-124**	**R-125**	**R-134a**	**R-141b**	**R-142b**	**R-143a**	**R-152a**	**R-218**	**R-227ea**
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	1	1	3	1	1	1	1
Chloride[3]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Boiling points*, boiling ranges, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Because R-11, R-113, R-123, R-141b, R-245fa, R-1233zd(E), R-1336mzz(E) and R-1336mzz(Z) have *boiling points* at or above room temperature, non-condensable determinations are not required for these refrigerants.
3. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable; — = Intentionally left blank

Table 3 Single Component Fluorocarbon Refrigerants Characteristics and Allowable Levels of Contaminants [R-236f through R-1336mzz(E)]

	Reporting Units	Reference Section	R-236fa	R-245fa	R-1224yd(Z)	R-1233zd(E)	R-1234yf	R-1234ze(E)	R-1336mzz(Z)	R-1336mzz(E)
Characteristics										
Boiling Point[1]	°C @ 101.3 kPa	N/A	-1.4	14.9	14.5	18.3	-29.4	-19	33.4	7.4
Boiling Point Range[1]	K	N/A	±0.3	±0.3	N/A	N/A	N/A	N/A	N/A	N/A
Critical Temperature[1]	°C	N/A	124.9	154.1	155.5	165.6	94.8	109.4	171.3	130.2
Isomer(s)	—	N/A	N/A	R-245ca, R-245cb, R-245ea, R-245eb	R-1224yd(E)	N/A	N/A	R-1234ze(Z)	R-1336mzz(E)	R-1336mzz(Z)
Quantity of Isomer	% by weight	N/A	N/A	0-0.1 of each	0-1.0	N/A	N/A	0-0.3	0-0.1	0-0.1
Vapor Phase Contaminants										
Air and Other Non-condensables, Maximum	% by volume @ 25°C	4.10	1.5	N/A[2]	N/A[2]	N/A[2]	1.5	1.5	N/A[2]	N/A[2]
Liquid Phase Contaminants										
Water, Maximum	ppm by weight	4.4	10	20	20	20	10	10	20	20
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

	Reporting Units	Reference Section	R-236fa	R-245fa	R-1224yd(Z)	R-1233zd(E)	R-1234yf	R-1234ze(E)	R-1336mzz(Z)	R-1336mzz(E)
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	1	1	1	1	1
Chloride[3]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Boiling points*, boiling ranges, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Because R-11, R-113, R-123, R-141b, R-245fa, R-1233zd(E), R-1336mzz(E), and R-1336mzz(Z) have *boiling points* at or above room temperature, non-condensable determinations are not required for these refrigerants.
3. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable; — = Intentionally left blank

Table 4 Single Component Hydrocarbon Refrigerants Characteristics and Allowable Levels of Contaminants

	Reporting Units	**Reference Section**	**R-50**	**R-170**	**R-E170**	**R-290**	**R-600**	**R-600a**	**R-601**	**R-601a**	**R-610**	**R-1150**	**R-1270**
Characteristics													
Boiling Point[1]	°C at 101.3 kPa	N/A	-161.5	-88.6	-24.8	-42.1	-0.5	-11.8	36.1	27.8	34.6	-103.8	-47.6
Boiling Point Range[1]	K	N/A	±0.5	±0.5	±0.5	±0.5	±0.5	±0.5	±0.5	±0.5	±0.5	±0.5	±0.5
Minimum Nominal Composition	% weight	N/A	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5
Allowable Impurities	—	N/A	N/A	N/A	N/A	N/A	N/A	N/A	R-601a	R-601	N/A	N/A	R-290
Allowable Impurity Quantity	% weight	N/A	N/A	N/A	N/A	2[2]	2[2]	2[2]	0-1	0-1	N/A	N/A	0-1
Vapor Phase Contaminants[3]													
Air and Other Non-condensables, Maximum	% by volume at 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Liquid Phase Contaminants[4]													
Sulphur Odor	Pass or Fail	4.13	No sulfur odor	No sulfur odor	No sulfur odor	No sulfur odor	No sulfur odor	No sulfur odor	No sulfur odor	No sulfur odor	No sulfur odor	No sulfur odor	No sulfur odor
HBR, Maximum	% weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	1	1	1	1	1	1	1	1
Water, Maximum	mg/kg	4.4	10	10	10	10	10	10	10	10	10	10	10

	Reporting Units	**Reference Section**	**R-50**	**R-170**	**R-E170**	**R-290**	**R-600**	**R-600a**	**R-601**	**R-601a**	**R-610**	**R-1150**	**R-1270**
All Other Volatile Impurities, Maximum	% weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Total C_3, C_4, and C_5 Polyolefins, Maximum	% weight	4.12	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Notes:

1. *Boiling points* and *boiling point ranges* are provided for informational purposes.
2. Two percent of other C3 and C4 saturated hydrocarbons can be used.
3. Taken from vapor phase.
4. Vaporized from liquid phase.

N/A = Not applicable; — = Intentionally left blank

Table 5 Carbon Dioxide Refrigerant Characteristics and Allowable Levels of Contaminants

	Reporting Units	**R-744**
Characteristics		
Sublimation Point[1]	°C at 101 kPa	-78.4
Sublimation Point Range[1]	K	± 0.3
Vapor Phase Contaminants[2]		
Air and Other Non-condensables, Maximum	% by volume at 10°C less than the *critical temperature* and measure non-condensable directly	1.5
Liquid Phase Contaminants[3]		
Water, Maximum	ppm by weight	10
HBR, Maximum	% by weight	0.0005
Particulates/Solids	Pass or Fail	Visually clean
Minimum Purity	% by weight	99.9

Notes:

1. Sublimation point and sublimation point range are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Sample taken from vapor phase.
3. Sample vaporized from liquid phase.

Table 6 Zeotropic Blends (400 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-401A through R-405A)

	Reporting Units	**Reference Section**	**R-401A**	**R-401B**	**R-402A**	**R-402B**	**R-403A**	**R-403B**	**R-404A**	**R-405A**
Characteristics										
Refrigerant Components	N/A	N/A	R-22/ 152a/ 124	R-22/ 152a/ 124	R-125/ 290/ 22	R-125/ 290/ 22	R-290/ 22/ 218	R-290/ 22/ 218	R-125/ 143a/ 134a	R-22/ 152a/ 142b/ C318
Nominal Composition	% by weight	N/A	53.0/ 13.0/ 34.0	61.0/ 11.0/ 28.0	60.0/ 2.0/ 38.0	38.0/ 2.0/ 60.0	5.0/ 75.0/ 20.0	5.0/ 56.0/ 39.0	44.0/ 52.0/ 4.0	45.0/ 7.0/ 5.5/ 42.5
Allowable Composition	% by weight	N/A	51.0-55.0/ 11.5-13.5/ 33.0-35.0	59.0-63.0/ 9.5-11.5/ 27.0-29.0	58.0-62.0/ 1.0-2.1/ 36.0-40.0	36.0-40.0/ 1.0-2.1/ 58.0-62.0	3.0-5.2/ 73.0-77.0/ 18.0-22.0	3.0-5.2/ 54.0-58.0/ 37.0-41.0	42.0-46.0/ 51.0-53.0/ 2.0-6.0	43.0-47.0/ 6.0-8.0/ 4.5-6.5/ 40.5-44.5
Bubble Point[1]	°C @ 101.3 kPa	N/A	-33.3	-34.9	-49	-47	-47.8	-49.2	-46.2	-32.9
Dew Point[1]	°C @ 101.3 kPa	N/A	-26.4	-28.8	-46.9	-44.7	-44.3	-46.8	-45.5	-24.5
Critical Temperature	°C	N/A	105.3	103.5	76	83	87	79.7	72.1	106
Vapor Phase Contaminants										
Air and Other Non-condensables, Maximum	% by volume @ 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

	Reporting Units	**Reference Section**	**R-401A**	**R-401B**	**R-402A**	**R-402B**	**R-403A**	**R-403B**	**R-404A**	**R-405A**
Liquid Phase Contaminants										
Water, Maximum	ppm by weight	4.4	10	10	10	10	10	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	1	1	1	1	1
Chloride[2]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Table 7 Zeotropic Blends (400 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-406A through R-407G)

	Reporting Units	**Reference Section**	**R-406A**	**R-407A**	**R-407B**	**R-407C**	**R-407D**	**R-407E**	**R-407F**	**R-407G**
Characteristics										
Refrigerant Components	N/A	N/A	R-22/ 600a/ 142b	R-32/ 125/ 134a	R-32/ 125/ 134a	R-32/ 125/ 134a	R-32/ 125/ 134a	R-32/ 125/ 134a	R-32/ 125/ 134a	R-32/ 125/ 134a
Nominal Composition	% by weight	N/A	55.0/ 4.0/ 41.0	20.0/ 40.0/ 40.0	10.0/ 70.0/ 20.0	23.0/ 25.0/ 52.0	15.0/ 15.0/ 70.0	25.0/ 15.0/ 60.0	30.0/ 30.0/ 40.0	2.5/ 2.5/ 95.0
Allowable Composition	% by weight	N/A	53.0-57.0/ 3.0-5.0/ 40.0-42.0	18.0-22.0/ 38.0-42.0/ 38.0-42.0	8.0-12.0/ 68.0-72.0/ 18.0-22.0	21.0-25.0/ 23.0-27.0/ 50.0-54.0	13.0-17.0/ 13.0-17.0/ 68.0-72.0	23.0-27.0/ 13.0-17.0/ 58.0-62.0	28.0-32.0/ 28.0-32.0/ 38.0-42.0	2.0-3.0/ 2.0-3.0/ 94.0-96.0
Bubble Point[1]	°C @ 101.3 kPa	N/A	-32.7	-45.3	-46.8	-43.6	-39.5	-42.9	-46.1	-29.2
Dew Point[1]	°C @ 101.3 kPa	N/A	-23.5	-38.9	-42.5	-36.6	-32.9	-35.8	-39.7	-27.2
Critical Temperature	°C	N/A	116.5	82.3	75	86	91.4	88.5	83	99.5
Vapor Phase Contaminants										
Air and Other Non-condensables, Maximum	% by volume @ 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

	Reporting Units	**Reference Section**	**R-406A**	**R-407A**	**R-407B**	**R-407C**	**R-407D**	**R-407E**	**R-407F**	**R-407G**
Liquid Phase Contaminants										
Water, Maximum	ppm by weight	4.4	10	10	10	10	10	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	1	1	1	1	1
Chloride[2]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Table 8 Zeotropic Blends (400 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-407H through R-411A)

	Reporting Units	**Reference Section**	**R-407H**	**R-407I**	**R-408A**	**R-409A**	**R-409B**	**R-410A**	**R-410B**	**R-411A**
Characteristics										
Refrigerant Components	N/A	N/A	R-32/ 125/ 134a	R-32/ 125/ 134a	R-125/ 143a/ 22	R-22/ 124/ 142b	R-22/ 124/ 142b	R-32/ 125	R-32/ 125	R-1270/ 22/ 152a
Nominal Composition	% by weight	N/A	32.5/ 15.0/ 52.5	19.5/ 8.5/ 72.0	7.0/ 46.0/ 47.0	60.0/ 25.0/ 15.0	65.0/ 25.0/ 10.0	50.0/ 50.0	45.0/ 55.0	1.5/ 87.5/ 11.0
Allowable Composition	% by weight	N/A	31.5-33.5/ 14.0-16.0/ 50.5-54.5	17.5-20.5/ 7.5-10.5/ 70.0-74.0	5.0-9.0/ 45.0-47.0/ 45.0-49.0	58.0-62.0/ 23.0-27.0/ 14.0-16.0	63.0-67.0/ 23.0-27.0/ 9.0-11.0	48.5-50.5/ 49.5-51.5	44.0-46.0/ 54.0-56.0	0.5-1.5/ 87.5-89.5/ 10.0-11.0
Bubble Point[1]	°C @ 101.3 kPa	N/A	-44.6	-39.8	-44.6	-34.7	-35.6	-51.4	-51.3	-39.5
Dew Point[1]	°C @ 101.3 kPa	N/A	-37.6	-33.0	-44.1	-26.4	-27.9	-51.4	-51.6	-36.6
Critical Temperature	°C	N/A	86.5	92.0	83.1	106.9	106.9	71.4	70.8	99.1
Vapor Phase Contaminants										
Air and Other Non-condensables, Maximum	% by volume @ 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

	Reporting Units	Reference Section	R-407H	R-407I	R-408A	R-409A	R-409B	R-410A	R-410B	R-411A
Liquid Phase Contaminants										
Water, Maximum	ppm by weight	4.4	10	10	10	10	10	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	1	1	1	1	1
Chloride[2]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Table 9 Zeotropic Blends (400 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-411B through R-416A)

	Reporting Units	Reference Section	R-411B	R-412A	R-413A	R-414A	R-414B	R-415A	R-415B	R-416A
Characteristics										
Refrigerant Components	N/A	N/A	R-1270/ 22/ 152a	R-22/ 218/ 142b	R-218/ 134a/ 600a	R-218/ 124/ 600a/ 142b	R-22/ 124/ 600a/ 142b	R-22/ 152a	R-22/ 152a	R-134a/ 124/ 600
Nominal Composition	% by weight	N/A	3.0/ 94.0/ 3.0	70.0/ 5.0/ 25.0	9.0/ 88.0/ 3.0	51.0/ 28.5/ 4.0/ 16.5	50.0/ 39.0/ 1.5/ 9.5	82.0/ 18.0	25.0/ 75.0	59.0/ 39.5/ 1.5
Allowable Composition	% by weight	N/A	2.0-3.0/ 94.0-96.0/ 2.0-3.0	68.0-72.0/ 3.0-7.0/ 24.0-26.0	8.0-10.0/ 86.0-90.0/ 2.0-3.0	49.0-53.0/ 26.5-30.5/ 3.5-4.5/ 15.5-17.0	48.0-52.0/ 37.0-41.0/ 1.0-2.0/ 8.5-10.0	81.0-83.0/ 17.0-19.0	24.0-26.0/ 74.0-76.0	58.0-59.5/ 39.0-40.5/ 1.3-1.6
Bubble Point[1]	°C @ 101.3 kPa	N/A	-41.6	-38	-30.6	-34	-32.9	-37.5	-27.7	-23.4
Dew Point[1]	°C @ 101.3 kPa	N/A	-40	-28.7	-27.9	-25.8	-24.3	-34.7	-26.2	-21.8
Critical Temperature	°C	N/A	96	107.2	98.5	110.7	111	100	111.3	108.2
Vapor Phase Contaminants										
Air and Other Non-condensables, Maximum	% by volume @ 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

	Reporting Units	Reference Section	R-411B	R-412A	R-413A	R-414A	R-414B	R-415A	R-415B	R-416A
Liquid Phase Contaminants										
Water, Maximum	ppm by weight	4.4	10	10	10	10	10	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	1	1	1	1	1
Chloride[2]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Table 10 Zeotropic Blends (400 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-417A through R-421A)

	Reporting Units	Reference Section	R-417A	R-417B	R-417C	R-418A	R-419A	R-419B	R-420A	R-421A
Characteristics										
Refrigerant Components	N/A	N/A	R-125/ 134a/ 600	R-125/ 134a/ 600	R-125/ 134a/ 600	R-290/ 22/ 152a	R-125/ 134a/ E170	R-125/ 134a/ E170	R-134a/ 142b	R-125/ 134a
Nominal Composition	% by weight	N/A	46.6/ 50.0/ 3.4	79.0/ 18.3/ 2.7	19.5/ 78.8/ 1.7	1.5/ 96.0/ 2.5	77.0/ 19.0/ 4.0	48.5/ 48.0/ 3.5	88.0/ 12.0	58.0/ 42.0
Allowable Composition	% by weight	N/A	45.5-47.7/ 49.0-51.0/ 3.0-3.5	78.0-80.0/ 17.3-19.3/ 2.2-2.8	18.5-20.5/ 77.8-79.8/ 1.2-1.8	1.0-2.0/ 95.0-97.0/ 2.0-3.0	76.0-78.0/ 18.0-20.0/ 3.0-5.0	47.5-49.5/ 47.0-49.0/ 3.0-4.0	88.0-89.0/ 11.0-12.0	57.0-59.0/ 41.0-43.0
Bubble Point[1]	°C @ 101.3 kPa	N/A	-38	-44	-32.7	-41.2	-42.6	-37.4	-25	-40.8
Dew Point[1]	°C @ 101.3 kPa	N/A	-32.9	-41.5	-29.2	-40.1	-36	-31.5	-24.2	-35.5
Critical Temperature	°C	N/A	89.9	75.2	95.4	96.7	79.1	90.4	105.4	78.5
Vapor Phase Contaminants:										
Air and Other Non-condensables, Maximum	% by volume @ 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

	Reporting Units	**Reference Section**	**R-417A**	**R-417B**	**R-417C**	**R-418A**	**R-419A**	**R-419B**	**R-420A**	**R-421A**
Liquid Phase Contaminants										
Water, Maximum	ppm by weight	4.4	10	10	10	10	20	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	1	1	1	1	1
Chloride[2]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Table 11 Zeotropic Blends (400 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-421B through R-424A)

	Reporting Units	**Reference Section**	**R-421B**	**R-422A**	**R-422B**	**R-422C**	**R-422D**	**R-422E**	**R-423A**	**R-424A**
Characteristics										
Refrigerant Components	N/A	N/A	R-125/ 134a	R-125/ 134a/ 600a	R-125/ 134a/ 600a	R-125/ 134a/ 600a	R-125/ 134a/ 600a	R-125/ 134a/ 600a	R-134a/ 227ea	R-125/ 134a/ 600a/ 600/ 601a
Nominal Composition	% by weight	N/A	85.0/ 15.0	85.1/ 11.5/ 3.4	55.0/ 42.0/ 3.0	82.0/ 15.0/ 3.0	65.1/ 30.5/ 3.4	58.0/ 39.3/ 2.7	52.5/ 47.5	50.5/ 47.0/ 0.9/ 1.0/ 0.6
Allowable Composition	% by weight	N/A	84.0-86.0/ 14.0-16.0	84.1-86.1/ 10.5-12.5/ 3.0-3.5	54.0-56.0/ 41.0-43.0/ 2.5-3.1	81.0-83.0/ 14.0-16.0/ 2.5-3.1	64.0-66.0/ 30.5-32.5/ 3.0-3.5	57.0-59.0/ 38.0-41.0/ 2.5-3.0	51.5-53.5/ 46.5-48.5	49.5-51.5/ 46.0-48.0/ 0.7-1.0/ 0.8-1.1/ 0.4-0.7
Bubble Point[1]	°C @ 101.3 kPa	N/A	-45.7	-46.5	-40.5	-45.3	-43.2	-41.8	-24.2	-39.1
Dew Point[1]	°C @ 101.3 kPa	N/A	-42.6	-44.1	-35.6	-42.3	-38.4	-36.4	-23.5	-33.3
Critical Temperature	°C	N/A	69	71.7	85.7	76.1	79.6	82.2	99	87.5
Vapor Phase Contaminants										
Air and Other Non-condensables, Maximum	% by volume @ 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

	Reporting Units	Reference Section	R-421B	R-422A	R-422B	R-422C	R-422D	R-422E	R-423A	R-424A
Liquid Phase Contaminants										
Water, Maximum	ppm by weight	4.4	10	10	10	20	10	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	1	1	1	1	1
Chloride[2]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Table 12 Zeotropic Blends (400 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-425A through R-431A)

	Reporting Units	Reference Section	R-425A	R-426A	R-427A	R-428A	R-429A	R-430A	R-431A
Characteristics									
Refrigerant Components	N/A	N/A	R-32/ 134a/ 227ea	R-125/ 134a/ 600/ 601a	R-32/ 125/ 143a/ 134a	R-125/ 143a/ 290/ 600a	R-E170/ 152a/ 600a	R-152a/ 600a	R290/ 152a
Nominal Composition	% by weight	N/A	18.5/ 69.5/ 12.0	5.1/ 93.0/ 1.3/ 0.6	15.0/ 25.0/ 10.0/ 50.0	77.5/ 20.0/ 0.6/ 1.9	60.0/ 10.0/ 30.0	76.0/ 24.0	71.0/ 29.0
Allowable Composition	% by weight	N/A	18.0-19.0/ 69.0-70.0/ 11.5-12.5	4.1-6.1/ 92.0-94.0/ 1.1-1.4/ 0.4-0.7	13.0-17.0/ 23.0-27.0/ 8.0-12.0/ 48.0-52.0	76.5-78.5/ 19.0-21.0/ 0.4-0.7/ 1.7-2.0	59.0-61.0/ 9.0-11.0/ 29.0-31.0	75.0-77.0/ 23.0-25.0	70.0-72.0/ 28.0-30.0
Bubble Point[1]	°C @ 101.3 kPa	N/A	-38.1	-28.5	-43	-48.3	-25.5	-27.6	-43.2
Dew Point[1]	°C @ 101.3 kPa	N/A	-31.3	-26.7	-36.3	-47.5	-24.9	-27.4	-43.2
Critical Temperature	°C	N/A	93.9	100.2	85.3	69	123.5	107	100.3
Vapor Phase Contaminants									
Air and Other Non-condensables, Maximum	% by volume @ 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5

	Reporting Units	**Reference Section**	**R-425A**	**R-426A**	**R-427A**	**R-428A**	**R-429A**	**R-430A**	**R-431A**
Liquid Phase Contaminants									
Water, Maximum	ppm by weight	4.4	10	10	10	10	20	20	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	1	1	1	1
Chloride[2]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Table 13 Zeotropic Blends (400 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-434A through R-442A)

	Reporting Units	**Reference Section**	**R-434A**	**R-435A**	**R-437A**	**R-438A**	**R-439A**	**R-440A**	**R-442A**
Characteristics									
Refrigerant Components	N/A	N/A	R-125/ 143a/ 134a/ 600a	R-E170/ 152a	R-125/ 134a/ 600/ 601	R-32/ 125/ 134a/ 600/ 601a	R-32/ 125/ 600a	R-290/ 134a/ 152a	R-32/ 125/ 134a/ 152a/ 227ea
Nominal Composition	% by weight	N/A	63.2/18.0/ 16.0/2.8	80.0/20.0	19.5/ 78.5/ 1.4/0.6	8.5/ 45.0/ 44.2/ 1.7/ 0.6	50.0/ 47.0/ 3.0	0.6/ 1.6/ 97.8	31.0/ 31.0/ 30.0/ 3.0/ 5.0
Allowable Composition	% by weight	N/A	62.2-64.2/ 17.0-19.0/ 15.0-17.0/ 2.6-2.9	79.0-81.0/ 19.0-21.0	17.7-20.0/ 77.8-80.0/ 1.2-1.5/ 0.4-0.7	7.0-9.0/ 43.5-46.5/ 42.7-45.7/ 1.5-1.8/ 0.4-0.7	49.0-51.0/ 46.0-48.0/ 2.5-3.5	0.5-0.7/ 1.0-2.2/ 97.3-98.3	30.0-32.0/ 30.0-32.0/ 29.0-31.0/ 2.5-3.5/ 4.0-6.0
Bubble Point[1]	°C @ 101.3 kPa	N/A	-45.1	-26	-32.9	-43	-52	-25.5	-46.5
Dew Point[1]	°C @ 101.3 kPa	N/A	-42.4	-25.8	-29.2	-36.4	-51.7	-24.3	-39.9
Critical Temperature	°C	N/A	75.6	125.2	95.3	84.2	72	112.9	82.4
Vapor Phase Contaminants									
Air and Other Non-condensables, Maximum	% by volume @ 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5

	Reporting Units	**Reference Section**	**R-434A**	**R-435A**	**R-437A**	**R-438A**	**R-439A**	**R-440A**	**R-442A**
Liquid Phase Contaminants									
Water, Maximum	ppm by weight	4.4	10	20	10	10	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	1	1	1	1
Chloride[2]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Table 14 Zeotropic Blends (400 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-444A through R-449A)

	Reporting Units	**Reference Section**	**R-444A**	**R-444B**	**R-445A**	**R-446A**	**R-447A**	**R-447B**	**R-448A**	**R-449A**
Characteristics										
Refrigerant Components	N/A	N/A	R-32/ 152a/ 1234ze(E)	R-32/ 152a/ 1234ze(E)	R-744/ 134a/ 1234ze(E)	R-32/ 1234ze(E)/ 600	R-32/ 125/ 1234ze(E)	R-32/ 125/ 1234ze(E)	R-32/ 125/ 1234yf/ 134a/ 1234ze(E)	R-32/ 125/ 1234yf/ 134a
Nominal Composition	% by weight	N/A	12.0/ 5.0/ 83.0	41.5/ 10.0/ 48.5	6.0/ 9.0/ 85.0	68.0/ 29.0/ 3.0	68.0/ 3.5/ 28.5	68.0/ 8.0/ 24.0	26.0/ 26.0/ 20.0/ 21.0/ 7.0	24.3/ 24.7/ 25.3/ 25.7
Allowable Composition	% by weight	N/A	11.0-13.0/ 4.0-6.0/ 81.0-85.0	40.5-42.5/ 9.0-11.0/ 47.5-49.5	5.0-7.0/ 8.0-10.0/ 83.0-87.0	67.0-68.5/ 28.4-31.0/ 2.0-3.1	67.5-69.5/ 3.0-5.0/ 27.5-29.5	66.0-69.0/ 7.0-10.0/ 22.0-25.0	24.0-26.5/ 25.5-28.0/ 18.0-20.5/ 20.0-23.0/ 5.0-7.5	23.3-24.5/ 24.5-25.7/ 24.3-25.5/ 25.5-26.7
Bubble Point[1]	°C @ 101.3 kPa	N/A	-34.3	-44.6	-50.3	-49.4	-49.3	-50.0	-45.9	-46
Dew Point[1]	°C @ 101.3 kPa	N/A	-24.3	-34.9	-23.5	-42.1	-44.2	-46.0	-39.8	-39.9
Critical Temperature	°C	N/A	103.2	91.5	98	84.2	82.6	83.6	81.6	81.5
Vapor Phase Contaminants										
Air and Other Non-condensables, Maximum	% by volume @ 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

	Reporting Units	**Reference Section**	**R-444A**	**R-444B**	**R-445A**	**R-446A**	**R-447A**	**R-447B**	**R-448A**	**R-449A**
Liquid Phase Contaminants										
Water, Maximum	ppm by weight	4.4	10	10	10	10	10	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	N/A	1	1	1	1	1
Chloride[2]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Table 15 Zeotropic Blends (400 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-449B through R-452C)

	Reporting Units	**Reference Section**	**R-449B**	**R-449C**	**R-450A**	**R-451A**	**R-451B**	**R-452A**	**R-452B**	**R-452C**
Characteristics										
Refrigerant Components	N/A	N/A	R-32/125/1234yf/134a	R-32/125/1234yf/134a	R-134a/1234ze(E)	R-1234yf/134a	R-1234yf/134a	R-32/125/1234yf	R-32/125/1234yf	R-32/125/1234yf
Nominal Composition	% by weight	N/A	25.2/24.3/23.2/27.3	20.0/20.0/31.0/29.0	42.0/58.0	89.8/10.2	88.8/11.2	11.0/59.0/30.0	67.0/7.0/26.0	12.5/61.0/26.5
Allowable Composition	% by weight	N/A	23.7-25.5/24.0-25.8/21.7-23.5/27.0-28.8	18.5-20.5/19.5-21.5/29.5-31.5/28.5-30.5	40.0-44.0/56.0-60.0	89.6-90.0/10.0-10.4	88.6-89.0/11.0-11.4	9.3-12.7/57.2-60.8/29.0-30.1	65.0-69.0/5.5-8.5/24.0-28.0	11.0-13.0/60.0-62.0/25.0-27.0
Bubble Point[1]	°C @ 101.3 kPa	N/A	-46.1	-44.6	-23.4	-30.8	-31	-47	-51.0	-47.5
Dew Point[1]	°C @ 101.3 kPa	N/A	-40.2	-38.1	-22.8	-30.5	-30.6	-43.2	-50.3	-44.2
Critical Temperature	°C	N/A	84.2	83.5	104.4	95.4	95.5	74.9	75.7	75.8
Vapor Phase Contaminants										
Air and Other Non-condensables, Maximum	% by volume @ 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

	Reporting Units	Reference Section	R-449B	R-449C	R-450A	R-451A	R-451B	R-452A	R-452B	R-452C
Liquid Phase Contaminants										
Water, Maximum	ppm by weight	4.4	10	10	10	10	10	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	1	1	1	1	1
Chloride[2]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Table 16 Zeotropic Blends (400 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-453A through R-455C)

	Reporting Units	**Reference Section**	**R-453A**	**R-454A**	**R-454B**	**R-454C**	**R-454D**	**R-455A**	**R-455B**	**R-455C**
Characteristics										
Refrigerant Components	N/A	N/A	R-32/ 125/ 134a/ 227ea/ 600/601a	R-32/ 1234yf	R-32/ 1234yf	R-32/ 1234yf	R-32/ 1234yf	R-744/ 32/ 1234yf	R-744/ 32/ 1234yf	R-744/ 32/ 1234yf
Nominal Composition	% by weight	N/A	20.0/20.0/ 53.8/5.0/ 0.6/0.6	35.0/ 65.0	68.9/ 31.1	21.5/ 78.5	43.0/ 57.0	3.0/ 21.5/ 75.5	6.0/ 42.0/ 52.0	7.5/ 78.0/ 54.0
Allowable Composition	% by weight	N/A	19.0-21.0/ 19.0-21.0/ 52.8-54.8/ 4.5-5.5/ 0.4-0.7/ 0.4-0.7	33.0-37.0/ 63.0-67.0	67.9-69.9/ 30.1-32.1	19.5-23.5/ 76.5-80.5	41.0-45.0/ 55.0-59.0	2.0-5.0/ 19.5-22.5/ 73.5-77.5	5.5-6.5/ 41.0-43.0/ 51.0-53.0	2.0-3.5/ 41.0-45.0/ 52.0-56.0
Bubble Point[1]	°C @ 101.3 kPa	N/A	-42.2	-48.4	-50.9	-46.0	-48.7	-51.6	-57.4	-53.4
Dew Point[1]	°C @ 101.3 kPa	N/A	-35	-41.6	-50.0	-37.8	-44.5	-39.1	-46.7	-45.7
Critical Temperature	°C	N/A	88	86.2	76.5	82.4	80.2	82.8	77.6	78.8
Vapor Phase Contaminants										
Air and Other Non-condensables, Maximum	% by volume @ 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

	Reporting Units	Reference Section	R-453A	R-454A	R-454B	R-454C	R-454D	R-455A	R-455B	R-455C
Liquid Phase Contaminants										
Water, Maximum	ppm by weight	4.4	10	10	10	10	10	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	1	1	N/A	N/A	N/A
Chloride[2]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Table 17 Zeotropic Blends (400 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-456A through R-460B)

	Reporting Units	Reference Section	R-456A	R-457A	R-457B	R-457C	R-457D	R-459B	R-460A	R-460B
Characteristics										
Refrigerant Components	N/A	N/A	R-32/ 134a/ 1234ze(E)	R-32/ 1234yf/ 152a	R-32/ 1234yf/ 152a	R-32/ 1234yf/ 152a	R-32/ 1234yf/ 152a	R-32/ 1234yf/ 1234ze(E)	R-32/ 125/ 134a/ 1234ze(E)	R-32/ 125/ 134a/ 1234ze(E)
Nominal Composition	% by weight	N/A	6.0/45.0/ 49.0	18.0/70.0/ 12.0	35.0/ 55.0/ 10.0	7.5/ 78.0/ 14.5	4.0/ 82.0/ 14.0	21.0/ 69.0/ 10.0	12.0/ 52.0/ 14.0/ 22.0	28.0/ 25.0/ 20.0/ 27.0
Allowable Composition	% by weight	N/A	5.0-7.0/ 44.0-46.0/ 48.0-50.0	16.5-18.5/ 68.5-70.5/ 10.1-12.1	33.5-36.0/ 53.5-55.5/ 8.1-10.1	6.0-8.0/ 77.0-79.0/ 13.0-15.0	2.5-4.5/ 81.0-83.0/ 12.5-14.5	20.0-21.5/ 67.0-71.0/ 9.0-11.0	11.0-13.0/ 51.0-53.0/ 13.0-15.0/ 21.0-23.0	27.0-29.0/ 24.0-26.0/ 19.0-21.0/ 26.0-28.0
Bubble Point[1]	°C @ 101.3 kPa	N/A	-30.4	-42.7	-46.4	-37.3	-34.5	-44.0	-44.6	-45.2
Dew Point[1]	°C @ 101.3 kPa	N/A	-25.6	-35.5	-40.4	-32.1	-30.9	-36.1	-37.2	-37.1
Critical Temperature	°C	N/A	102.4	92.6	85.3	94.1	95.3	89.8	81.6	85.7
Vapor Phase Contaminants										
Air and Other Non-condensables, Maximum	% by volume @ 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

	Reporting Units	**Reference Section**	**R-456A**	**R-457A**	**R-457B**	**R-457C**	**R-457D**	**R-459B**	**R-460A**	**R-460B**
Liquid Phase Contaminants										
Water, Maximum	ppm by weight	4.4	10	10	10	10	10	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	1	1	1	1	1
Chloride[2]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Table 18 Zeotropic Blends (400 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-460C through R-467A)

	Reporting Units	Reference Section	R-460C	R-461A	R-462A	R-463A	R-464A	R-465A	R-466A	R-467A
Characteristics										
Refrigerant Components	N/A	N/A	R-32/125/134a/1234ze(E)	R-125/143a/134a/227ea/600a	R-32/125/143a/134a/600	R-744/32/125/1234yf/134a	R-32/125/1234ze(E)/227ea	R-32/290/1234yf	R-32/125/13I1	R-32/125/134a/600a
Nominal Composition	% by weight	N/A	2.5/ 2.5/ 46.0/ 49.0	55.0/ 5.0/ 32.0/ 5.0/ 3.0	9.0/ 42.0/ 2.0/ 44.0/ 3.0	6.0/ 36.0/ 30.0/ 14.0/ 14.0	27.0/ 27.0/ 40.0/ 6.0	21.0/ 7.9/ 71.1	49.0/ 11.5/ 39.5	22.0/ 5.0/ 72.4/ 0.6
Allowable Composition	% by weight	N/A	2.0-3.0/ 2.0-3.0/ 45.0-47.0/ 48.0-50.0	54.0-56.0/ 4.5-5.5/ 31.0-33.0/ 4.5-5.5/ 2.6-3.1	8.0-10.5/ 40.0-44.0/ 1.0-3.0/ 42.0-46.0/ 2.0-4.0	5.0-8.0/ 34.0-38.0/ 28.0-32.0/ 12.0-16.0/ 12.0-16.0	26.0-28.0/ 26.0-28.0/ 39.0-41.0/ 5.5-6.5	19.5-21.5/ 7.0-8.0/ 70.1-72.1	47.0-49.5/ 11.0-13.5/ 39.0-41.5	21.5-22.1/ 4.5-5.5/ 70.9-72.9/ 0.5-0.7
Bubble Point[1]	°C @ 101.3 kPa	N/A	-29.2	-42	-42.6	-58.4	-46.5	-51.8	-51.7	-40.5
Dew Point[1]	°C @ 101.3 kPa	N/A	-26.0	-37	-36.6	-46.9	-36.9	-40.0	-51	-33.3
Critical Temperature	°C	N/A	99.5	81.4	83.5	75.8	82.6	89.4	76.5	92
Vapor Phase Contaminants										
Air and Other Non-condensables, Maximum	% by volume @ 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

	Reporting Units	**Reference Section**	**R-460C**	**R-461A**	**R-462A**	**R-463A**	**R-464A**	**R-465A**	**R-466A**	**R-467A**
Liquid Phase Contaminants										
Water, Maximum	ppm by weight	4.4	10	10	10	10	10	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	N/A	1	1	1	1
Chloride[2]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Table 19 Zeotropic Blends (400 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-468A through R-472A)

	Reporting Units	Reference Section	R-468A	R-468B	R-468C	R-469A	R-470A	R-470B	R-471A	R-472A
Characteristics										
Refrigerant Components	N/A	N/A	R-1132a/ 32/ 1234yf	R-1132a/ 32/ 1234yf	R-1132a/ 32/ 1234yf	R-744/ 32/ 125	R-744/ 32/ 125/ 134a/ 1234ze(E)/ 227ea	R-744/ 32/ 125/ 134a/ 1234ze(E)/ 227ea	R-1234ze(E)/ 227ea/ 1336mzz(E)	R-744/ 32/ 134a
Nominal Composition	% by weight	N/A	3.5/ 21.5/ 75.0	6.0/ 13.0/ 81.0	6.0/ 42.0/ 52.0	35.0/ 32.5/ 32.5	10.0/ 17.0/ 19.0/ 7.0/ 44.0/ 3.0	10.0/ 11.5/ 11.5/ 3.0/ 57.0/ 7.0	78.7/ 4.3/ 17.0	69.0/ 12.0/ 19.0
Allowable Composition	% by weight	N/A	2.0-3.7/ 19.5-23.5/ 73.0-77.0	5.0-6.5/ 12.0-13.5/ 80.0-83.0	5.0-6.5/ 41.0-42.5/ 50.0-54.0	32.0-37.0/ 30.5-34.5/ 30.5-34.5	9.0-11.0/ 16.0-18.0/ 18.0-20.0/ 6.5-7.5/ 42.0-46.0/ 2.5-3.5	9.0-11.0/ 10.5-12.5/ 10.5-12.5/ 2.5-3.5/ 55.0-59.0/ 6.5-7.5	77.2-79.1/ 3.9-5.8/ 16.6-18.5	68.0-70.0/ 11.0-13.0/ 18.0-20.0
Bubble Point[1]	°C @ 101.3 kPa	N/A	-51.3	-52.4	-56.6	-78.5	-62.7	-61.7	-16.9	-84.3
Dew Point[1]	°C @ 101.3 kPa	N/A	-39.0	-36.8	-46.2	-61.5	-35.6	-31.4	-13.8	-61.5
Critical Temperature	°C	N/A	83.9	85.0	76.8	57	94.3	94.3	111.8	50.2
Vapor Phase Contaminants										
Air and Other Non-condensables, Maximum	% by volume @ 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

	Reporting Units	Reference Section	R-468A	R-468B	R-468C	R-469A	R-470A	R-470B	R-471A	R-472A
Liquid Phase Contaminants										
Water, Maximum	ppm by weight	4.4	10	10	10	10	10	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	1	1	1	N/A	N/A	N/A	1	N/A
Chloride[2]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Table 20 Zeotropic Blends (400 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-472B through R-478A)

	Reporting Units	**Reference Section**	**R-472B**	**R-473A**	**R-475A**	**R-476A**	**R-477A**	**R-477B**	**R-478A**
Characteristics									
Refrigerant Components	N/A	N/A	R-744/ 32/ 134a	R-1132a/ 23/ 744/ 125	R-1234yf/ 134a/ 1234ze(E)	R-134a/ 1234ze(E)/ 1336mzz(E)	R-1270/ 600a	R-1270/ 600a	R-744/ 32/ 125/ 134a/ 152a/ 1234ze(E)/ 227ea
Nominal Composition	% by weight	N/A	58.0/ 10.0/ 32.0	20.0/ 10.0/ 60.0/ 10.0	45.0/ 43.0/ 12.0	10.0/ 78.0/ 12.0	84.0/ 16.0	38.0/ 62.0	7.0/ 26.0/ 15.0/ 15.0/ 3.0/ 30.0/ 4.0
Allowable Composition	% by weight	N/A	57.0-59.0/ 9.0-11.0/ 31.0-33.0	19.0-20.5/ 9.0-11.0/ 58.0-62.0/ 9.0-11.0	44.0-46.0/ 42.0-44.0/ 11.0-13.0	9.5-12.0/ 76.0-78.5/ 11.5-14.0	82.0-86.0/ 14.0-18.0	36.0-39.0/ 61.0-64.0	6.5-7.5/ 25.0-27.0/ 14.0-16.0/ 14.0-16.0/ 2.8-3.2/ 29.0-31.0/ 3.5-4.5
Bubble Point[1]	°C @ 101.3 kPa	N/A	-82.9	-87.6	-28.8	-19.1	-44.6	-31.5	-58.4
Dew Point[1]	°C @ 101.3 kPa	N/A	-54.8	-83	-28.3	-16.1	-37.2	-23.1	-37.4
Critical Temperature	°C	N/A	57.9	29.7	99.3	110.2	100.5	121.7	88

	Reporting Units	Reference Section	R-472B	R-473A	R-475A	R-476A	R-477A	R-477B	R-478A
Vapor Phase Contaminants									
Air and Other Non-condensables, Maximum	% by volume @ 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Liquid Phase Contaminants									
Water, Maximum	ppm by weight	4.4	10	10	10	10	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight (as HCl)	4.7	N/A	1	1	1	1	1	N/A
Chloride[2]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Table 21 Hydrocarbon Blends (400 Series Refrigerants) Characteristics and Allowable Levels of Contaminants

	Reporting Units	**Reference Section**	**R-432A**	**R-433A**	**R-433B**	**R-433C**	**R-436A**	**R-436B**	**R-436C**	**R-441A**	**R-443A**
Characteristics											
Refrigerant Components	N/A	N/A	R-1279/ E170	R-1270/ 290	R-1270/ 290	R-1270/ 290	R-290/ 600a	R-290/ 600a	R-290/ 600a	R-170/ 290/ 600a/ 600	R-1270/ 290/ 600a
Nominal Composition	% by weight	N/A	80.0/ 20.0	30.0/ 70.0	5.0/ 95.0	25.0/ 75.0	56.0/ 44.0	52.0/ 48.0	95.0/ 5.0	3.1/ 54.8/ 6.0/ 36.1	55.0/ 40.0/ 5.0
Allowable Composition	% by weight	N/A	79.0-81.0/ 19.0-21.0	29.0-31.0/ 69.0-71.0	4.0-6.0/ 94.0-96.0	24.0-26.0/ 74.0-76.0	55.0-57.0/ 43.0-45.0	51.0-53.0/ 47.0-49.0	93.8-96.5/ 3.8-6.2	2.8-2.4/ 52.8-56.8/ 5.4-6.6/ 34.1-38.1	53.0-57.0/ 38.0-42.0/ 3.8-6.2
Bubble Point[1]	°C @ 101.3 kPa	N/A	-45.2	-44.4	-42.5	-44.1	-34.3	-33.3	-41.5	-41.5	-45.2
Dew Point[1]	°C @ 101.3 kPa	N/A	-42.4	-44	-42.4	-43.7	-26.1	-25	-39.5	-20.3	-42.1
Critical Temperature[1]	°C	N/A	97.3	94.4	96.3	94.8	115.9	117.4	96.8	117.3	95.1
Vapor Phase Contaminants											
Air and Other Non-condensables, Maximum	% by volume @ 25.0°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

	Reporting Units	**Reference Section**	**R-432A**	**R-433A**	**R-433B**	**R-433C**	**R-436A**	**R-436B**	**R-436C**	**R-441A**	**R-443A**
Liquid Phase Contaminants[4]											
Sulfur Odor[2]	No odor to pass	4.13	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/ Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight	4.7	1	1	1	1	1	1	1	1	N/A
Water, Maximum	ppm by weight	4.4	20	10	10	10	10	10	10	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Total C_3, C_4 and C_5 Polyolefins, Maximum	% by weight	4.12	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Chloride[3]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	N/A	N/A

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Including hydrogen sulfide and mercaptans.
3. Taken from vapor phase.
4. Vaporized from liquid phase.

N/A = Not applicable

Table 22 Azeotropic Blends (500 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-500 through R-512A)

	Reporting Units	**Reference Section**	**R-500**	**R-502**	**R-503**	**R-507A**	**R-508A**	**R-508B**	**R-509A**	**R-510A**	**R-511A**	**R-512A**
Characteristics												
Refrigerant Components	N/A	N/A	R-12/ 152a	R-22/ 115	R-23/ 13	R-125/ 143a	R-23/ 116	R-23/ 116	R-22/ 218	R-E170/ 600a	R-290/ E170	R-134a/ 152a
Nominal Composition	% by Weight	N/A	73.8/ 26.2	48.8/ 51.2	40.1/ 59.9	50.0/ 50.0	39.0/ 61.0	46.0/ 54.0	44.0/ 56.0	88.0/ 12.0	95.0/ 5.0	5.0/ 95.0
Allowable Composition	% by weight	N/A	72.8-74.8/ 25.2-27.2	44.8-52.8/ 47.2-55.2	39.0-41.0/ 59.0-61.0	49.5-51.5/ 48.5-50.5	37.0-41.0/ 59.0-63.0	44.0-48.0/ 52.0-56.0	42.0-46.0/ 56.0-60.0	87.5-88.5/ 11.5-12.5	94.0-96.0/ 4.0-6.0	4.0-6.0/ 94.0-96.0
Bubble Point[1]	°C @ 101.3 kPa	N/A	-33.6	-45.2	-87.8	-46.7	-87.4	-87	-49.8	-24.9	-42	-24
Dew Point[1]	°C @ 101.3 kPa	N/A	-33.6	-45	-87.8	-46.7	-87.4	-87	-48.1	-24.9	-42	-24
Critical Temperature[1]	°C	N/A	102.1	80.2	18.4	70.6	10.8	11.8	68.6	125.7	97	112.9
Vapor Phase Contaminants												
Air and Other Non-condensables, Maximum	% by volume @ 25°C	4.10	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

	Reporting Units	**Reference Section**	**R-500**	**R-502**	**R-503**	**R-507A**	**R-508A**	**R-508B**	**R-509A**	**R-510A**	**R-511A**	**R-512A**
Liquid Phase Contaminants												
Water, Maximum	ppm by weight	4.4	10	10	10	10	10	10	10	20	20	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Particulates/Solids	Pass/Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight	4.7	1	1	1	1	1	1	1	1	1	1
Chloride[2]	Pass/Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Table 23 Azeotropic Blends (500 Series Refrigerants) Characteristics and Allowable Levels of Contaminants (R-513A through R-516A)

	Reporting Units	**Reference Section**	**R-513A**	**R-513B**	**R-514A**	**R-515A**	**R-516A**
Characteristics							
Refrigerant Components	N/A	N/A	R-1234yf/ 134a	R-1234yf/ 134a	R-1336mzz(Z)/ 1130(E)	R-1234ze(E)/ 227ea	R-1234yf/134a/ 152a
Nominal Composition	% by weight	N/A	56.0/ 44.0	58.5/ 41.5	74.7/ 25.3	88.0/ 12.0	77.5/ 8.5/ 14.0
Allowable Composition	% by weight	N/A	55.0-57.0/ 43.0-45.0	58.0-59.0/ 41.0-42.0	74.2-76.2/ 23.8-25.8	86.0-89.0/ 11.0-14.0	76.1-78.9/ 7.0-9.0/ 12.1-14.1
Bubble Point[1]	°C @ 101.3 kPa	N/A	-29.2	-29.2	29.0	-18.9	-29.4
Dew Point[1]	°C @ 101.3 kPa	N/A	-29.1	-29.1	29.0	-18.9	-29.4
Critical Temperature[1]	°C	N/A	96.5	95.5	178.1	108.4	99.3
Vapor Phase Contaminants							
Air and Other Non-condensables, Maximum	% by volume @ 25°C	4.10	1.5	1.5	N/A	1.5	1.5

	Reporting Units	**Reference Section**	**R-513A**	**R-513B**	**R-514A**	**R-515A**	**R-516A**
Liquid Phase Contaminants							
Water, Maximum	ppm by weight	4.4	10	10	20	10	10
All Other Volatile Impurities, Maximum	% by weight	4.11	0.5	0.5	0.5	0.5	0.5
HBR, Maximum	% by volume or % by weight	4.8	0.01	0.01	0.01	0.01	0.01
Particulates/Solids	Pass or Fail	4.9	Visually clean	Visually clean	Visually clean	Visually clean	Visually clean
Acidity, Maximum	ppm by weight	4.7	1	1	1	1	1
Chloride[2]	Pass or Fail	4.6	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity	No visible turbidity

Notes:

1. *Bubble points*, *dew points*, and *critical temperatures*, although not required, are provided for informational purposes. Refrigerant data compiled from REFPROP 10.0.
2. Recognized chloride level for pass/fail is 3 ppm.

N/A = Not applicable

Section 8. Characterization of Refrigerants and Contaminants

8.1 Single Component Fluorocarbon and Zeotropic/Azeotropic Blend Refrigerants

Characterization of single component fluorocarbon (Table 1 through Table 3) and zeotropic/azeotropic blend (Table 6 through Table 20, Table 22, and Table 23) refrigerants and contaminants are listed in the following classifications:

8.1.1 Isomer Content

See Table 1 through Table 3.

8.1.2 Air and Other Non-condensables

See Table 1 through Table 3, Table 6 through Table 20, Table 22, and Table 23.

8.1.3 Water

See Table 1 through Table 3, Table 6 through Table 20, Table 22, and Table 23.

8.1.4 All Other Volatile Impurities

See Table 1 through Table 3, Table 6 through Table 20, Table 22, and Table 23.

8.1.5 High Boiling Residue

See Table 1 through Table 3, Table 6 through Table 20, Table 22, and Table 23.

8.1.6 Particulates/Solids

See Table 1 through Table 3, Table 6 through Table 20, Table 22, and Table 23.

8.1.7 Acidity

See Table 1 through Table 3, Table 6 through Table 20, Table 22, and Table 23.

8.1.8 Chloride

See Table 1 through Table 3, Table 6 through Table 20, Table 22, and Table 23.

8.2 Hydrocarbon Refrigerants

Characterization of hydrocarbon refrigerants (Table 4 and Table 21) and contaminants are listed in the following classifications:

8.2.1 Nominal Composition

See Table 4 and Table 21.

8.2.2 Other Allowable Impurities

See Table 4.

8.2.3 Air and Other Non-condensables

See Table 4 and Table 21.

8.2.4 Sulfur Odor

See Table 4 and Table 21.

8.2.5 High Boiling Residue

See Table 4 and Table 21.

8.2.6 Particulates/Solids

See Table 4 and Table 21.

8.2.7 Acidity

See Table 4 and Table 21.

8.2.8 Water

See Table 4 and Table 21.

8.2.9 All other volatile impurities

See Table 4 and Table 21.

8.2.10 Total C3, C4 and C5 polyolefins

See Table 4 and Table 21.

8.2.11 Chloride

See Table 21.

8.3 Carbon Dioxide Refrigerants

Characterization of carbon dioxide and carbon dioxide’s contaminants are shown in Table 5 in the following classifications:

- Purity
- Air and other non-condensables
- Water
- High boiling residue
- Particulates/Solids

Section 9. Recording Procedure

The source, either manufacturer, reclaimer, or repackager, of the packaged refrigerant shall be identified. The refrigerant shall be identified by its accepted refrigerant number or the chemical name, or both. Maximum allowable levels of contaminants are shown in Table 1 through Table 23. Test results shall be tabulated in the same manner.

APPENDIX A. REFERENCES – NORMATIVE

This appendix lists all standards, handbooks, and other publications essential to the development and implementation of the standard. All references in this appendix are part of the standard.

A.1. AHRI Standard 740-2016 (SI), *Performance Rating of Refrigerant Recovery Equipment and Recovery/Recycling Equipment*, 2016 Air-Conditioning, Heating, and Refrigeration Institute, 2111 Wilson Blvd., Suite 500, Arlington, VA 22201, USA

A.2. ANSI/ASHRAE Standard 34-2022, *Designation and Safety Classification of Refrigerants*, 2022, with Addenda, ASHRAE, 180 Technology Parkway NW, Peachtree Corners, Georgia 30092, USA.

A.3. ASHRAE *Handbook – Fundamentals*, 2021, ASHRAE, 180 Technology Parkway NW, Peachtree Corners, Georgia 30092, USA.

A.4. ASHRAE *Terminology*. ASHRAE. Accessed August 9, 2024. https://www.ashrae.org/technical-resources/free-resources/ashrae-terminology

A.5. ASTM Standard D1296-01-2012, *Standard Test Method for Odor of Volatile Solvents and Diluents*, 2012, ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428, USA.

A.6. ISO 817:2014, *Refrigerants – Designation and Safety Classification*, 2014, International Organization for Standardization, Chemin de Blandonnet 8 CP 401 - 1214 Vernier, Geneva, Switzerland.

A.7. GPA 2177-20, *Analysis of Natural Gas Liquid Mixtures by Gas Chromatography*, 2020, GPA Midstream Association, 6060 S American Plaza St E #700, Tulsa, OK 74135, USA.

A.8. REFPROP Reference Fluid Thermodynamic and Transport Properties NIST Standard Reference Database 23 Version 10.0, 2018, U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, Standard Reference Data Program, Gaithersburg, MD 20899, USA.

APPENDIX B. REFERENCES – INFORMATIVE

This appendix lists standards, handbooks and other publications that can provide useful information and background but are not essential for the use of this standard. All references in this appendix are not part of the standard.

B.1. U.S. *Code of Federal Regulations*, Title 40, Part 82, 2024, Office of the Federal Register, National Archives and Records Administration, 800 North Capitol Street, NW, Washington, DC 20402, USA.

APPENDIX C. ANALYTICAL PROCEDURES – NORMATIVE

C.1. Determination of Acidity in New and Reclaimed Refrigerants by Titration

C.1.1. Purpose

This test method determines the amount of acidity in new and reclaimed refrigerants.

C.1.2. Scope

This test method is for use with low, medium, and high pressure fluorocarbon refrigerants.

C.1.3. Definitions

Definitions for this section are identical to those in Section 3 and AHRI 740.

C.1.4. Principle

A known quantity of a liquid refrigerant sample is added to, or bubbled through, an extraction solvent that is a mixture of toluene, isopropanol and water to which bromothymol blue indicator has been added. The acidity imparted to the extraction solvent by the sample quantity is titrated with potassium hydroxide (KOH) to the indicator endpoint. The acidity is recorded in ppm as HCl.

C.1.5. Applicability

This method is applicable to the routine quantitative determination of acidity in low, medium, and high pressure refrigerants.

C.1.6. Limitations and Interferences

None of the refrigerants tested interfere with the acidity determination. The test shall be performed after the indicator solution is brought to its blue/green end point to prevent interferences from atmospheric carbon dioxide.

C.1.7. Sensitivity, Precision and Accuracy

C.1.7.1. Sensitivity

The sensitivity of the acidity test using 50 g of sample in 100 g of extraction solvent is 0.1 ppm. Samples shall be handled to prevent cross contamination when performing this test.

C.1.7.2. Precision

Data is not provided.

C.1.7.3. Accuracy

Data is not provided.

C.1.8. Special Apparatus and Reagents

1) Capillary tubing 1/16-in x 0.05-in stainless steel
2) Top loading balance, 1000 g with 0.1 g resolution
3) 1/16-in x 1/4-in stainless steel tube compression fitting reducing union
4) 1/4-in compression x 1/4-in flare AN female adaptor
5) 250 mL Erlenmeyer flask
6) Bromothymol blue sodium salt endpoint indicator
7) Reagent grade isopropanol
8) Reagent grade toluene
9) 0.1 N Potassium hydroxide in methanol
10) 0.1 N Sulfuric acid
11) Absolute methanol (anhydrous, reagent grade)
12) Stir plate/stir bar

13) Glass distilled water
14) Buret (10 mL with 0.05 mL graduation)

C.1.9. Procedure

C.1.9.1. Capillary Tubing Connector

Take a 1/16-in x 0.05-in stainless steel tubing and make a compression fitting (swage) connection using a 1/16-in nut and ferrule. Connect this to a 1/16-in x 1/4-in compression-fitting-reducing union and then connect this combination to the 1/4-in compression fitting x 1/4-in flare adaptor. The 1/4-in flare adaptor can then be connected to the 1/4-in flare fitting on the sample cylinder just before each acidity determination.

C.1.9.2. Reagent Preparation

C.1.9.2.1. 0.01 N Potassium Hydroxide Solution

Pipet 100 mL of 0.1 N potassium hydroxide solution into a 1000 mL volumetric flask. Dilute to the mark with absolute methanol and mix thoroughly.

C.1.9.2.2. 0.01 N Sulfuric Acid Solution

Pipet 100 mL of 0.1 N sulfuric acid solution into a 1000 mL volumetric flask. Dilute to the mark with distilled water and mix thoroughly.

C.1.9.2.3. Extraction Solvent

Add 495 mL of toluene to 495 mL of isopropanol. Add 10 mL of water to the toluene/isopropanol solution and mix thoroughly.

C.1.9.2.4. Bromothymol Blue Indicator Solution

Dissolve 1 g of bromothymol blue sodium salt in 100 mL of methanol. Mix thoroughly and store in a dropper bottle.

C.1.9.3. Sample Analysis

1) Attach the 1/4-in stainless flare fitting to the vapor valve of the sample cylinder.
2) Add 100 mL of the prepared extraction solvent to a 250 mL Erlenmeyer flask. Add a clean magnetic stirring bar. Add six drops of the indicator solution to the extraction solvent and initiate moderate stirring.
3) If the extraction solvent/indicator solution is yellow, add 0.01 N potassium hydroxide through the buret until a just-noticeable difference between yellow and light green is seen in the extraction solvent. Half drops from the buret can be used to achieve the real end point.
4) If the extraction solvent/indicator solution is green or blue, add 0.01 N sulfuric acid through the buret dropwise until the solution is yellow and then proceed as in Section C.1.9.3(3).
5) Attach the cleaned 0.05 in ID stainless steel capillary connector to the sample cylinder and weigh the sample cylinder to the nearest 0.1 g. Slowly introduce 50 g to 75 g of liquid sample into the extraction solvent/indicator solution by gradually opening the cylinder valve and metering the liquid sample to maintain a controlled flow into the solvent. The cylinder can be held by the analyst or clamped to a ring stand throughout the procedure.

   Note: This procedure takes practice to obtain the target mass added on the first try.

6) Once the sample has been added, record the post addition weight to the nearest 0.1 g and subtract from the starting weight, and ensure that the addition is between 50 g and 75 g. Observe the color change. If the color of the solution is green or blue, the result is non-detected. If the solution is yellow, record the buret volume to the nearest 0.01 mL (designate this value as V_1) and add 0.01 N potassium hydroxide dropwise until the original green color endpoint is reached. Record the final buret volume to the nearest 0.01 mL (designate this value as V_2).
7) When testing samples with high concentrations of carbon dioxide as a contaminant, carbon dioxide (R-744) refrigerant or blends containing carbon dioxide (R-744), following the addition of the 50 g to 75 g, the titration solvent shall be purged with dry nitrogen for five minutes to evaporate the entrenched carbon dioxide prior to titrating with potassium hydroxide. Failure to do so results in over-titration and over reporting of the acidity value. Following titration, wait an additional five minutes prior to testing the next sample. If the solvent turns blue or very dark green, repeat the acidity test by increasing the nitrogen purge to ten minutes.

   The final volume, designated as V_f, of 0.01 N potassium hydroxide added is determined as shown in Equation 1.

$$V_f = V_2 - V_1 \qquad \textbf{1}$$

8) The calculation of total acidity expressed in ppm as HCl is shown in Equation 2.

$$ppm\ as\ HCl = \frac{V_f\ \cdot normality\ KOH\ \cdot 36\ 500}{refrigerant\ weight\ sampled} \qquad \textbf{2}$$

   Note: The value 36 500 is the equal weight of HCl (36.5 x 10^3).

C.2. Determination of Water in New and Reclaimed Refrigerants by Coulometric Karl Fischer (KF) Titration

C.2.1. Purpose

This test method determines moisture in new and reclaimed refrigerants by the coulometric KF titration method.

C.2.2. Scope

This test method is for use with low, medium, and high pressure refrigerants.

C.2.3. Definitions

Definitions for this section are identical to those in Section 3 and AHRI 740.

C.2.4. Principle

KF titration is based upon the redox reaction of water, iodine, and sulfur dioxide as shown in Equation 3.

$$\mathrm{H_2O + I_2 + SO_2 \rightarrow 2HI + SO_3} \qquad \textbf{3}$$

The solvent is a mixture of methanol and a weak organic base (imidazole and pyridine) with the base serving to neutralize the reaction products. In coulometric KF titration, iodine is generated at the anode in direct proportion to the amount of water introduced, and the end point is detected bi-amperametrically as the first appearance of excess free iodine. The added refrigerant eventually evaporates; hence, the solvent can be used repeatedly until either the sulfur dioxide or the base solution is consumed.

C.2.5. Applicability

This method is applicable to the routine quantitative determination of small amounts of water in low, medium, and high pressure refrigerants.

C.2.6. Limitations and Interferences

None of the refrigerants tested interfere with the titration. Oxidizing agents such as MnO_4^-, $Cr_2O_7^{-2}$, H_2O_2, Fe (III), Cu (II), and reducing agents such as S^{-2}, thiosulphates, and Sn (II) interferes. Certain compounds such as basic oxides and salts of weak acids ($NaHCO_3$, for example) can form water with the KF reagent. None of these interferences are present in new or reclaimed refrigerants.

C.2.7. Sensitivity, Precision, and Accuracy

C.2.7.1. Sensitivity

The sensitivity of the analyzer in this method using a 10 g sample is 1 ppm. Samples shall be handled to achieve this sensitivity.

C.2.7.2. Precision and Accuracy

The mean of the analysis ($\overline{X}$), standard deviation (σ), and 95% confidence limits (CL) established for the single operator precision of this method are shown in Table 24.

The data in Table 24 were calculated from seventeen replicate analyses of one sample (10 g) performed by one analyst over a period of two days.

The samples in Table 25 are tested for total percent recovery and prepared by analyzing R-12 and R-22 to 4.8 ppm and 7.1 ppm, respectively, and then contaminating the refrigerants with known amounts of water. Both samples are mixed for a period of twenty-four hours before analyzing. Results are shown in Table 25.

The total percent recovery for each sample was 99.3% for R-12 and 99.7% for R-22.

Table 24 Single Operator Method Precision

	Mean ($\overline{X}$)	**Standard Deviation (σ)**	**95% Confidence Limit**
Water (R-12), ppm by weight	10.6	0.11	0.26
Water (R-22), ppm by weight	28.1	0.29	0.77

Table 25 Testing for Percent Water Recovery

	Original Value	**Amount Contaminated**	**Calculated Total**	**Recovered Total**	**Percent Recovery**
Water (R-12), ppm by weight	6.8	6.9	13.7	13.6	99.3
Water (R-22), ppm by weight	19.2	19.0	38.2	38.1	99.7

C.2.8. Special Apparatus and Reagents

1) Coulometric KF titrator system (contains a drying tube for venting refrigerant, anode and cathode solutions, septum, and water vaporizer)
2) Desiccant, 20-40 mesh
3) Desiccator, containing desiccant
4) Refrigerant sample cylinder, such as 50 mL, 500 mL, or 1000 mL stainless steel double ended 1/4-in FNPT cylinder (1800 psig), steel cylinder, 2.2 lb, single 9-gauge valve, 3/8-in pipe neck, disposable can, 17 oz, or other cylinder
5) Stainless steel integral bonnet non-rotating stem valve, 1/4-in MNPT x 1/4-in FNPT
6) Brass screwed-bonnet needle valve, 1/4-in MNPT

7) Male Luer lock 10-32 standard thread needle connector, cut threads back 1/8-in (threads are too long as received)
8) Needle, 19 gauge Luer lock, 4-1/2-in length
9) 1/4-in compression fitting to 1/4-in AN female flare adaptor
10) Quick Seal Flare Cap, No. NFT5-4, 1/4-in tubular seal gasket
11) See Figure 1 for an example of an injection needle and valve attachment. Remove the inner gasket-then drill and tap for a 10/32-in standard thread through the center of the flare cap. Coat the threads with epoxy, screw the adapted male Luer lock need connector into the hole until snug, and then let the epoxy set overnight. After curing, attach the needle to the connector and then screw the assembly onto the needle valve AN female flare adapter.
12) Syringe, 10 mL, gas tight
13) Syringe needle, 19 gauge with a 4-in deflected point

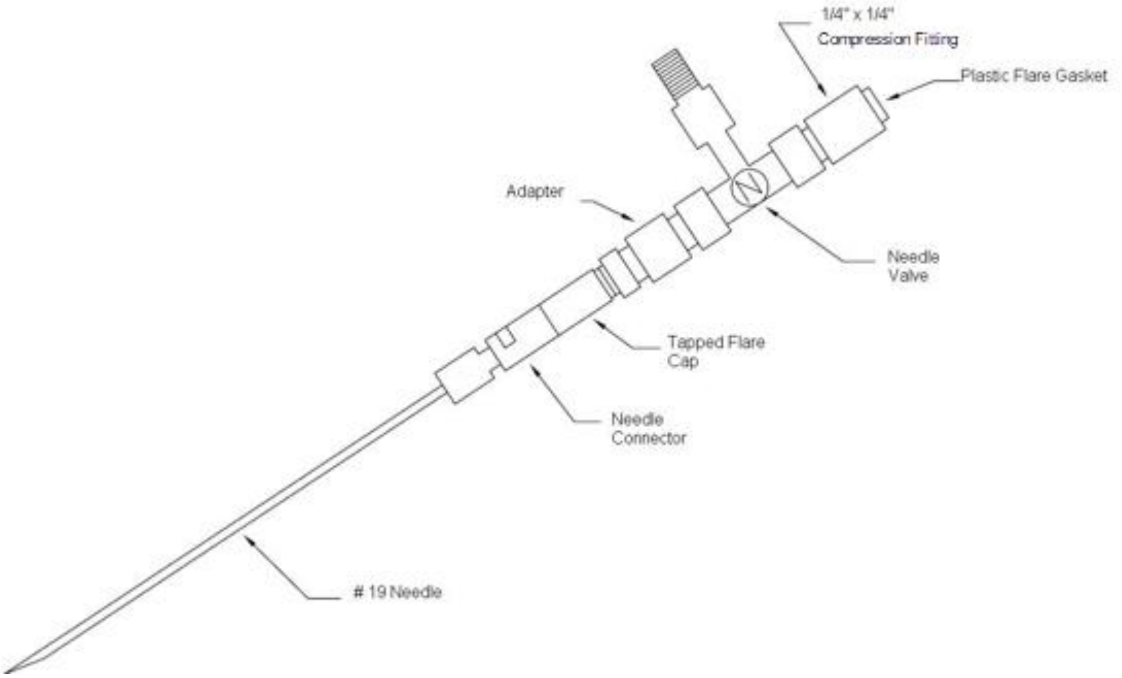


Figure 1 Example Needle Attachment Assembly for Cylinder Sampling (Informative)

C.2.9. Procedure

C.2.9.1. Verification

Verify that the instrument is operating accurately by injecting quantified moisture standard prior to sample testing.

C.2.9.2. Sample Analysis

Note: To minimize contamination from moisture, the sample should be introduced directly from the refrigerant sample cylinder into the coulometric titrator to prevent a secondary container transfer, whenever able. The effects of moisture contamination and phase distribution are minimized if the sample container is 60% to 80% liquid filled with refrigerant. If the sample is a very high pressure refrigerant, cool the cylinder to 14K less than the *critical temperature* of the refrigerant and wait thirty minutes for equilibrium to be established before starting the analysis.

1) Refer to the instruction manual for moisture analyzer installation and operation.

   Note: Instrument sensitivity should be set at 0.10 and a new septum should be attached.

2) Turn-on the analyzer and magnetic stirrer and wait until the background current (µg of H_2O per second) has reached a low, steady level. The titration vessel can be swirled to contact (wash down) any water mist on the upper inside walls with the anode solution. Optimum levels are less than 0.10 µg of H_2O per second, between 0.02 µg of H_2O to 0.05 µg of H_2O.

   Note: If after fifteen minutes a low (< 0.1 µg of H_2O per second) background current is not obtained or if the cathode solution turns a dark reddish-brown color, turn off the moisture meter and, using a small funnel, renew both anode and cathode solutions. If a negative background reading persists (free iodine in the anode solution), introduce a drop of R-113 or methanol-water wetting solution into the vessel to eliminate the free iodine through reaction with water and produce a positive background. This wetting solution can be made by adding a small amount of water (less than 500 ppm) to methanol or R-113.

3) Using a heat gun, dry-off the valve threaded end of the sample cylinder valve that contains a pressure relief valve (350 psi to 400 psi) and cylinder stem valve (1/4-in MNPT x 1/4-in FNPT).

4) Remove the needle/needle valve attachment (see Figure 1) from the oven or desiccator and immediately attach to the sample cylinder valve.

5) Open the refrigerant sample cylinder valve, then slowly open the needle valve and purge a small amount of sample liquid phase to flush the air from the needle (one second to two second purge). Close both valves.

6) Using a heat gun (high position), dry the needle for twenty seconds to thirty seconds.

7) Weigh the refrigerant sample cylinder plus attachment on a top loader balance (nearest 0.1 g) and record on a work sheet.

8) Using a clamp (or clamps) and weighted ring stand, invert and position the sample cylinder such that the needle punctures the septum and is immersed to the hub of the needle.

   Note: The needle should be submerged about one inch below the surface of the KF solution.

   Note: The background current rises after the needle is inserted, then returns to the low valve.

9) At this juncture, with the instrument turned on, preset for a five-minute titration start delay, and verify that the background current is at a low value such as 0.02 µg to 0.05 µg.

   a) The titration shall not be initiated unless and until the background current has stabilized at a low µg value.

   b) The coulometric titrator background signal, given as µg H_2O per second, is subtracted from the analyzed result and represents the background moisture accumulated during the time taken to introduce and to titrate the sample. The background value subtracted is the final value read just before sample addition begins. An artificially elevated background value results in an erroneously low result (meaning negatively biased). The background value shall be determined. The titration cell can be physically swirled to rinse moisture accumulated on the inner walls into the KF solution. This operation can speed up the process of reaching a low background signal.

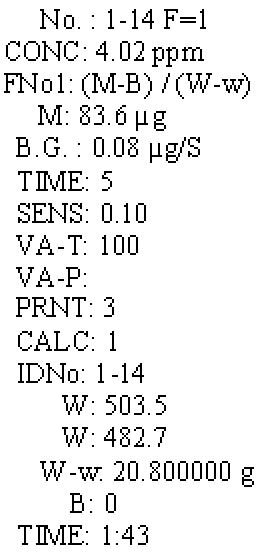
10) The desiccant tube shall be clear of obstructions.

11) Enter the gross cylinder weight (W_1) from Section C.2.9.2(7) into the moisture meter, if applicable, or record the initial weight of the cylinder to the nearest 0.1 g.
12) If applicable, remove any prior number displayed for the second weight.
13) When the moisture meter is stable, initiate a run, slowly open the needle valve, and introduce sample at a moderate rate such that foaming is not observed on the KF solution surface. Add at a rate such that 15 g to 20 g of the sample is added over a ten-minute period. The sample addition count down (delay) can be used.
14) A 20-g sample is used for best accuracy. Observe the cell potential reading or microgram reading. If during the sample addition this reading climbs rapidly to a range of 200 ppm by weight to 300 ppm by weight, the sample contains high moisture, and a smaller sample size of 5 g to 10 g can be used.
15) The titration initiates after the proper sample size has been added or after the countdown (delay) period ends.

    If the sample contains high moisture, the rate of titration can never exceed the rate of H_2O addition and the titration shall be terminated (closing off the needle valve) before too much of the sample is added.

    Note: Conversely, if the sample added is 4 g to 5 g and the moisture level is 5 ppm to 10 ppm, the sample should be reanalyzed using a longer sample addition delay, for example, ten minutes, to achieve better accuracy.
16) Remove the sample cylinder/assembly and reweigh to the nearest 0.1 g (W_2).

    Note: If a 4 g to 5 g sample size is used, a more accurate balance should be utilized, and weights should be recorded to the nearest 0.01 g.
17) Enter the weight from Section C.2.9.2(16) into the moisture meter if applicable, or record the final weight of the cylinder to the nearest 0.1 g.
18) Calculate and print a report of the ppm or microgram water result. See Figure 2 for an example of the printed results.



```
    No. : 1-14 F=1
CONC: 4.02 ppm
FNo1: (M-B) / (W-w)
    M: 83.6 µg
 B.G. : 0.08 µg/S
 TIME: 5
 SENS: 0.10
 VA-T: 100
 VA-P:
 PRNT: 3
 CALC: 1
 IDNo: 1-14
       W: 503.5
       W: 482.7
    W-w. 20.800000 g
        B: 0
 TIME: 1:43
```

Figure 2 Example of Moisture Analyzer Report (Informative)

C.2.9.3. Calculation

Equation 4 shows moisture concentration.

$$MoistureConcentration, ppm = \frac{micrograms\ of\ H_2O}{grams\ of\ sample(W_1 - W_2)} \quad 4$$

Record all results to the nearest 1 ppm. If the results are less than 2 ppm, record as "< 2 ppm."

Note: Erratic and out-of-specification moisture results can be the result of poor or improper sampling, or both.

Moisture contamination occurs faster when the relative humidity is high.

C.3. Determination of High Boiling Residue in New and Reclaimed Refrigerants by Volumetric or Gravimetric Measurement and Determination of Particulate Residue by Visual Indication

C.3.1. Purpose

This test method determines *HBR* and visible particulates in new and reclaimed refrigerants.

C.3.2. Scope

This test method is for use with low, medium, and high pressure refrigerants.

C.3.3. Definitions

Definitions for this section are identical to those in Section 3 and AHRI 740.

C.3.4. Principle

HBR is determined by evaporating a known amount of refrigerant in a Goetz bulb at an ambient or elevated temperature. The remaining residue is then visually measured or weighed. If greater than specification volume is observed, the bulb is placed in a 60.0°C ± 2°C oven for thirty minutes and, after cooling, the volume of residue is again measured. For gravimetric determination, the residue is redissolved in a high-purity solvent such as R-514A and quantitatively transferred into a small, tared aluminum pan. The solvent is removed by evaporation and the pan reweighed to obtain the weight of residue.

Prior to evaporation, the measured volume of liquid refrigerant is visually examined for the presence of insoluble materials such as packing fibers, rust, and dirt. The residue from high pressure samples is redissolved in a clean solvent, swirled, and then visually examined for any insoluble particulates.

C.3.5. Applicability

This method is applicable to the routine quantitative determination of *HBR* and visible evidence of particulates in all low, medium, and high pressure new and reclaimed refrigerants. The method was developed to measure *HBR* and particulates in compliance with the specifications for *HBR* and particulates shown in Table 1 through Table 23.

C.3.6. Limitations and Interferences

To achieve the statistical parameters stated for this method, at least 100 mL of refrigerant sample is required. There are not any known interferences to this method.

C.3.7. Sensitivity, Precision, and Accuracy

C.3.7.1. Sensitivity

Based upon a 100 mL volume of sample, the method detects 0.01 mL of *HBR*, and that is the first mark on the Goetz bulb buret. This 0.01% value is the specification for refrigerants in Table 1 through Table 23. The DL by weight is less than 0.01% due to the sensitivity of the analytical balance and because 0.01 mL of residue (can be oil) weighs less than 0.01 g. Except for very high pressure refrigerants, the weight of 100 mL of liquid refrigerant weighs greater than 100 g.

C.3.7.2. Precision

The precision for the *HBR* determination at 0.03 volume percent was found to be ± 0.005 at the 95% CL. This is based upon an analysis of R-11 by two analysts, each of whom used silicone oil as the residue.

C.3.7.3. Accuracy

The relative mean error at the 0.03% volume level was found to be 3.3%.

Note: These statistical parameters are not applicable to visual observations of particulates.

C.3.8. Special Apparatus and Reagents

1) Goetz graduated centrifuge tube: 100 mL
2) Boiling chips, carborundum crystal
3) Disposable aluminum dish

C.3.9. Procedure

C.3.9.1. Calibration

For the *HBR* procedure, a calibration solution of 0.03% by weight of silicone oil in R-11 can be prepared by weighing 0.220 g of silicone oil and dissolving in 500 mL (738 g) of high purity R-11, mixing thoroughly, labeling, and storing in a screw-capped glass bottle in a refrigerator. Alternatively, weigh 0.187 g of oil and dissolve in 500 mL of R-514A or other solvent.

C.3.9.2. Sample Analysis for HBR Volume Percent Measurement and Particulates

1) Measure 100 mL of refrigerant sample into the Goetz bulb as follows:
    i. For low pressure refrigerants (R-11, R-113, R-123) add 100 mL of liquid refrigerant from a glass graduate into the Goetz bulb. Alternatively, add liquid from the sample container to the 100 mL mark of the Goetz bulb.
    ii. While holding the bulb at arm’s length, gently swirl the sample solution and then position the bulb in front of a light source such as a window and visually examine for the presence of particulate matter. Record as “Pass” if particulates are not observed. Proceed to Section C.3.9.2(2).
    iii. For medium and high pressure refrigerants: Tare the sample cylinder to the nearest 0.1 g, invert the cylinder and, by positioning the valve opening just inside the neck of the Goetz bulb, open the valve to let the liquid phase discharge into the bulb. A liquid refrigerant, other than very high pressure refrigerants [see Section C.3.9.2(1)(iv)], begins to accumulate in the Goetz bulb. Continue to add sample until 60 mL to 75 mL of liquid has been collected. Turn off the sample valve. Reweigh the sample cylinder and record the difference as the weight of sample added.

        While firmly holding the bulb at arm’s length, gently swirl the sample solution and then position the bulb in front of a light source such as a window and visually examine for the presence of particulate matter. Record the description of particulates if observed. Proceed to Section C.3.9.2(2).

        Note: Use isopropyl alcohol, a finger, or a paper towel to remove frost from the outside of the bulb to create a window to facilitate the visual observation.

iv. For very high pressure refrigerants (R-503, R-13, R-23), the sample cylinder is precooled to 4.4°C in ice water before flashing the liquid phase into the Goetz bulb. Continue to add the liquid phase until the sample cylinder weigh-back shows that between 100 g and 130 g of refrigerant has been flashed into the bulb. At this point, little or no liquid phase refrigerant accumulates in the bulb. Record this weight as the grams of sample added. Add 100 mL of a high-purity solvent such as R-514A to the bulb, put the stopper in the bulb, swirl to dissolve any residue on the inner walls of the bulb, and remove the stopper.

Stopcock grease shall not be present on the glass stopper or on the neck of the bulb.

v. Repeat Section C.3.9.2(1)(ii).

2) Add one small boileezer and place the Goetz bulb in a 45.0°C constant temperature water bath, for example, 60.0°C for R-113. Immerse the bulb in the bath to about the 20 mL to 25 mL mark. The bulb shall not be removed from the bath until all the refrigerant has completely evaporated. This is determined by observing the disappearance of refrigerant condensation around the neck of the bulb.

3) Remove the Goetz bulb from the bath, wipe the outside dry and visually measure the mL residue (if any) at the bottom of the buret (ignore the boileezer). Measure to the nearest 0.005 mL.

4) If the observed residue is less than or equal to 0.01 mL, proceed to Section C.3.9.3. If the observed residue is greater than 0.01 mL, proceed to Section C.3.9.2(5).

5) Place the Goetz bulb upright in a 60.0°C oven for thirty minutes, remove, cool, then measure and record the volume of residue to the nearest 0.005 mL in the buret as described in Section C.3.9.2(3). To measure weight percent, save the residue in the Goetz bulb for Section C.3.9.4.

C.3.9.3. Calculation

Use Equation 5 to calculate *HBR* by volume.

$$HBR\ Volume\ \% = \frac{A \cdot 100}{B} \qquad (5)$$

Where:

A = volume of residue (mL) in buret

B = mL of sample added to bulb [Section C.3.9.2(1)]

Note: To calculate the volume of high and very high pressure refrigerant samples, in mL, divide the weight of the sample by the liquid density of the refrigerant at the ambient sample temperature (see Table 26).

Record all results to the nearest 0.01% volume. If the results are less than 0.01%, record as “< 0.01% volume.”

C.3.9.4. Sample Analysis for Weight Percent Measurement

1) Rinse an aluminum pan in acetone and place the pan in a 60.0°C oven for at least thirty minutes. Remove using tweezers and place in a desiccator until cool, fifteen minutes to twenty minutes.

2) Using tweezers, remove the pan from the desiccator and determine the tare weight of the pan to the nearest 0.0001 g.

3) Add approximately 20 mL of a high-purity solvent such as R-514A to the Goetz bulb saved from Section C.3.9.2(5). Stopper the bulb and shake to either redissolve the residue or to resuspend the particulates if present in the solvent, or both.

4) Pour the solution from the Goetz bulb into the pan. Use 10 ml to 20 ml of solvent and repeat Section C.3.9.4(3) if necessary to complete the quantitative transfer of residue. The boiling chip shall not fall into the aluminum pan; however, if that does occur, remove the boiling chip using metal tweezers.
5) Place the aluminum pan inside a hood and let the high-purity solvent evaporate. Alternatively, the pan can be placed on the hot water bath.
6) Place the pan in the 60.0°C oven for thirty minutes, remove, and then place in the desiccator until cool, twenty minutes to thirty minutes.
7) Using tweezers, remove and reweigh the pan and record the difference in weight from Section C.3.9.4(2) as the weight of residue.

C.3.9.5. Calculation

Equation 6 shows *HBR* by mass.

$$HBR\ weight\ \% = \frac{A\ \cdot 100}{B} \qquad \textbf{6}$$

Where:

A = grams of residue from Section C.3.9.4(7)
B = grams of sample taken from Section C.3.9.2(1)

Note: To determine the amount of a low pressure sample refrigerant such as R-11, R-113, or R-123, multiply the volume taken times the density. See Table 26.

Record the results to the nearest 0.01% weight. If the results are less than 0.01% weight, record as "< 0.01% weight."

Table 26 Densities of Common Liquid Refrigerants at 25°C

Refrigerant	Density (g/mL)
R-11	1.476
R-12	1.311
R-22	1.194
R-32	0.961
R-123	1.468
R-124	1.364
R-125	1.19
R-134a	1.21
R-142b	1.114
R-152a	0.899
R-290	0.492
R-404A	1.167
R-407A	1.142
R-407C	1.134
R-410A	1.031
R-438A	1.147
R-448A	1.097
R-449A	1.097
R-454B	0.985
R-500	1.168
R-502	1.217
R-507	1.17
R-513A	1.134
R-514A	1.311
R-515B	1.180
R-600	0.573
R-600a	0.551
R-744	0.711
R-1270	0.506
R-1233zd(E)	1.163
R-1234yf	1.092

C.4. Determination of Chloride in New and Reclaimed Refrigerants by Silver Chloride Precipitation

C.4.1. Purpose

This test method qualitatively determines the presence of chloride in new and reclaimed refrigerants.

C.4.2. Scope

This test method is for use with low, medium, and high pressure refrigerants.

C.4.3. Definitions

Definitions for this section are identical to those in Section 3 and AHRI 740.

C.4.4. Principle

Equation 7 shows the qualitative determination of chloride in refrigerants is based on precipitation of the chloride anion as silver chloride.

$$Ag^{+} + Cl^{-} \rightarrow AgCl \qquad 7$$

Add the same volume of methanol as the volume of refrigerant found in Section C.4.9.3(7) to a 100 mL beaker. For each 5 mL of methanol used, add three drops of saturated silver nitrate ($AgNO_3$) solution to the methanol. Also, add one drop of concentrated nitric acid to the solution before adding the refrigerant sample. Visual turbidity indicates the presence of chloride and the test failed. If turbidity is not observed, chloride is within limits as the test passed.

C.4.5. Applicability

This method is applicable to the routine qualitative determination of chloride in low, medium, and high pressure refrigerants.

C.4.6. Limitations and Interferences

None of the refrigerants tested interfere with the chloride determination. Anions of weak acids can be an interference in the determination, but these interferences are not present in new or reclaimed refrigerants. Samples containing insoluble lubricants and oils can show a visual haze or turbidity, however, such levels of lubricant or oil necessary to show such visual turbidity are not present in new or reclaimed refrigerants.

C.4.7. Sensitivity, Precision and Accuracy

C.4.7.1. Sensitivity

The sensitivity of the chloride turbidity test using 5 mL of sample in 5 mL of methanol containing three drops of saturated $AgNO_3$ is 3 ppm. Sample handling shall prevent cross contamination when performing this test.

C.4.7.2. Precision

Data is not provided.

C.4.7.3. Accuracy

Data is not provided.

C.4.8. Special Apparatus and Reagents

1) Stainless steel capillary tubing
2) Top loading balance, 1000 g with 0.1 g resolution
3) Methanol anhydrous reagent
4) $AgNO_3$
5) 75 mL stainless steel double ended 1/4-in FNPT cylinder
6) Two 1/4-in stainless steel valves with MNPT fittings
7) Two 1/4-in FNPT x 1/4-in flare fittings
8) 1/16-in x 1/4-in stainless steel tube compression fitting reducing union
9) 1/4-in compression fitting x 1/4-in flare AN female adaptor
10) 1/4-in x 1/4-in copper flare connector
11) 1/4-in inlet MNPT x 1/4-in outlet FNPT pressure relief valve

C.4.9. Procedure

C.4.9.1. Stainless Steel Capillary Tubing Connector

Take a 1/16-in x 0.007-in stainless steel tubing and attach a 1/16-in nut and ferrule. Connect this to a 1/16-in x 1/4-in compression fitting reducing union and then connect this combination to the 1/4-in compression fitting x 1/4-in flare adaptor. The 1/4-in flare adaptor can then be connected to the 1/4-in flare fitting on the cylinder assembly just before each chloride determination.

C.4.9.2. Cylinder Assembly

The cylinder assembly is used as the sampling apparatus for chloride determination of medium and high pressure refrigerants. To complete this assembly, all pipe fittings shall be tetrafluoroethylene taped to confirm a proper seal at each joint.

Attach the pressure relief valve to the 75 mL stainless steel cylinder. Attach one of the 1/4-in MNPT x 1/4-in MNPT stainless steel valves to the pressure relief valve. Connect a 1/4-in FNPT x 1/4-in flare fitting to the 1/4-in MNPT valve. To the other side of the 75 mL cylinder, attach another 1/4 in MNPT x 1/4 in MNPT valve. Sampling shall always occur from the side of the 75 mL cylinder that does not employ the pressure relief valve.

C.4.9.3. Sample Analysis

1) Thoroughly clean the 75 mL stainless steel cylinder, the valve, the capillary tube, the copper connector, and the 100 mL beaker before initiating testing. Heat all of the components to 110°C and pull a vacuum.
2) Weigh the cylinder assembly to the nearest 0.1 g and designate this weight as “X.”
3) Attach the 1/4-in copper fitting to the gas valve of the sample cylinder and to the cylinder assembly. Loosen the connector and quickly tighten the fitting.
4) Invert the sample cylinder with the attached cylinder assembly. Open the sample cylinder valve and then the cylinder assembly valve. Introduce the refrigerant into the cylinder assembly until 30 g to 40 g of refrigerant has been sampled.

   Note: For very high pressure refrigerants such as R-13, R-23, or R-503, the sample cylinder and the cylinder assembly shall be precooled to 4.0°C to provide liquid phase sample for this test.
5) Close the cylinder assembly valve and set the sample cylinder upright. Close the sample cylinder valve, loosen the 1/4-in connector, and remove the cylinder assembly.
6) Reweigh the cylinder assembly with the refrigerant and designate this value as “Y.” The weight of the refrigerant is given by Y-X = grams of refrigerant sampled. The value for “X” is in Section C.4.9.3(2).
7) Calculate the volume of refrigerant sampled with Equation 8.

$$volume = \frac{grams\ sampled}{density} \tag{8}$$

   The values of the densities for each refrigerant can be found in Table 26.
8) For medium and high pressure refrigerants, proceed to Section C.4.9.3(9). For low pressure refrigerants, pour 25 mL of the refrigerant into a 100 mL beaker and proceed as in Section C.4.9.3(8). After adding the methanol and saturated $AgNO_3$ solution, stir the mixture for thirty seconds. If any turbidity is present in the methanol layer, the test failed.

9) Add the same volume of methanol as the volume of refrigerant found in Section C.4.9.3(7) to a 100 mL beaker. For each 5 mL of methanol used, add three drops of saturated $AgNO_3$ solution to the methanol. Add one drop of concentrated nitric acid to the solution before adding the refrigerant sample.

   This chloride test is valid only if the sample solution being tested is acidic. This prevents the formation of silver oxide if the sample pH is greater than 7.

10) Attach the cleaned capillary connector to the cylinder assembly containing the refrigerant sample and slowly introduce the entire sample into the methanolic $AgNO_3$.

11) If turbidity is present, the test failed. If turbidity does not exist, the test passed.

C.5. Determination of NCG in New and Reclaimed Refrigerants by Gas Chromatography

C.5.1. Purpose

This test method determines *NCG* levels in new and reclaimed refrigerants using gas chromatography.

C.5.2. Scope

This test method is for use with medium, high, and very high pressure refrigerants.

C.5.3. Definitions

Definitions for this section are identical to those in Section 3 and AHRI 740.

C.5.4. Principle

NCG is measured in the vapor space above the refrigerant liquid phase by isothermal gas chromatography using a TCD and an external standard calibration. *NCG* includes gases such as oxygen and nitrogen (air), carbon dioxide, argon, and carbon monoxide. However, in the refrigerant sample, air is the only *NCG* present in amounts and the other gases are not routinely analyzed. Very high pressure refrigerants (R-13, R-23, R-503) do not always contain liquid phase and these are analyzed directly. *NCG* equilibrium between the refrigerant liquid phase and the vapor phase is temperature dependent and sample temperature corrections are applied to record results at the 24.0°C specification temperature.

C.5.5. Applicability

This method is applicable to the routine quantitative analysis of *NCG* in medium, high, and very high pressure refrigerants.

C.5.6. Limitations and Interferences

None of the refrigerants interfere with the determination as all chromatographically elute after the air peak. Methane elutes about 0.10 minutes after the air peak and, if present in amounts greater than 0.10% by volume, begins to interfere. However, the amounts of methane (formed during compressor burn-out) in reclaimed refrigerants range from 0 ppm to 50 ppm by weight and does not interfere at these levels.

C.5.7. Sensitivity, Precision and Accuracy

C.5.7.1. Sensitivity

The method detects 0.02% by volume *NCG* in any of the refrigerants listed as applicable in Table 1 through Table 23.

C.5.7.2. Precision

The precision was determined at 5.2% by volume concentration and was found to be ± 0.07% by volume at the 95% CL. This is based upon twelve repetitive analyses of an R-12 sample by two technicians over a two-day period.

C.5.7.3. Accuracy

A 5.1% by volume certified calibration standard (air in helium) was analyzed nine times following the initial calibration during a one-day period by one technician. The relative mean error was 1.63%.

C.5.8. Special Apparatus and Reagents

1) Gas chromatograph: Equipped with a manual sample injection valve, 1 mL sample loop and a TCD
2) Gas chromatographic column: 1.8 m x 3.17 mm (6.0 ft x 0.125 in) OD stainless steel, divinylbenzene/ethylvinylbenzene crosslinked polymers, 80-100 mesh
3) Chromatography data system: Capable of electronic integration and processing the chromatographic data
4) Calibration standard: 1.5% by volume, air in helium, 30 lb cylinder
5) Digital thermometer
6) Temperature probe

C.5.9. Procedure

C.5.9.1. Chromatographic Operating Conditions

Set the GC and data integration system as shown in Table 27.

Table 27 Chromatographic Operating Conditions for the Determination of NCG in New and Reclaimed Refrigerants

Parameter	Setting
Detector sensitivity	low sensitivity
Carrier gas flow	30 mL helium per minute
Attenuator	x1[1]
Detector temperature, ºC	100
Injector port temperature, ºC	100
Head pressure	as required[2]
Column temperature, ºC	100
Sampling valve	load position
Integrator	External Standard method % volume

Notes:

1. Unattenuated
2. Twenty psi can be used.

C.5.9.2. Calibration

1) Refer to the operating manual to gain familiarity with the gas chromatograph (GC).
2) Attach a 51 cm (20 in) section of 1/4-in inside diameter flex line to the GC sample inlet line and terminate the other end with a 1/4-in female flare connector.
3) Attach a short piece of flex line to the GC sample exit line and terminate the tubing by placing the flex line inside a small beaker of water.
4) Connect the sample inlet line to the valve of the 1.5% *NCG* calibration standard cylinder.
5) Slowly open the standard cylinder valve, and slowly purge the sample vapor through the sample loop as indicated by bubbles in the exit line beaker of water. Purge for about ten seconds to expel air from the system.

   Note: One ten-second purge should be equal to 10 mL of vapor.

6) Close the cylinder valve and, when the bubbling stops, immediately rotate the sampling valve to the "Inject" position and immediately start the GC/integration system.

7) After the air peak has eluted 0.4 minutes, return the sampling valve to the "Load" position and terminate the integration.

8) Repeat Section C.5.9.2(5) through Section C.5.9.2(7) until three consecutive analyses yield essentially reproducible peak areas for the air peak.

9) Calculate the air peak absolute response factor (ARF) for each of the three analyses as shown in Equation 9.

$$ARF = \frac{A_i}{\%\ by\ volume\ air\ in\ calibration\ standard} \qquad \mathbf{9}$$

Where:

A_i = area of air peak

10) Average the three ARF values and assign the average value as the ARF for the method.

Note: The three ARF values should agree within about 1.6% relative mean error. The calibration standard should be analyzed at least daily, and the ARF updated as necessary.

C.5.9.3. Sample Analysis

Analyze the sample using the chromatographic conditions described in Section C.5.9.1.

Note: See example gas chromatograms in Appendix D.

1) Record the temperature to the nearest 0.5°C of the sample source liquid phase when the vapor phase is taken for analysis. If this information is unknown (customer samples, for example), record as 24.0ºC.

    i. To reestablish equilibrium in a liquid/vapor phase sample cylinder brought into the laboratory and that has changed temperature to a degree from the original temperature (standing several hours, for example), the cylinder shall be rolled to mix the contents for two minutes before sampling the vapor phase for gas chromatography (GC) analysis.

    Note: The outer wall temperature of the cylinder below the liquid level should be equal to that of the refrigerant contents and can be measured using a thermocouple probe.

    ii. If the vapor phase of a storage tank, road tanker, or ton cylinder, is sampled into a small, evacuated cylinder, regardless of what temperature the small sample cylinder vapor can be when analyzed by gas chromatography, the contents represent the vapor temperature at the original sample location point.

2) Connect the sample inlet line to the sample cylinder valve that directly accesses the sample vapor phase.

3) Slowly open the sample cylinder valve and slowly purge vapor (about ten seconds) to expel air from the sample loop and lines.

    i. When analyzing cylinders containing both a liquid phase and a vapor phase, a too rapid purge shall not be used when purging air from the chromatographic system. A too rapid purge can cause liquid refrigerant to expel and such droplets can evaporate resulting in a too rich in refrigerant vapor purge. The presence of refrigerant liquid can result in incorrect *NCG* values that are lower than the true value in the sample.

ii. For samples containing very small total headspace vapor (less than 500 mL), the sampling line loops are evacuated to less than 100 microns of Hg pressure (0.013 kPa) to the sample cylinder valve. The vacuum line is then closed, and the system is brought to the selected pressure such as 1 atm by slowly opening the sample cylinder and metering valves and then injecting into the GC as described. In this way, less total volume of headspace vapor is consumed compared to the purging method. See Figure 3.

4) Close the valve and, when the bubbling stops in the exit line beaker of water, immediately rotate the sampling valve to the "Inject" position and immediately start the GC/integration system.

5) Continue the chromatographic separation until the large refrigerant peak returns to the original baseline (refer to the ASHRAE *Handbook — Fundamentals*). Stop the integration.

6) Repeat Section C.5.9.3(3) through Section C.5.9.3(5) until the air peak area is reproducible (such as until all system air has been expelled). Two or three additional consecutive determinations can be used.

C.5.9.4. Calculation

1) The data system calculates the result for air (*NCG*) in % by volume that represents the temperature that the sample is taken for analysis as shown in Equation 10.

$$\%\ by\ volume\ NCG = \frac{A_i}{ARF} \qquad \textbf{10}$$

2) Correct the result to % *NCG* at 24.0ºC as in Equation 11. Use the vapor pressure-temperature graphs in the ASHRAE *Handbook — Fundamentals* or calculate through REFPROP. For R-403B, use the curve for R-125.

Note: In all liquid/vapor phase refrigerants, the *NCG* concentration in the vapor phase increases with decreasing temperature of the liquid phase. This is because the vapor concentration of the refrigerant decreases more so than that of air as the temperature drops.

$$C_1 = \frac{C_2 \cdot P_2 \cdot K_i}{T_2} \qquad \textbf{11}$$

For K values, see Table 28.

Where:

C_1 = *NCG*, % by volume, at 24.0ºC

C_2 = *NCG*, % by volume, at the sampling temperature

K_i = Temperature/pressure ratio for refrigerant *i* at 24.0ºC, see Table 28

P_2 = Vapor pressure (psia) of the refrigerant at the sampling temperature, T_2, in ºC (°F). This value is determined from the ASHRAE *Handbook — Fundamentals* or calculated through REFPROP.

T_2 = Sampling temperature in K (°R) such as T_2 = °C + 273.15

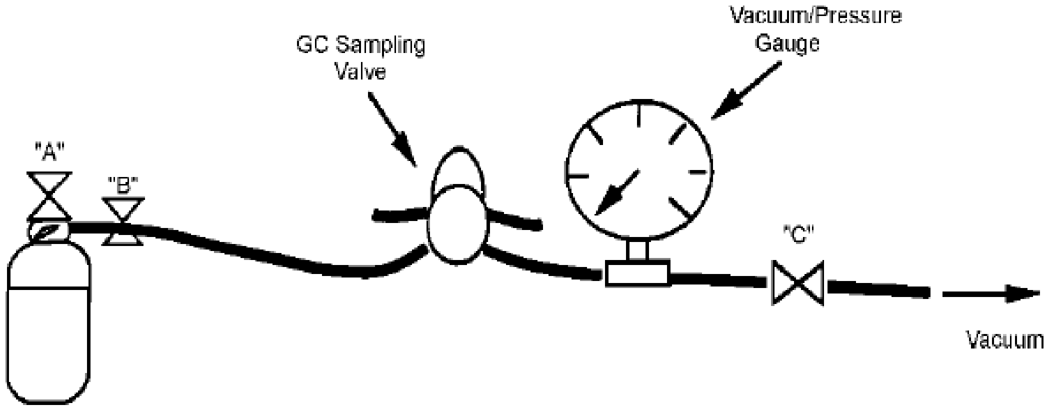
3) Record results to the nearest 0.01% by volume. If results are less than 0.02% by volume, record as "< 0.02% by volume."

Table 28 K_i Values for Selected Refrigerants at 24.0ºC

Refrigerant	K_i (K/MPa)	K_i (°R/psia)
R-12	478.705	5.941
R-114	1445.54	17.94
R-124	797.71	9.9
R-125	224.406	2.785
R-22	297.086	3.687
R-134a	439.625	5.456
R-115	340.597	4.227
R-142b	906.969	11.256
R-500	402.88	5.0
R-502	269.13	3.34
R-152a	552.352	6.855
R-32	180.66	2.242
R-1234yf	447.76	5.557
R-1234ze(E)	614.43	7.625

Note:

1. Source data for this table is the ASHRAE *Handbook — Fundamentals*.
2. Other refrigerant K-values can be calculated using data produced by REFPROP or other reference materials.



KEY
“A” Sample cylinder valve
“B” Metering valve
“C” Vacuum pump valve

Figure 3 Evacuated System Method of Introducing Vapor Sample into Gas Chromatograph

C.6. Determination of Purity of New and Reclaimed R-11 by Gas Chromatography

C.6.1. Purpose

This test method determines the purity of new and reclaimed trichlorofluoromethane (R-11) by gas chromatography.

C.6.2. Scope

This test method is for use with R-11.

C.6.3. Definitions

Definitions for this section are identical to those in Section 3 and AHRI 740.

C.6.4. Principle

The organic purity of new and reclaimed R-11 is determined by programmed temperature gas chromatography using a packed column with a flame ionization detector (FID). Component peak areas are integrated electronically and quantified by the area normalization response factor method.

C.6.5. Applicability

This method is applicable to the determination of the impurities that can be present in commercially manufactured R-11 and in R-11 recovered and reclaimed from operating refrigeration systems.

C.6.6. Limitations and Interferences

This method is calibrated for only those impurities commonly present in R-11. Other impurities that have been detected on occasion are listed (with retention times) in Table 30.

This method does not detect any impurities that can elute within the comparatively large R-11 peak matrix.

C.6.7. Sensitivity, Precision and Accuracy

Statistical parameters for each impurity are listed in Table 31. The data is obtained by analyzing an R-11 calibration mixture seven times during one day by one operator.

C.6.8. Special Apparatus and Reagents

1) Gas chromatograph: Equipped with an FID and capable of oven temperature programming.
2) Chromatography data system: Capable of electronic integration and processing chromatographic data.
3) Gas chromatographic column (Packed): 1% high molecular weight compound of polyethylene glycol and a diepoxide reacted with nitroterephthalic acid on (60-80) mesh graphitized carbon with a nominal surface area of 100 square meters per gram in a 7.3 m (24 ft), 3.2 mm (1/8 in) OD stainless steel column. Prepacked columns are commercially available from multiple vendors.
4) Serum bottle: 125 mL

   Note: Bottle holds 160 mL when liquid full.
5) Crimp seal with 20 mm Septa.
6) Glass collecting tube: 125 mL

   Enlarge side outlet opening to accommodate a crimp-on 2 cm septum. Apply fiberglass tape outside for protection.
7) Syringe, 10 µL, liquid.

   Externally cool the syringe and sample to 10°C before sampling.
8) R-11 and impurities for calibration standard preparation: CCl_4, $CHCl_3$, CH_2Cl_2, and trichloroethylene (TCE) and all other fluorochemicals are commercially available.

   The purity of each calibration component shall be predetermined by gas chromatography FID or TCD, or both and, if necessary, by gas chromatography/mass spectrometry (GC-MS).

C.6.9. Procedure

C.6.9.1. Chromatographic Operating Conditions

Table 29 shows chromatographic operating conditions.

Table 29 Chromatographic Operating Conditions for the Determination of Purity of New and Reclaimed R-11

Parameters	Settings
Detector	FID
Carrier gas	30 mL helium per minute
Initial column temperature, °C	125
Initial hold	Four minutes
Program, °C per minute	10
Final column temperature, °C (°F)	180
Post hold	Fourteen minutes
Detector temperature, °C	250[1]
Injector port temperature, °C	200[1]
Sample	1 µL (liquid syringe)
Maximum safe column temperature, °C	225 (for conditioning purposes)

Notes:

1. Condition can be optimized for specific gas chromatograph used.

C.6.9.2. Calibration Standard for Preparation and Analysis

1) Obtain a stock of the highest purity R-11 as evidenced by the chromatograms using the procedure in Section C.6.
2) Determine the tare weight to the nearest 0.01 g of a 125 mL serum bottle with septum and cap loosely attached, then fill with stock R-11 to within 5/8 inch of the top. Crimp on the septum.
3) Reweigh and subtract the tare weight in Section C.6.9.2(2) to obtain the grams of R-11 added.

   Note: The purest R-11 does contain impurities listed in Table 30. The amounts of impurities already in the stock R-11 are determined through the method of standards addition. Individual impurity peak areas in the stock are increased in the calibration standard by the amount of the corresponding impurity added. The amount already present is combined with the amount added to give the total component present, in ppm, in the calibration standard.

4) Individually and in turn add the volumes of each calibration component indicated in Table 31 through the septum and below the R-11 liquid surface in the bottle. Use a gas tight syringe with a deflected point needle for gases and a liquid µL syringe for liquids. Shake the bottle to mix after addition of each component.

Note: To preserve the stock of calibration gases, a small 125 mL gas collecting tube that has been evacuated to 1 atm should be loaded from the liquid phase as illustrated in Figure 4. The volume is then withdrawn and injected into the serum bottle containing the R-11. For impurities that are liquids at ambient temperature, inject the indicated µL volumes of each respective component into the serum bottle.

5) Total the mass added column and combine this weight with that of Section C.6.9.2(3) to obtain the total weight to the nearest 0.01 g of calibration sample in the bottle.
6) Calculate the amount added to the nearest 1 ppm for each component by dividing the mass added by the total weight of sample in the serum bottle [Section C.6.9.2(5)].
7) Calculate the amount present for each component by combining the amount present in the stock R-11, if any, and the amount of the component added in ppm [see the note in Section C.6.9.2(3)]. The component present values, in ppm, are those used for determining the method response factors.
8) Place the serum bottle standard in an ice bath and, after the serum is ice cold, remove the serum and immediately replace the septum with a new septum.
9) Write the amount of the present values for each component on the label in ppm, along with the date of preparation, the gross weight, and the total grams of calibration sample. Store in a refrigerator. Discard and prepare a new standard when the sample weight falls below 60% of the original weight [see the note in Section C.6.9.2(4)].

C.6.9.3. Determination of Component Response Factors

Depending upon the data system used, the ppm values can be converted to weight % for response factor calculations and for recording purposes.

1) Set up the chromatography data system for an area normalization-response factor calibration.
2) Analyze the calibration standard bulb in triplicate using the chromatographic conditions described in Table 29.
3) Using R-11 as the reference peak, perform the necessary functions to have the integrator or the chromatography data system determine each component relative response factor (*RRF$_i$*) that is then stored. Response factors are calculated as shown in Equation 12 and Equation 13.

$$ARF_i = \frac{weight\ \%\ in\ calibration\ standard}{A_i} \qquad \mathbf{12}$$

$$ARF_{R-11} = \frac{100.0000\ -\ S}{A_{R-11}} \qquad \mathbf{13}$$

Where:

ARF = Absolute response factor of component *i*

A_i = peak area of component *i* (average of three determinations)

S = weight % sum of all impurities present to four decimal places

Using R-11 as the reference peak, the relative response factor (RRF) can be determined. See Equation 14.

$$RRF_i = \frac{ARF_i}{ARF_{R-11}} \quad \textbf{14}$$

RRF_i values are computed to the nearest 0.0001 unit.

C.6.9.4. Sample Analysis

Analyze the sample using the chromatographic conditions described in Section C.6.9.1. The sample and syringe are precooled (refrigerator, ice bath) to 10ºC before sampling to simplify loading into the µL syringe. To identify an unknown peak, use component spiking, GC-MS (if provided), or both.

Note: See example gas chromatograms in Appendix D.

C.6.9.5. Calculations

The weight percentage of each component is calculated as shown in Equation 15.

$$W_i = \frac{RRF_i \cdot A_i \cdot 100}{\sum(A_i \cdot RRF_i)} \quad \textbf{15}$$

Where:

A_i = peak area of component *i*

RRF_i = Relative response factor (RFF) for component *i*

W_i = weight percent of component *i*

$\sum(A_i \cdot RRF_i)$ = sum of all component peak areas times their respective relative response factors

Record sample component concentrations to the nearest 0.0001% (or to the nearest 1 ppm).

Table 30 shows retention time data for identified impurities not observed.

Table 30 Retention Time Data for Identified Impurities Not Observed

Impurity	Retention Time, min
R-32[1]	2.37
R-114	4.1
R-290	8.0

Note:

1. Coelutes with R-23. To separate, attach a 0.30-m section of a porous polymer T column to the detector end of the column and reanalyze the chromatograph (R-23 elutes first).

Table 31 shows component statistical parameters for the determination of purity of R-11.

Table 31 Component Statistical Parameters for the Determination of Purity of New and Reclaimed R-11

Component	Detection Limit, ppm	Range Investigated, ppm	Precision at 95% CL, ppm	Relative Mean Error, %
R-23	2	15	0.37	-2.8
R-13	3	20	0.53	-3.1
R-152a	1	30	0.47	1.7
R-22	2	50	0.98	-0.8
R-115	2	30	0.8	0.7
R-12	2	60	1.1	1.1
R-133a	1	25	0.33	-2.5
R-21	2	30	0.67	1.2
R-30	2	25	0.33	-2.5
R-114	2	40	1.91	-2.7
R-123a	3	25	2.7	-4.8
R-123	2	50	1.33	3.3
R-20	2	25	0.73	0.7
R-113	2	60	2.31	2.2
R-10	2	25	1.7	-3.3
R-1120	2	25	1.77	1.8

Table 32 shows primary calibration standard components.

Table 32 Primary Calibration Standard Components for the Determination of Purity of New and Reclaimed R-11

Component	Molecular Weight	Volume Added	Mass Added[1], µg	Added Concentration[2], ppm	Total Concentration Present[3], ppm
R-23[4]	70	1.2 mL	3436	15	
R-13[4]	105	1.0 mL	4274	19	
R-152a[4]	66	2.5 mL	6748	30	
R-22[4]	86	3.2 mL	11 321	50	
R-115[4]	136	1.2 mL	6650	29	
R-12[4]	121	2.8 mL	13 845	61	
R-133a[4]	118	1.1 mL	5332	24	
R-21[4]	103	1.6 mL	6740	30	
R-30	85	5.0 µL	6680	29	
R-114[4]	170	1.3 mL	9061	40	
R-123a	153	5.0 µL	7490	33	
R-123	153	10.0 µL	14 750	64	
R-20	120	5.0 µL	7445	33	
R-113	188	10.0 µL	15 650	68	
R-10	154	10.0 µL	15 950	70	
R-1120	132	5.0 µL	7278	32	

Notes:

1. The mass added for the purity of the calibration component previously established can be corrected.
2. Values shown are for illustration; exact values are determined in Section C.6.9.2(6).
3. Fill in column [see Section C.6.9.2(7)] after determining amount present, in ppm, in stock R-11. See the note in Section C.6.9.2(3). Intentionally left blank to enter data.
4. These impurities are gases at ambient room temperature. The others are liquids with low *boiling points*.

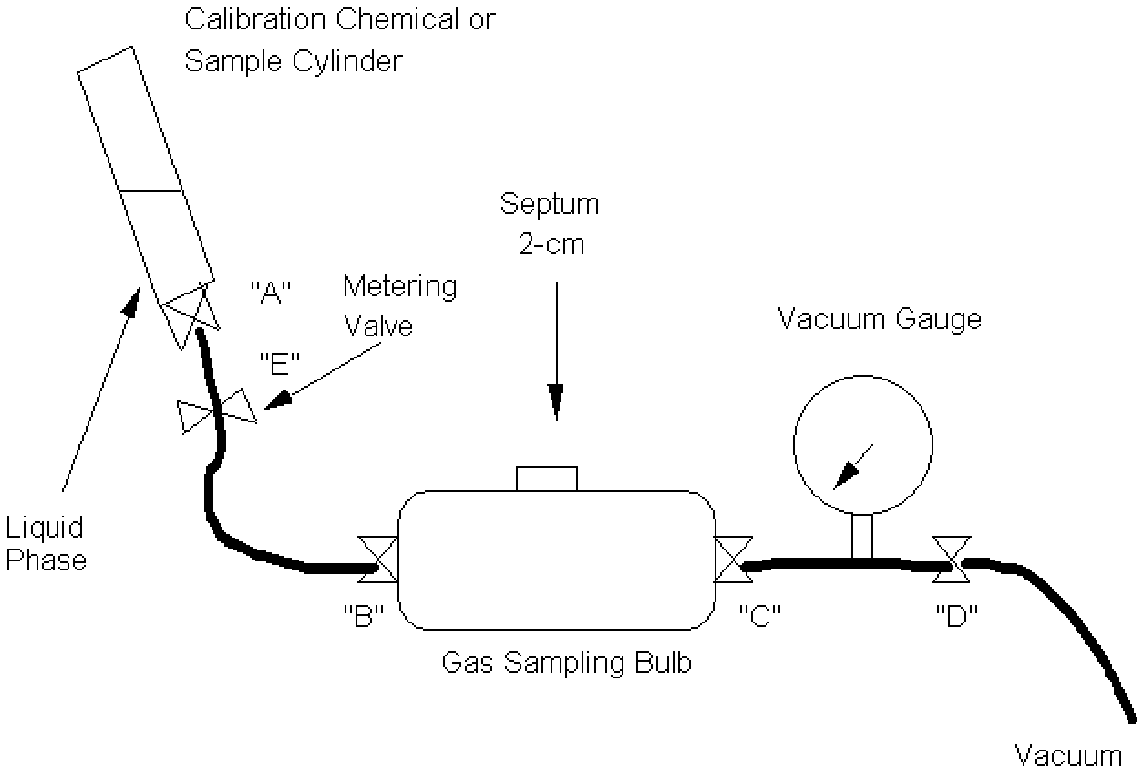


Figure 4 Apparatus Used for Calibration Standard Preparation

C.7. Determination of Purity of New and Reclaimed R-12, R-13, R-22, R-23, R-114, R-115, R-116, R-124, R-125, R-143a, R-152a, R-218, R-290, R-600, and R-600a by Packed Column Gas Chromatography

C.7.1. Purpose

This test method determines the purity of new and reclaimed R-12, R-13, R-22, R-23, R-114, R-115, R-116, R-124, R-125, R-143a, R-152a, R-218, R-290, R-600, and R-600a by gas chromatography.

C.7.2. Scope

This test method is for use with new and reclaimed R-12, R-13, R-22, R-23, R-114, R-115, R-116, R-124, R-125, R-143a, R-152a, R-218, R-290, R-600, and R-600a.

Note: R-290, R-600, and R-600a are components of fluorocarbon blends.

C.7.3. Definitions

Definitions for this section are identical to those in Section 3 and AHRI 740.

C.7.4. Principle

The purity of refrigerants is determined by gas chromatography using a packed column with a liquid phase coated onto a solid support. Separated components are detected using an FID or a TCD. The peak areas from the detector are measured with a data system capable of electronic integration, and component concentrations are quantified by the area normalization response factor method.

C.7.5. Applicability

This method is applicable to the routine gas chromatographic determination of new and reclaimed R-12, R-13, R-22, R-23, R-114, R-115, R-116, R-124, R-125, R-143a, R-152a, R-218, R-290, R-600, and R-600a.

C.7.6. Limitations and Interferences

This method is calibrated only for impurities found in new and reclaimed refrigerant. Any impurity that elutes within the matrix of the major component interferes if present in concentration.

C.7.7. Sensitivity, Precision, and Accuracy

The DL, 95% CLs (95% CL), and accuracy (relative mean error, RME) were established for single operator. Statistical parameters for each impurity are listed in Table 34. The data is calculated from seven replicate analyses from one sample of an R-12 calibration standard performed by one technician over a period of one day.

C.7.8. Special Apparatus and Reagents

1) Gas chromatograph: Equipped with a packed column injector with either an FID or TCD, or both, and capable of oven temperature programming.
2) Chromatography data system: Capable of electronic integration and processing the chromatographic data. The data system shall be configured to capture peak areas enabling measurement of peaks greater than or equal to 0.001% by weight. If the peak is identified, then the peak shall be quantified using its measured response factor.

   Note: Peaks that are not identified by the data system should be given a default response factor that is the greater of the average response factors for the calibrated components or R-22.
3) Gas chromatographic column (packed): 1% high molecular weight compounds of polyethylene glycol and a diepoxide reacted with nitroterephthalic acid on 60-80 mesh graphitized carbon with a nominal surface area of 100 m^2/g in a 7.3 m, 3.20 mm OD stainless steel column. Prepacked columns are commercially available.
4) Glass collecting tubes: 125 mL and 500 mL. (Enlarge side outlet opening to accommodate a crimp-on 2-cm septum. Apply fiberglass tape to the outside for protection.)
5) Syringe, 1 mL, gas tight
6) Deflected point needle: Standard hub 22 gauge x 1-1/2-in stainless steel
7) Impurities for calibration standard preparation: These impurities are commercially available.

C.7.9. Procedure

C.7.9.1. Chromatographic Operating Conditions

Table 33 shows chromatographic operating conditions for R-12, R-13, R-22, R-23, R-114, R-115, R-116, R-124, R-125, R-143a, R-152a, R-218, R-290, R-600, and R-600a.

Table 33 GC Operating Conditions for R-12, R-13, R-22, R-23, R-114, R-115, R-116, R-124, R-125, R 143a, R-152a, R-218, R-290, R-600, and R-600a

Condition	R-12, R-22, R-114, R-115, R-116, R-124, R-125, R-143a, R-152a, R-218, R-290, R-600, and R-600a	R-13	R-23
Detector	FID	TCD	TCD
Detector temperature, °C[1]	200	200	200
Injection port temperature, °C[1]	200	200	200
Carrier gas, mL helium per minute	20	20	20
Sample size, mL (gas syringe)[1]	0.5	0.5	0.5
Initial column temperature, °C	50	40	35
Initial hold, min	6	6	4
Program, °C/min	10	10	10
Final column temperature, °C	175	160	125
Post hold, min	15	6	4
Maximum column temperature, °C	225 (conditioning purposes only)		

Note:

1. Condition can be optimized for specific GC used.

C.7.9.2. Example - Primary Calibration Standard, Preparation and Analysis for R-12

Note: Modify procedure for other refrigerants as necessary.

1) Determine the internal volume of a 500 mL gas bulb by weighing the bulb empty, then fill the bulb to maximum capacity with water. Record the grams of water as mL volume capacity on the outside of the bulb (to the nearest 1.0 mL). Thoroughly dry the inside of the gas bulb then crimp-on the septum.
2) Assemble the apparatus as illustrated in Figure 5.
3) Attach a cylinder of high purity stock refrigerant to the gas sampling bulb.

   Note: The purest stock refrigerant contains the impurities found in the method. The ppm amounts of impurities already in the stock refrigerant are determined through the method of standards addition. Individual impurity peak areas in the stock refrigerant are increased in the calibration standard by the ppm amount of the corresponding impurity added. The ppm already present is combined with the ppm added to give the total ppm component present in the calibration standard.

4) With valve “A” closed, open all other valves, and evacuate to less than 100 microns of Hg pressure (0.013 kPa).
5) Close valve “D” and monitor the gauge to confirm the system is not leaking.

6) Close metering valve “E,” open valve “A,” and then slowly open valve “E” and flash liquid phase stock refrigerant to bring the system to one atmosphere pressure. Close valve “A.”
7) Repeat Section C.7.9.2(4) through Section C.7.9.2(6).
8) Close valves “B” and “C” and remove the bulb from the vacuum/sampling apparatus.
9) Calculate the grams of the stock refrigerant added to the bulb as shown in Equation 16.

$$grams\ added = \frac{MW_{ref}\ \cdot internal\ volumen\ of\ bulb(ml)}{24\,450} \qquad \textbf{16}$$

Where:

MW_{ref} = molecular weight of the stock refrigerant in g/mole

24 450 = volume (mL) occupied by 1 mole of refrigerant at 25°C and 1 atm

10) Individually, and in turn, add the volumes of each calibration impurity component of interest indicated in Table 35 to the calibration bulb. Use a µL or mL gas tight syringe with a deflected point needle.

    Note: To preserve the stock of calibration component, a small 125 mL gas collecting tube that has been evacuated to 1 atm should be loaded from the liquid phase as illustrated in Figure 5. The volume is then withdrawn and injected into the 500 mL calibration bulb.
11) Preparing a vapor phase standard by weighing the components into the gas bulb can be used as an alternate for Section C.7.9.2(10).
12) Into a 30 mL (37 mL filled) serum bottle, capped and crimped with a septum, add the exact volumes of the liquid impurities from Table 35 in the order given. Add by syringe injection through the septum using a 22-gauge or smaller needle as a vent. After addition, shake bottle vigorously to mix. Label, date, and store in a refrigerator.

    Note: For calibration components that have *boiling points* above ambient temperature, cool the material and syringe to 10°C before transferring.
13) Refer to Figure 5. Evacuate a 125 mL bulb (internal volume premeasured) and fill to 1 atm with refrigerant stock.
14) Accurately withdraw and inject exactly 5.0 µL of solution from the 30 mL serum bottle into the 125 mL bulb. Equilibrate for thirty minutes.
15) Using a 5 mL gas tight syringe, withdraw vapor from the 125 mL bulb and inject exactly 5.0 mL into the 500 mL calibration bulb. The mass of each component thus added is calculated as follows and is added to column four of Table 35. See Equation 17.

$$m = \frac{V_W\ \cdot\ 25\,000}{V\ \cdot A} \qquad \textbf{17}$$

Where:

25 000 = dilution ratio

A = internal mL of 125 mL bulb

m = mass added, µg

V = total mL of solution from Section C.7.9.2(12)

V_w = volume added, mL, from Table 35

C.7.9.3. Determination of Component Response Factors

Note: Depending upon the data integration system used, the ppm values can be converted to weight % for response factor calculations and for recording purposes.

1) Set up the chromatography data system for an area normalization response factor calibration.
2) Analyze the calibration standard gas bulb in triplicate using the chromatographic conditions described in Section C.7.9.3(1).
3) Perform the necessary functions to have the data system determine each component response factor that is then stored.
4) Response factors for each component are calculated as shown in Equation 18 and Equation 19.

$$ARF_i = \frac{weight\%_i \ in \ calibration \ standard}{A_i} \tag{18}$$

$$ARF_i = \frac{100.0000 \ - \ S}{A_r} \tag{19}$$

Where:

A_i = peak area of component *i*

A_r = peak area of major refrigerant

ARF_i = Absolute response factor of component *i*

ARF_r = Absolute response factor of the major refrigerant

S = weight % sum of all impurities present

Then using the major refrigerant, *r*, as the reference peak, the RRF can now be determined as shown in Equation 20 and Equation 21.

$$RRF_i = \frac{ARF_i}{ARF_r} \tag{20}$$

The weight percentage of each component is calculated as follows:

$$W_i = \frac{RRF_i \ \cdot \ A_i \ \cdot 100}{\sum(A_i \ \cdot \ RRF_i)} \tag{21}$$

Where:

A_i = peak area of component *i*

RRF_i = Relative response factor for component *i*

W_i = weight percent of component *i*

$\sum(A_i \cdot RRF_i)$ = sum of all component peak areas times their respective relative response factors

C.7.9.4. Sampling

Submitted sample cylinders shall contain liquid phase for analysis.

Note: Eighty percent liquid full should be used for analysis.

Special handling for low *critical temperature* refrigerants R-13, R-23, and R-116: A vapor phase sample shall be used to determine non-condensables and volatile impurities, including other refrigerants. The vapor phase sample is obtained by regulating the sample container temperature to 5°C or more above the refrigerant *critical temperature*. *Critical temperatures*: R-13 = 28.8°C, R-23 = 25.9°C, and R-116 = 19.7°C.

C.7.9.5. Sample Analysis

Analyze the sample using the chromatographic conditions described in Section C.7.9.1. Load the sample injection device by slowly and completely vaporizing the liquid phase, for example, by bubbling the vapor into water through flexible polymer tubing and then puncturing the tubing with the syringe needle. An alternative apparatus for vaporizing a liquid sample into a glass gas sample bulb allowing repeat injections of the same sample is shown in Figure 5.

Note: See example gas chromatograms in Appendix D.

C.7.9.6. Calculations

1) The weight percentage of each component is calculated as shown in Equation 22.

$$W_i = \frac{RRF_i \cdot A_i \cdot 100}{\sum(A_i \cdot RRF_i)} \qquad \mathbf{22}$$

Where:

A_i = peak area of component *i*

RRF_i = Relative response factor for component *i*

W_i = weight percent of component *i*

$\sum(A_i \cdot RRF_i)$ = sum of all component peak areas times their respective relative response factors

2) Record the sample component concentrations to the nearest 0.01%.

Table 34 Component Statistical Parameters for the Determination of Purity of New and Reclaimed R-12, R-13, R-22, R-23, R-114, R-115, R-116, R-124, R-125, R 143a, R-152a, R-218, R-290, R-600, and R-600a

Component	Detection Limit, ppm	Concentration Range Investigated, ppm	Concentration Precision at 95% Confidence Limit, ppm	Relative Mean Error, %
Methane	1	5	0.07	4
R-23	2	25	0.54	-2.3
R-1150 (C_2H_4)	1	5	0.13	-5.6
R-170 (C_2H_6)	1	5	0.1	-4.1
R-13	3	30	0.47	-3.8
R-143a	1	25	0.3	3.3
R-152a	1	30	0.63	1.7
R-40	1	20	0.37	2.3
R-134a	1	45	0.27	-3.3
R-22	2	65	1.75	2.7
R-1170 (C_3H_6)	1	5	0.1	3.4
R-115	2	115	1.67	1.8
R-142b	1	20	0.23	-1.3
R-124	1	25	0.37	1.8
R-133a	1	35	0.23	1.8
R-21	2	50	0.83	1.8
R-600a	1	20	0.23	-2.8
R-114	2	50	0.83	2
R-600	1	20	0.18	-3.3
2-butene-T	1	5	0.06	-3.8
R-11	4	40	0.87	1.1
R-123	2	35	1.05	-4.7
2-butanol	2	20	0.33	1.6
MEK	2	25	0.47	-2.3
R-113	2	30	0.87	-4
n-pentane	1	5	0.25	-3.7

Table 35 Primary Calibration Standard Components for the Determination of Purity of New and Reclaimed R-12, R-13, R-22, R-23, R-114, R-115, R-116, R-124, R-125, R 143a, R-152a, R-218, R-290, R-600, and R-600a

Component	Molecular Weight	Volume Added, µL	Mass Added[1], µg	Added[2] Concentration, ppm	Total Concentration Present[3], ppm
Methane	16	20	13.1	5	
R-23	70	22	63	23	
C_2H_4	28	12	13.7	5	
C_2H_6	30	11	13.5	5	
R-13	104	20	85.4	31	
R-143a	84	20	68.8	25	
R-152a	66	30	81	30	
R-40	50	28	57.8	21	
R-134a	102	30	125.1	46	
R-22	86	50	176.9	64	
C_3H_6	42	8	13.7	5	
R-115	154	50	315.9	115	
R-142b	100	15	61.7	22	
R-124	136	12	67	24	
R-133a	118	20	97	35	
R-21	103	32	134.7	49	
isobutane	58	25	59.3	22	
R-114	170	20	139.8	51	
n-butane	58	25	59.3	22	
2-butene-T	56	6	13.7	5	
R-11[4]	137	—	—[5]	57	
R-123[4]	153	—	—[5]	38	
MEK[4]	72	—	—[5]	17	
R-113[4]	188	—	—[5]	27	
2-butanol[4]	74	—	—[5]	21	

Component	Molecular Weight	Volume Added, µL	Mass Added[1], µg	Added[2] Concentration, ppm	Total Concentration Present[3], ppm
n-pentane[4]	72	—	—[5]	5	

Notes:

1. If necessary, correct the mass added for the purity of the calibration component previously established.
2. Values shown are for illustration; exact values are determined in Section C.7.9.2(10).
3. Fill in column after determining the amount present in stock R-12 [see the note in Section C.7.9.2(3)]. Intentionally left blank to enter data.
4. These components are liquids at ambient laboratory temperature and are added to the 500 mL bulb as described in Section C.7.9.2(12) through Section C.7.9.2(15).
5. See Section C.7.9.2(15) to determine mass added.

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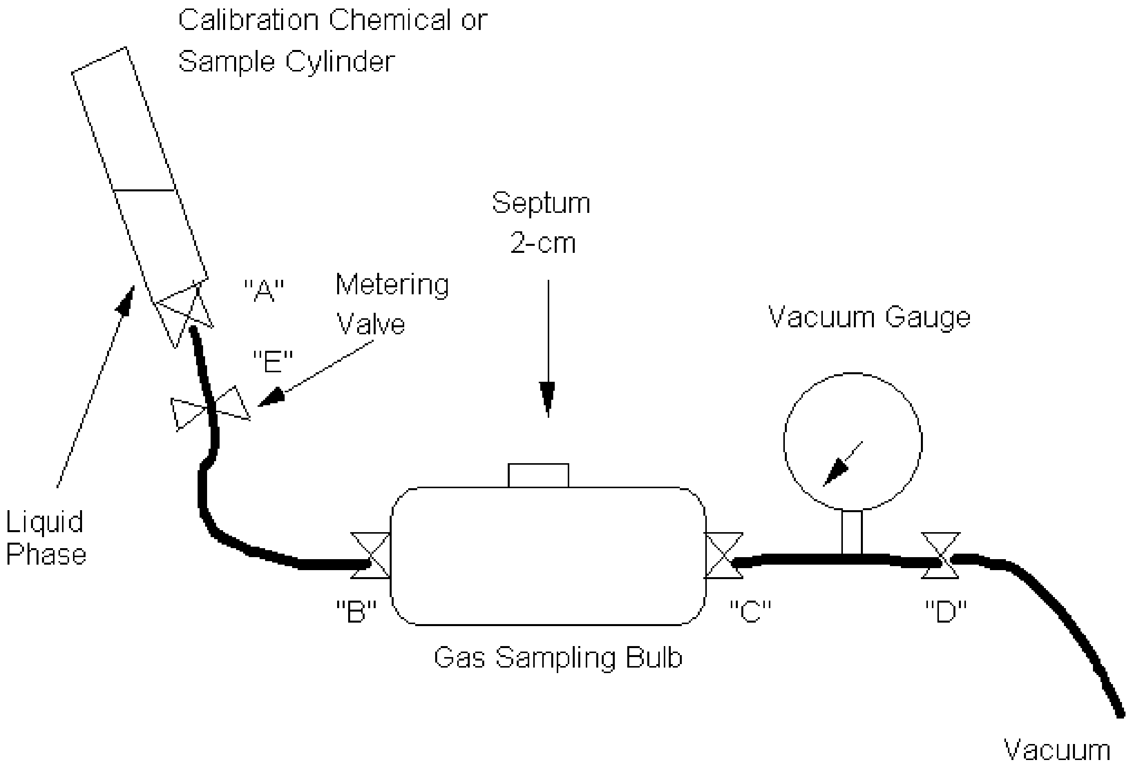

Figure 5 Apparatus Used for Calibration Standard Preparation and for Cylinder Sampling

C.8. Determination of Purity of New and Reclaimed R-123 by Capillary and Packed Column Gas Chromatography

C.8.1. Purpose

This test method determines the purity of new and reclaimed 1,1-dichloro-2,2,2-trifluoroethane (R-123) by gas chromatography.

C.8.2. Scope

This test method is for use with R-123.

C.8.3. Definitions

Definitions for this section are identical to those in Section 3 and AHRI 740.

C.8.4. Principle

The organic purity of new and reclaimed R-123 is determined by programmed temperature subambient capillary column gas chromatography, and the R-123 and R-113 isomers determined isothermally using a packed column. Component peak areas are integrated electronically and quantified by the area normalization response factor method.

C.8.5. Applicability

This method is applicable to the determination of the impurities present in commercially manufactured R-123. The impurities profile in reclaimed R-123 is expected (more or less) to be the same as the new product.

C.8.6. Limitations and Interferences

This method is calibrated for only those impurities commonly present in R-123 from commercial sources. Other impurities that have been detected on occasion are listed (with retention times) in Table 39. The method does not detect any impurity that can elute within the comparatively large R-123 peak matrix on either column.

C.8.7. Sensitivity, Precision and Accuracy

Statistical parameters for each impurity are listed in Table 38. The data was obtained by analyzing an R-123 calibration mixture seven times during one day by one operator.

C.8.8. Special Apparatus and Reagents

The following is a list of special apparatus and reagents unique to this analysis:

1) Gas chromatograph: Equipped with an FID, capillary column split injector, subambient (liquid nitrogen) cooling valve, and packed column capability.
2) Chromatography data system: Capable of electronic integration and processing chromatographic data.
3) Gas chromatographic column (packed): One percent high molecular weight compounds of polyethylene glycol and a diepoxide reacted with nitroterephthalic acid on 60-80 mesh graphitized carbon with a nominal surface area of 100 m^2/g in a 7.3 m, 3.20 mm OD stainless steel column. Prepacked columns are commercially available.
4) Gas chromatographic column (capillary): 210 m (connect the following two columns together with the first column end attached to the injection port):
    a) 105 m 14 % cyanopropylphenyl-86% methylpolysiloxane, 0.25 mm, 1µm.
    b) 105 m 5 % diphenyl-95% dimethyl polysiloxane, 0.32 mm, 1µm.
5) Glass collecting tube: 125 mL. Enlarge side outlet opening to accommodate a crimp-on 2 cm septum. Apply fiberglass tape outside for protection.
6) Syringe, 10 µL, liquid
7) Serum bottle: 125 mL

    Note: The bottle holds 160 mL of liquid when full.
8) R-123 and most impurities for calibration standard preparation are commercially available.

The purity of each calibration component shall be predetermined by gas chromatography FID or TCD, or both, and, if necessary, by gas chromatography/mass spectroscopy (GC-MS).

C.8.9. Procedure

C.8.9.1. Chromatographic Operating Conditions, Packed Column

Table 36 shows chromatographic operating conditions for R-123 packed columns.

Table 36 Chromatographic Operating Conditions for R-123 Packed Column

Parameters	Settings
Detector	FID
Carrier gas	40 mL helium per minute
Column temperature, °C	125 isothermal
Detector temperature, °C	250[1]
Injector port temperature, °C	150[1]
Sample	2 μL[2]
Maximum safe column temperature, °C	225 (for conditioning purposes)

Notes:

1. Condition can be optimized for specific GC used.
2. Externally cool the syringe and sample to 10°C before sampling.

C.8.9.2. Chromatographic Operating Conditions, Capillary Column

Table 37 shows chromatographic operating conditions for R-123 capillary columns.

Table 37 Chromatographic Operating Conditions for R-123 Capillary Column

Parameters	Settings
Detector	FID
Carrier gas	1.4 mL helium per minute
Split flow	40:1
Injector port temperature, °C	200[1]
Detector temperature	200[1]
Sample	2 µL[2]
Initial column temperature, °C	0 (subambient, liquid N_2)
Initial hold	twenty-one minutes
Program, °C per minute	15
Final temperature, °C	165
Post hold	eighteen minutes

Notes:

1. Condition can be optimized for specific GC used.
2. Externally cool the syringe and sample to 10°C before sampling.

C.8.9.3. Calibration Standard, Preparation and Analysis

1) Obtain a stock of the highest purity R-123 as evidenced by the chromatograms using the procedures described in Section C.8.9.

   Note: To accurately calibrate for R-1112a, select a stock R-123 that does not contain any detectable R-114aB1. The purest R-123, however, contains the impurities listed in Table 38 in low concentrations. Individual impurity peak areas in the stock R-123 are increased in the calibration standard by the amount of the corresponding impurity added in ppm. The amounts in the stock are thereby determined by the method of standards addition. The amount present, if any, is combined with the amount added to give the total of the component present, in ppm, in the calibration standard.

2) Determine the tare weight to the nearest 0.0001 g with a 125 mL serum bottle with septum and cap loosely attached; then fill with stock R-123 to within 5/8 in of the top. Crimp-on the septum.

3) Reweigh and subtract the tare weight determined in Section C.8.9.3(2) to obtain the grams of R-123 added.

4) Individually and in turn add the volumes of each calibration component indicated in Table 40 through the septum and below the R-123 liquid surface in the bottle. Use a µL or mL gas tight syringe with a deflected point needle. Shake the bottle to mix after addition of each component.

Note: To preserve the stock of calibration component that are gases, a small 125 mL gas collecting tube that has been evacuated to 1 atm should be loaded from the liquid phase of the gas as illustrated in Figure 6. The volume is then withdrawn and injected into the serum bottle containing the R-123.

5) Total the mass added to the bottle and combine this weight with that of Section C.8.9.3(3) to obtain the total weight to the nearest 0.0001 g of calibration sample in the bottle.

6) Calculate the amount added to the nearest 1 ppm for each component by dividing the mass added by the total weight of sample in the serum bottle, see Section C.8.9.3(5).

7) Calculate the amount present for each component by combining the amount present in the stock R-123 (if any) to the amount of the component added [see the note in Section C.8.9.3(1) and the following note]. The component present values, in ppm, are those used for determining the method response factors.

Note: The concentration of R-123a in the stock is determined separately by the method of standards addition (adding percent amounts of R-123a to the stock R-123 and chromatographing as in Section C.8.9.1). The calculated $RRF_{R\text{-}123a}$ value is assigned to the R-123b isomer, as R-123b is not commercially available for separate calibration. The amounts present are added to Table 40; the R-123a isomer shown as percent present.

8) Write the present values for each component on the label in ppm, as well as the date of preparation, the gross weight, and the total grams of the calibration sample. Store in a refrigerator. Discard and prepare a new standard when the sample weight falls below 60% of the original weight.

C.8.9.4. Determination of Component Response Factors

1) Set up the chromatography data system for an external standard area normalization calibration.

2) Analyze the calibration standard solution in triplicate using the chromatographic conditions described in Section C.8.9.1 and Section C.8.9.2.

3) Using R-123 as the reference peak, perform the necessary functions to have the integrator determine each component relative response factor (RRF_i) that is then stored. Response factors are calculated as shown in Equation 23 and Equation 24.

$$ARF_i = \frac{weight\%\ in\ calibration\ standard}{A_i} \qquad \mathbf{23}$$

$$ARF_{R-123} = \frac{100.0000 - S}{A_{R-123}} \qquad \mathbf{24}$$

Where:

A_i = peak area of component *i* (average of three determinations)

ARF_i = Absolute response factor of component *i*

S = weight % sum of all impurities present to ppm levels

Then, using R-123 as the reference peak, the RRF can be calculated as shown in Equation 25.

$$RRF_i = \frac{ARF_i}{ARF_{R-123}} \qquad \textbf{25}$$

RRF_i values are computed to the nearest 0.0001 unit.

Samples shall be submitted in either metal cylinders or in glass bottles, containing at least 60% liquid but not more than 80% full.

C.8.9.5. Sample Analysis

Analyze the sample using the chromatographic conditions described in Section C.8.9.1 and Section C.8.9.2. The sample and syringe are precooled in a refrigerator to 10°C before sampling to simplify loading liquid sample into the µL syringe. By spiking components or doing GC-MS, or both, unidentified peaks can be identified. Use the *ECN method* wherever applicable to estimate the concentration of any identified components not in the calibration table (see Table 39).

Note: See example gas chromatograms in Appendix D.

C.8.9.5.1. Check for Presence of R-114aB1

The capillary column procedure does not resolve R-1112a and (if present) R-114aB1. If the R-114B1 peak is small or absent, then R-114aB1 is not present. To resolve R-1112a and R-114aB1, the sample is reanalyzed exactly as in Section C.8.9.2 except the column initial temperature is 40°C. The higher starting temperature resolves the R-114B1, R-114aB1 and R-1112a into a triplet in the order given with 0.12 minutes separation between the three peaks. In the absence of R-114aB1, the peak separation between R 114B1 and R-1112a remains at 0.25 minutes. Use the *ECN method* (Table 39) to estimate the amount of R-114aB1 present.

C.8.9.5.2. Check for R-122 Isomers

If R-122 isomers are suspected to be present, extend the capillary column procedure post hold for an additional fifteen minutes (see Table 39).

C.8.9.6. Calculation

1) The weight percentage of each component is calculated as shown in Equation 26.

$$W_i = \frac{RRF_i \cdot A_i \cdot 100}{\sum(A_i \cdot RRF_i)} \qquad \textbf{26}$$

Where:

A_i = peak area of component *i*

RRF_i = relative response factor for component *i*

W_i = weight percent of component *i*

$\sum(A_i \,.\, RRF_i)$ = sum of all component peak areas times their respective relative response factors

2) Record the sample component concentrations to either the nearest 0.0001% or to the nearest 1 ppm.

Table 38 Component Statistical Parameters for the Determination of Purity of New and Reclaimed R-123

Component	*ECN*[1]	Detection Limit, ppm	Range Investigated, ppm	Precision at 95% CL[2], ppm	Relative Mean Error, %
R-1113	1.69	1	25	0.37	0.95
R-12	0.35	3	25	0.37	-1.1
R-22	0.4	2	25	0.24	1.4
R-114	1.04	2	50	1.2	-2.1
R-1317mx	3.63	1	30	0.88	4.3[3]
R-31	0.92	1	10	0.52	2.2
R-216ba	2.16	1	20	0.67	-1.8
R-1326mxz	3.65	1	15	0.33	0.7
R-133a	1.93	1	40	0.67	1.9
R-114B1	0.95	2	50	0.8	2.4
R-1112a	1.64	1	25	0.3	-0.7
R-1112	1.64	1	15	0.27	-0.5
R-123a	1.84	2	50 000	1300	0.3
R-123b	1.8	2	400	12.7	—
R-11	0.43	3	60	2.2	1.8
R-30	0.63	2	50	1.1	0.3
R-113	1.6	3	300	7.3	-0.2
R-113a	1.68	3	250	7	-0.15
R-1111	1.9	2	15	0.67	0.8

Notes:

1. *ECN* determined experimentally or estimated. Refer to scientific literature on *ECN*.
2. Intra-lab, multiple operator
3. Combining both isomers

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Table 39 Additional Impurities Observed in R-123, Quantitation by ECN Method

Impurity	Capillary Column Retention Time, min	*ECN*[1]
R-1132	9.18	2
R-125	9.46	0.79
R-134a	9.8	1.67
R-114a	11.22	1.17
R-124a	11.56	1.27
R-1122	11.57	1.76
R-124	11.77	1.33
R-E328lcc ether[2]	14.59	3.9
R-114aB1	15	0.8
R-141b	19.9	2
R-1121	23	1.75
R-132b	25.35	1.9
R-1130-E	25.64	2.25
R-123B1	28.72	1.7
R-122b	36.28	1.75
R-122a	37.24	1.75
R-122	38	1.76
R-112a	43.55	1.48

Notes:

1. *ECN* determined experimentally or estimated. Refer to scientific literature on *ECN* as shown in Section C.8.9.7 and Equation 27.
2. Structure tentatively identified as: $CHClF\text{-}CF_2\text{-}O\text{-}CF_2\text{-}CF_3$.

C.8.9.7. Quantitation by ECN Method

Select a nearby peak in the chromatogram whose identification and response factor (RF) have been established (the internal standard). See Equation 27.

$$\frac{RF_i}{RF_r} = \frac{ECN_r}{ECN_i} = \frac{MW_i}{MW_r} \qquad \mathbf{27}$$

Where:

RF = either absolute or relative response factor

MW_i = molecular weight of the component to be determined

MW_r = molecular weight of the internal standard reference peak

Table 40 Primary Calibration Standard Components for the Determination of of Purity of New and Reclaimed R-123

Component	Molecular Weight	Volume Added, µL	Mass Added[1], µg	Added Concentration[2], ppm	Total Concentration Present[3], ppm
R-1113	116	1	4765	22	
R-12	121	1	4946	23	
R-22	86	1.5	5307	24	
R-114	170	1.5	10 454	48	
R-1317mx[4]	216	6	9289	416	
R-31	68	0.75	2101	10	
R-216ba[5]	221	0.5	4517	21	
R-1326mxz	198	0.4	3270	15	
R-133a	118	1.8	8720	40	
R-114B1[6]	215	6	11 109	49	
R-1112a	133	1	5450	25	
R-1112	133	0.5	2725	13	
R-123a	153	—[7]	—[7]	1000 - 70 000	
R-123b	153	—[7]	—[7]	200 - 700	
R-11[6]	137	10	14 869	65	
R-30[6]	85	10	13 360	59	
R-113[6]	188	50	78 795	361	
R-113a[6]	188	50	78 986	362	
R-1111[6]	149	6	9279	41	

Notes:

1. If necessary, correct the mass added for the purity of the calibration component previously established.
2. Values shown are for illustration; exact values are determined at Section C.8.9.3(6).
3. Fill in column after determining the amount present in stock R-123, see Section C.8.9.3(1) and Section C.8.9.3(7). Intentionally left blank to enter data.
4. The R-1317mx resolves into the cis and trans isomer peaks with a ratio of 1:2, respectively.
5. Although other R-216 isomers comprise the usual R-216 peak multiple, the R-216ba isomer is used for calibration purposes.
6. Add by syringe injection of the liquid.
7. Refer to Section C.8.9.3(7) for mass and volume added.

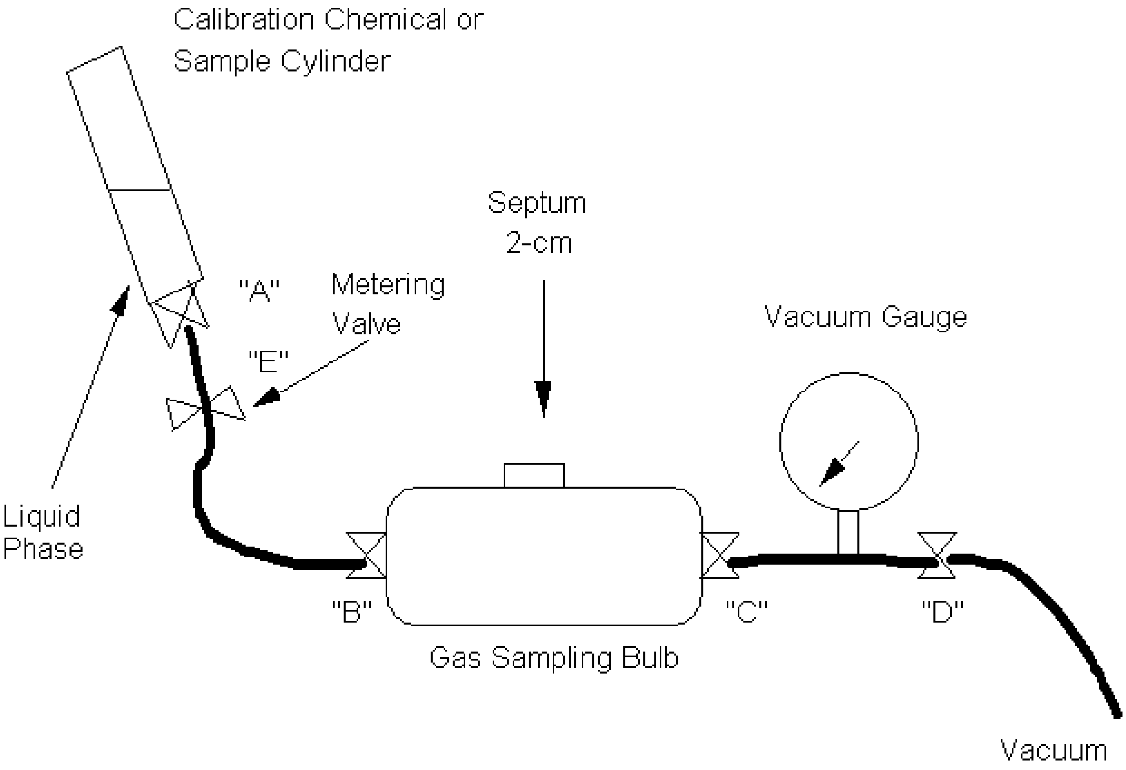

Figure 6 Apparatus Used for Calibration Standard Preparation

C.9. Determination of Purity of New and Reclaimed R-22, R-32, R-113, R-134a, R-141b, R-142b, R-245fa, R-1234yf, R-1234ze(E), R-236fa, and R-1233zd(E) by Capillary Column Gas Chromatography

C.9.1. Purpose

This test method determines the purity of new and reclaimed R-22, R-32, R-113, R-134a, R-141b, R-142b, R-245fa, R-1234yf, R-1234ze (E), R-236fa, and R-1233zd(E) by gas chromatography.

C.9.2. Scope

This test method is for use with R-22, R-32, R-113, R-134a, R-141b, R-142b, R-245fa, R-1234yf, R-1234ze(E), R-236fa, and R-1233zd(E).

C.9.3. Definitions

Definitions for this section are identical to those in Section 3 and AHRI 740.

C.9.4. Principle

The organic purity of new and reclaimed R-22, R-32, R-113, R-134a, R-141b, R-142b, R-245fa, R-1234yf, R-1234ze(E), R-236fa, and R-1233zd(E) is determined by programmed temperature gas chromatography using capillary columns with an FID. A capillary column procedure is used because the impurities are not resolved by the packed column method. Because R-22 obscures R-31 on the packed column method (Section C.7), R-31 is determined separately by this capillary method. Component peak areas are integrated electronically and quantified by the area normalization response factor method.

C.9.5. Applicability

This method can be applicable to the determination of the impurities that can be present in commercially manufactured and reclaimed R-22, R-32, R-113, R-134a, R-141b, R-142b, R-245fa, R-1234yf, R-1234ze(E), R-236fa, and R-1233zd(E).

C.9.6. Limitations and Interferences

This method is calibrated for only those impurities commonly present in R-22, R-32, R-113, R-134a, R-141b, R-142b, R-245fa, R-1234yf, R-1234ze(E), R-236fa, and R-1233zd(E). Any impurity that elutes within the matrix of the major component interferes if present in concentration. Other impurities that have been detected are listed (with retention times) in Table 42.

C.9.7. Sensitivity, Precision, and Accuracy

Statistical parameters for each impurity are listed in Table 43. The data was obtained by analyzing an R-134a calibration standard mixture seven times during one day by one operator.

C.9.8. Special Apparatus and Reagents

1) Gas chromatograph: Equipped with an FID, capillary column split injector, subambient cooling valve (liquid nitrogen), and packed column capability
2) Chromatography data system: Capable of electronic integration and processing chromatographic data
3) Gas chromatographic column (capillary): 135 m x 0.25 mm, 1 µm DF, 6% cyanopropylphenyl-94% dimethyl polysiloxane
4) Glass collecting tubes: 125 mL and 500 mL. (Enlarge the side outlet opening to accommodate a crimp-on 2-cm septum. Apply fiberglass tape outside for protection.)
5) Steel cylinder: 1 L, with a single 9-gauge valve
6) Syringe, 1 mL, gas tight
7) Deflected point needle: Standard hub 22 gauge x 1-1/2-in stainless steel
8) Swivel union: 1/4 in female flare x 1/4-in female flare
9) R-134a and impurities for calibration standard preparation. The identified impurities R-1336mzz and R-1234yf are not commercially available. The purity of each calibration component shall be predetermined by gas chromatography FID or TCD, or both, and, if necessary, by GC-MS.

C.9.9. Procedure

C.9.9.1. Chromatographic Operating Conditions, Capillary Column Gas Chromatography

Table 41 GC Operating Conditions

Condition	R-22	R-113/ R-1233zd(E)/ R-514A	R-134a/ R-32/ R-1234yf/ R-1234ze(E)/ R-236fa	R-141b	R-142b	R-245fa
Detector	FID	FID	FID	FID	FID	FID
Carrier gas, mL helium per minute	1.3	1	1	1	1	1
Injection port temperature[1], °C	200	200	200	200	200	200
Detector temperature[1], °C	200	200	200	200	200	200
Sample, mL	1	1	1	1	1	1
Initial column temperature, °C	-20	35	-20	10	10	-20
Initial hold, min	14	10	20	12	12	20
Program 1						
Ramp, °C/min	20	10	20	10	10	20
Column temperature, °C	175	160	190	100	100	125
Hold, min	6.25	11.5	4.5	5	6	10
Program 2						
Ramp, °C/min	—	—	—	15	—	20
Column temperature, °C				150		190
Hold, min				6.67		19.5
Total run time, min	30	34	35	36	27	60
Split ratio	40:01:00					
Subambient cooling	Liquid N_2					
Maximum safe column temperature, °C	280					

Note:

1. Condition can be optimized for specific GC used.

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C.9.9.2. Example - Primary Calibration Standard, Preparation and Analysis for R-134a

Note: Modify procedure for other refrigerants as necessary.

1) Crimp-on the septum, then determine the internal volume of the 500 mL gas bulb by weighing the bulb empty, then fill to maximum capacity with water. Record the grams of water as mL volume capacity on the outside of the bulb to the nearest 1.0 mL. Thoroughly dry the inside of the glass bulb.
2) Assemble the apparatus as illustrated in Figure 7.

3) Attach a cylinder of high purity refrigerant stock to the gas sampling bulb.

   Note: The purest stock refrigerant can contain the impurities found in the method. The ppm amounts of impurities already in the stock refrigerant are determined via the method of standards addition. Individual impurity peak areas in the stock refrigerant are increased in the calibration standard by the ppm amount of the corresponding impurity added. The ppm already present is combined with the ppm added to give the total ppm component present in the calibration standard.

4) With valve “A” closed, open all other valves, and evacuate cylinder.

   Note: The cylinder should be evacuated to less than 100 µ of Hg pressure (0.013 kPa) to prevent cross-contamination.

5) Close valve “D” and monitor the gauge for several minutes to confirm that the system is not leaking.

6) Close metering valve “E,” open valve “A,” and then slowly open valve “E” and flash *liquid phase* stock refrigerant to bring the system to 1 atm. Close valve “A.”

7) Repeat Section C.9.9.2(4) through Section C.9.9.2(6).

8) Close valves “B” and “C” and remove the bulb from the vacuum/sampling apparatus.

9) Calculate the grams of stock refrigerant added to the bulb as shown in Equation 28.

$$grams\ added = \frac{MW_{ref}\ \cdot internal\ volume\ of\ bulb\ (ml)}{24\,450} \qquad \mathbf{28}$$

Where:

MW_{ref} = molecular weight of the stock refrigerant, g/mole

24 450 = volume (mL) occupied by 1 mole of R-134a at 25°C and 1 atm

10) Individually and in turn, add the volumes of each gaseous calibration component indicated in Table 39 to the calibration bulb. Use a µL or mL gas tight syringe with a deflected point needle. To preserve the stock of calibration component, a small, evacuated 125 mL gas collecting tube shall be loaded to 1 atm from the *liquid phase* as illustrated in Figure 7. The volume is then withdrawn and injected into the 500 mL calibration bulb.

11) Into a 30 mL (37 mL filled) serum bottle, capped and crimped with a septum, add the exact volumes of the liquid impurities from Table 45 in the order given. Add by syringe injection through the septum using a 22-gauge or smaller needle as a vent. After addition, shake bottle vigorously to mix. Label, date, and store the filled serum bottle in a refrigerator.

    Note: Cool the syringe and R-1112a to 10°C before transferring.

12) Refer to Figure 7. Evacuate a 125 mL bulb (internal volume premeasured) and fill to 1 atm with refrigerant stock.

13) Accurately withdraw and inject exactly 5.0 µL of solution from the 30 mL serum bottle into the 125 mL bulb. Equilibrate for thirty minutes.

14) Using a 5 mL gas tight syringe, withdraw vapor from the 125 mL bulb and inject exactly 5.0 mL into the 500 mL calibration bulb. The mass added (µg) of each component thus added is calculated as follows and is added to column four of Table 41. See Equation 29.

$$\mu g_i = \frac{g_i \cdot 25\,000}{V \cdot A} \qquad \textbf{29}$$

Where:

A = internal mL of 125 mL bulb

g_i = grams from Table 44

V = total mL of solution, see Section C.9.9.2(11)

25 000 = dilution ratio

15) Total the mass added column and combine this weight with that of Section C.9.9.2(9) to obtain the total weight of sample to the nearest 0.0001 g in the bulb.

16) Calculate the amount added, to the nearest 1 ppm, for each component by dividing the mass added by the total weight of sample in the gas bulb. See Section C.9.9.2(15).

17) Calculate the amount present for each component, in pm, by combining the amount present in the stock refrigerant, if any, and the amount of component added [see the note in Section C.9.9.2(3)]. The component present values, in ppm, are those used for determining the method response factors.

18) Let the gas calibration bulb stand for twenty minutes to thirty minutes to equilibrate. The standard is stable for three days to four days.

C.9.9.3. Determination of Component Response Factors

Note: Depending upon the data integration system used, the ppm values to weight % can be converted for response factor calculations and for recording purposes.

1) Set up the chromatography data system for an area normalization-response factor calibration.

2) Analyze the calibration standard bulb in triplicate using the chromatographic conditions described in Section C.9.9.1.

3) Perform the necessary functions to have the data system determine each component's relative response factor (RRF_i) that is stored. Response factors are calculated as shown in Equation 30 and Equation 31.

$$ARF_i = \frac{weight\%\ in\ calibration\ standard}{A_i} \qquad \textbf{30}$$

$$ARF_r = \frac{100.0000 - S}{A_r} \qquad \textbf{31}$$

Where:

A_i = peak area of component *i* (average of three determinations)

A_r = peak area of major refrigerant

ARF_i = Absolute response factor of component *i*

ARF_r = Absolute response factor of component *r*

S = weight % sum of all impurities present

Then, using the major refrigerant *r* as the reference peak, the RRF can now be determined as shown in Equation 32.

$$RRF_i = \frac{ARF_i}{ARF_r} \tag{32}$$

RRF_i values are computed to the nearest 0.0001 unit.

C.9.9.4. Example - Secondary Calibration Standard Preparation for R-134a

Note: A secondary calibration standard is prepared in much larger quantity due to the comparatively short lifetime of the primary bulb standard. The primary bulb standard is necessary initially because of the inherent phase distribution of added components if simply preparing and calibrating a standard such as described here. The secondary standard is analyzed as a sample against the primary standard and then used subsequently as the daily calibration standard.

Note: Modify procedure for other refrigerants as necessary.

1) Evacuate a one-liter steel cylinder and determine the cylinder’s tare weight to the nearest 0.1 g.

2) Attach a septum nut and septum to the valve and then cool the cylinder in ice water. Open the cylinder valve.

3) While keeping cold in ice water, individually and in turn add 500 times the volume of each gaseous component given in calibration Table 44 to the cylinder by syringe injection through the septum. Add 0.10 mL of the liquid refrigerant mixture from Section C.9.9.2(11). Close the cylinder valve and remove the septum nut and septum.

4) Evacuate a second clean, dry one-liter steel cylinder and determine the tare weight to the nearest 0.1 g.

5) Cool the cylinder in ice water and attach a section flex line that is not longer than 61 cm from the stock cylinder supply. Purge a small amount of the stock refrigerant through the flex line before immediately attaching the flex line to the one-liter cylinder.

6) Open the one-liter cylinder valve, then open the stock cylinder valve and, while keeping cold in the ice water, fill the one-liter cylinder with 950 g of liquid refrigerant. The flex line can be reconnected and more R-134a added until a total of 950 g has been added. If more than 950 g is added, vent the cylinder to 950 g.

   During the refrigerant addition to the one-liter cylinder (secondary standard preparation), the cylinder shall be brought to ambient temperature between each weight measurement.

7) Place the secondary one-liter standard cylinder, the cylinder mentioned in Section C.9.9.4(1), Section C.9.9.4(2), and Section C.9.9.4(3), in the ice bath and cool for thirty minutes.

8) Using a short double female swivel coupler, invert the 1 L cylinder containing the 950 g of refrigerant and connect to the secondary standard cylinder. Open the valve and purge the refrigerant vapor to sweep the coupler before immediately connecting to the secondary standard cylinder. Warm without overheating the cylinder containing the refrigerant with a heat gun.

9) Open the valves on both cylinders so that all the refrigerant transfers into the calibration standard cylinder. Close the cylinder valves.

10) Remove the calibration cylinder from the ice bath and allow the cylinder to reach ambient laboratory temperature before the final weighing. Dry off and then reweigh to the nearest 0.1 g.

11) Subtract the tare weight from the total weight to obtain the total grams of standard in the cylinder [see Section C.9.9.4(1)]. Record this weight together with the cylinder tare weight and date of preparation on the cylinder label.

12) Roll the cylinder for one hour to thoroughly mix.
13) Analyze the cylinder contents in triplicate as described in Section C.9.9.1 loading first into an evacuated gas bulb as shown in Figure 7.
14) Average the results calculated electronically (see Section C.9.9.7) and tabulate to the nearest 1 ppm. List each component on the cylinder label with the ppm amount for each. This cylinder is used henceforth as the calibration standard until the loss of standard weight indicates that the internal volume of liquid phase is less than 60% of the total internal volume of the cylinder. For liquid densities, see Table 26.

C.9.9.5. Sampling

Submitted sample cylinders shall contain liquid phase for analysis.

Note: Eighty percent liquid full should be used for analysis.

C.9.9.6. Sample Analysis

Analyze the sample using the chromatographic conditions described in Section C.9.9.1. Load the sample as illustrated in Figure 7 by flashing the liquid phase into an evacuated gas bulb and bringing to 1 atm pressure. Use component spiking or GC-MS (if provided), or both, to identify questionable peaks. Use the *ECN method* to estimate the concentration of identified components not in Table 35. To separate R-31 and R-1140, see Section C.9.9.6(2).

1) Alternatively, the sample liquid phase can be flashed into a gas sampling bag and the sample for gas chromatography analysis withdrawn from the bag.
2) The method does not detect any impurity that can elute within the comparatively large R-134a peak matrix on either column. For example, R-134, R-31, and R-152a elute within the large R-134a peak matrix. The capillary column resolves R-134, R-1234yf, R-31, and the R-152a/R-1243zf pair (elute together). R-12, if present, elutes on the far shoulder of the R-134 peak. To separate R-31 and R-1140 (coelute on the capillary column), repeat the capillary column analysis exactly as given in Section C.9.9.1 except that the column temperature is held at 50.0°C (isothermal) throughout. The two components are resolved at about fifteen minutes retention time with the R-31 peak eluting 0.8 minutes before the R-1140 peak.
3) See example gas chromatograms in Appendix D.

C.9.9.7. Calculations

1) The weight percentage of each component is calculated as shown in Equation 33.

$$W_i = \frac{RRF_i \cdot A_i \cdot 100}{\sum(A_i \cdot RRF_i)} \qquad \textbf{33}$$

Where:

A_i = peak area of component *i*

RRF_i = Relative response factor for component *i*

W_i = weight percent of component *i*

$\sum(A_i . RRF_i)$ = sum of all component peak areas times their respective relative response factors

2) Record sample component concentrations to either the nearest 0.0001% or to the nearest 1 ppm. If results are less than the individual DLs (see Table 42), then record less than the DL value given.

Table 42 Additional Impurities Observed in R-134a, Quantitation by ECN Method

Impurity	Column Retention Time Capillary, min	*ECN*[1]
R-1243zf	14.98	2.84
R-1336mzz	—	2.9
R-1234yf	13.75	2.65
R-22	16.4	0.4
R-123a	—	1.84
R-124a	—	1.27
R-245cb	—	2.6
R-1225ye	—	2.42
R-1113	—	1.69
R-263fb	—	2.95
R-1140	21.5	2.08
R-132b	—	1.9
R-13	—	0.23
R-1318my-T	—	2.95
R-1318my-C	—	2.95

Note:

1. *ECN* determined experimentally or estimated. Refer to scientific literature on *ECN* in Section C.9.9.8 and Equation 34.

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C.9.9.8. Quantitation by ECN Method

Select a nearby peak in the chromatogram whose identification and response factor (RF) have been established (the internal standard). See Equation 34.

$$\frac{RF_i}{RF_r} = \frac{ECN_r}{ECN_i} = \frac{MW_i}{MW_r} \qquad \mathbf{34}$$

Where:

RF = either absolute or relative response factor

MW_i = molecular weight of the component to be determined

MW_r = molecular weight of the internal standard reference

Table 43 Component Statistical Parameters for Capillary Column Gas Chromatography

Component	*ECN*[1]	DL, ppm	Range Investigated, ppm	Precision at 95% Confidence Level, ppm	Relative Mean Error, %
R-23	0.16	4	15	0.7	1.8
R-32	0.62	2	15	0.3	1.2
R-1123	1.93	1	20	0.2	-0.8
R-143a	2.12	1	20	0.2	1.5
R-125	0.79	2	30	0.25	3.2
R-115	0.76	5	60	0.65	-1.3
R-1243zf	2.84	1	10	0.2	-3.6
R-12	0.35	2	40	0.3	1.8
R-1122	1.76	1	15	0.2	2.2
R-124	1.33	1	40	0.45	2
R-31	0.92	1	15	0.8	1.7
R-133a	1.93	1	25	0.5	1.7
R-1336mzz	2.9	1	—	0.5[2]	—
R-114	1.04	2	30	1.1	-3.3
R-114a	1.1	2	50	1.2	4.3
R-11	0.43	4	50	2.6	2.6
R-1112a	1.64	1	15	0.3	-0.2
R-1121-C	1.75	1	10	0.3	-6.7
R-123	1.76	2	20	0.9	-3.3
R-1121-T	1.75	1	30	1	4.3
R-113	1.6	2	20	1.3	1.7
R-134	1.61	2	30	0.2	1.4
R-152a	1.08	1	30	0.2	0.8
R-1234yf	2.65	1	—	0.5[2]	—

Notes:

1. *ECN* were determined experimentally. Refer to scientific literature on *ECN*.
2. Precision estimated at 10 ppm based upon sample reproducibility.

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Table 44 Primary Calibration Standard Components for Capillary Column Gas Chromatography

Component	Molecular Weight	Volume Added, µL	Mass Added[1], µg	Added[2] Concentration, ppm	Total Concentration Present[3], ppm
R-23	70	12	34.73	15	
R-32	52	16	34.03	15	
R-1123	82	14	46.98	20	
R-143a	84	14	48.1	20	
R-125	120	14	68.72	30	
R-115	154	22	139.05	60	
R-134	102	28	116.81	50	
R-152a	66	25	67.49	30	
R-12	121	20	98.89	43	
R-1122	98	8	32.23	15	
R-124	136	16	89.32	39	
R-31	68	12	33.61	14.5	
R-133a	118	12	58.17	25	
R-114	170	10	69.46	30	
R-114a	170	20	138.92	60	
R-11[4]	137	—	—[6]	30	
R-1112a[4]	133	—	—[6]	18	
R-1121-C[4]	115	—	—[5, 6]	5	
R-123[4]	153	—	—[6]	19	
R-1121-T[4]	115	—	—[5, 6]	23.5	
R-113[4]	188	—	—[6]	24	

Notes:

1. If necessary, correct the mass added for the purity of the calibration component previously established.
2. Values shown are for illustration; exact values are determined at Section C.9.9.2(16).
3. Fill in column in accordance with Section C.9.9.2(17) after determining the amount present in stock R-134a. Intentionally left blank to enter data.
4. These components are liquids at ambient temperature and are added to the 500 mL bulb as described in Section C.9.9.2(11) through Section C.9.9.2(14).
5. R-1121 contains 17.5% of the cis isomer. The mass of R-1121 added times 0.175 is assigned to the cis isomer, the balance to the trans isomer.
6. See Section C.9.9.2(14) to determine mass added.

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Table 45 Primary Calibration Standard Liquid Impurities

Component	Volume Added, mL	Density at 20°C	Mass, g
R-113	6	1.565	9.39
R-1121	8	1.403	11.224
R-123	5	1.47	7.35
R-11	8	1.487	11.896
R-1112a	5	1.439 (at 10°C)	7.195

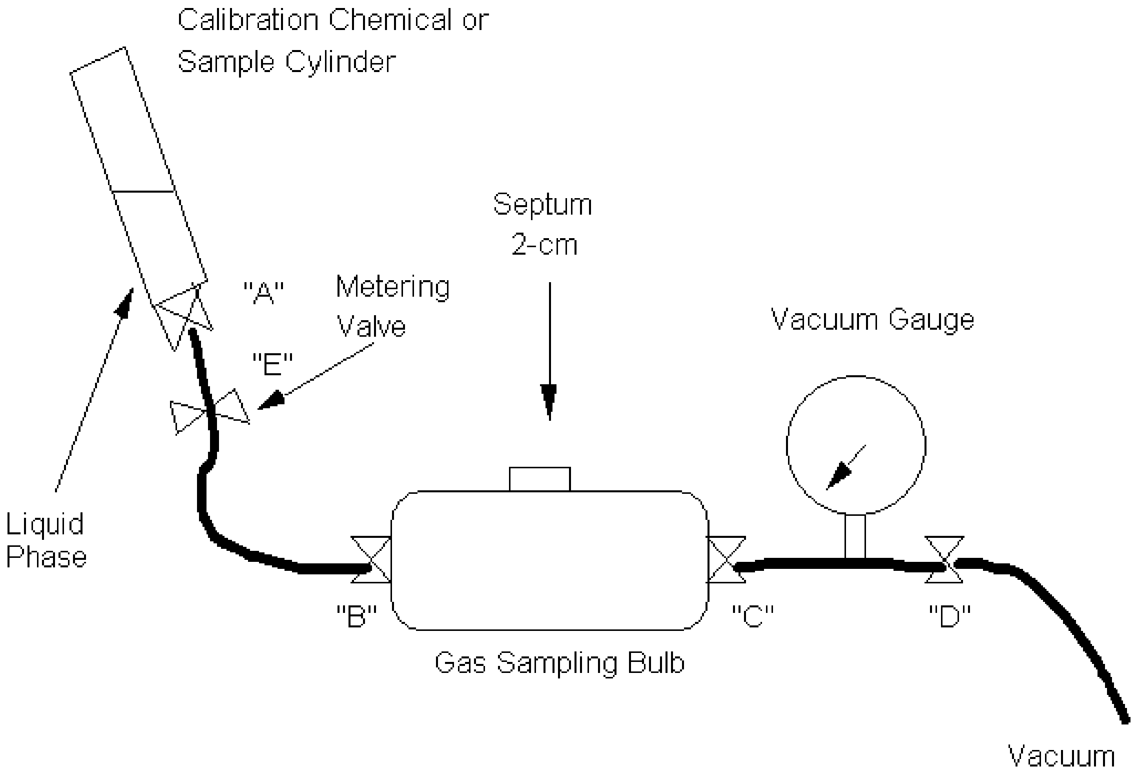


Figure 7 Apparatus Used for Calibration Standard Preparation and for Cylinder Sampling

C.10. Determination of Composition of New and Reclaimed 400 Series and 500 Series Refrigerant Blends by Gas Chromatography

C.10.1. Purpose

This test method determines the composition of all new and reclaimed 400 series and 500 series refrigerant blends by gas chromatography.

C.10.2. Scope

This test method is for use with all 400 series and 500 series refrigerant blends as listed in ASHRAE 34.

C.10.3. Definitions

Definitions for this section are identical to those in Section 3 and AHRI 740.

C.10.4. Principle

400 series and 500 series refrigerant blend compositions are separated by gas chromatography using a packed column with a liquid phase coated onto a solid support. Separated components are detected using a TCD. The peak areas from the detector are measured with a data system capable of electronic integration, and component concentrations are quantified by the area normalization response factor method.

C.10.5. Applicability

This method is applicable to the routine gas chromatographic determination of all new and reclaimed blends of 400 series and 500 series refrigerant blends mixture compositions. At laboratory ambient temperature, R-13/R-23 mixtures of R-503 and R-116/R-23 mixtures of R-508 are all in gas phase, as their *critical temperatures* are low.

C.10.6. Limitations and Interferences

This method does not address components other than those found as the major components in the 400 series and 500 series refrigerant blends. R-115 and R-290 elute at the same retention time and interfere with each other if both compounds are present. Any impurity that elutes within the matrix of any of the major components interferes if present.

C.10.7. Sensitivity, Precision, and Accuracy

C.10.7.1. Precision

C.10.7.1.1. Single Operator

The mean of the analysis ($\overline{X}$), standard deviation (σ), and 95% CLs (95% CL) established for the single operator precision of the test method are shown in Table 46.

Table 46 Standard Deviation and Measurement Uncertainty of R-404A Analysis for Single Operator

Component	$\overline{X}$, Weight %	σ	95% CL
R-143a	51.35	0.02	± 0.047
R-125	44.52	0.012	± 0.028
R-134a	4.13	0.017	± 0.040

The data in Table 46 was calculated from eight replicate analyses of one standard sample performed by one analyst over a single-day period.

C.10.7.1.2. Multiple Operators

The mean of the analysis ($\overline{X}$), standard deviation (σ), and 95% CLs (95% CL) established for the multiple operator precision of the test method are shown in Table 47.

Table 47 Standard Deviation and Measurement Uncertainty of R-404A Analysis for Multiple Operators

Component	$\bar{X}$, Weight %	σ	95% CL
R-143a	51.59	0.04	± 0.084
R-125	44.01	0.016	± 0.034
R-134a	4.4	0.032	± 0.068

The data in Table 47 was calculated from sixteen replicate analyses of a standard sample performed by four analysts over a two-day period.

C.10.7.2. Accuracy

The accuracy of this method was tested by analyzing a known R-401 blend as shown in Table 48.

Table 48 Standard Deviation and Measurement Uncertainty of R-401 Analysis

Component	Standard Concentration, Weight %	Relative Mean Error, Weight %
R-22	34.86	0.17
R-152a	25.65	0.16
R-124	39.49	0.05

The data in Table 48 was calculated from replicate analyses of a standard sample performed by multiple analysts over a single-day period.

C.10.8. Special Apparatus and Reagents

1) Gas chromatograph: Equipped with a packed column injector and a TCD capable of oven temperature programming.
2) Chromatography data system: Capable of electronic integration and processing the chromatographic data. The data system shall be configured to capture peak areas enabling measurement of peaks greater than or equal to 0.001% by weight. If the peak is identified, then the peak shall be quantified using its measured response factor.

   Note: Peaks that are not identified by the data system should be given a default response factor that is the greater of the average response factors for the calibrated components or R-22.
3) Gas chromatographic column (Packed): 1 percent high molecular weight compound of polyethylene glycol and a diepoxide reacted with nitroterephthalic acid on 60-80 mesh graphitized carbon with a nominal surface area of 100 m^2/g in a 7.3 m, 3.20 mm OD stainless steel column. Prepacked columns are commercially available.
4) Glass collecting tube: 500 mL. (Enlarge side outlet opening to accommodate a crimp-on 2 cm septum. Apply fiberglass tape to the outside for protection.)
5) 2 L steel cylinder
6) Syringe, 1 mL, gas tight
7) Deflected point needle: Standard hub 22 gauge x 1-1/2-in stainless steel

C.10.9. Procedure

C.10.9.1. Chromatographic Operating Conditions

Table 49 shows chromatographic operating conditions for the 400 series and 500 series refrigerant blends.

Table 49 Chromatographic Operating Conditions for 400 and 500 Series Refrigerant Blends

Parameters	Settings
Detector current	Low[1]
Detector temperature, °C	200[1]
Injection port temperature, °C	200[1]
Carrier gas	20 mL helium per minute
Reference flow	As required by the GC[1]
Sample size	0.5 mL (gas syringe)[1]
Initial column temperature, °C	40
Initial hold, minutes	12
Program, °C (°F) per minute	15
Final column temperature, °C	175
Post hold, minutes	11
Maximum column temperature, °C	225 (conditioning purposes only)
Note: 1. Condition can be optimized for specific GC used.	

C.10.9.2. Example - Primary Calibration Standard, Preparation, and Analysis for R-401

Note: Modify this procedure for other refrigerants as necessary.

1) Determine the tare weight of a dry, evacuated empty steel cylinder with a nominal volume of 2 L to the nearest 0.1 g (cylinder size can vary, but size is compensated for in the following procedure).
2) Calculate the weight of each component to be added to the standard. Fill the empty 2 L steel cylinder to 90% of its loading capacity. See Equation 35.

$$g\ component_i = \frac{desired\ weight\%\ component_i}{100} \cdot safe\ load \qquad \textbf{35}$$

Where:

safe load = liquid density · 0.9 · 2088 mL (allowing for 10% loading factor)

For liquid densities, refer to Table 26.

Note: The calculations used in this procedure should be corrected for any impurities found in the component refrigerants.

3) Purge the connecting line using the component with the highest *boiling point* first (such as R-124, the higher boiling component) to sweep out air; connect the line to the cylinder.
4) Add the component with the highest *boiling point* to the cylinder and reweigh the cylinder to the nearest 0.1 g.

Note: If the amount added is less than selected, more can be added. If the amount added is more than selected, the cylinder can be vented until the selected weight is obtained.

5) Record the weight of the cylinder plus the component with the highest *boiling point*. This weight minus the tare weight of the cylinder equals the weight of the component with the highest *boiling point*.
6) Cool the cylinder in wet ice and then add the component at the next highest *boiling point* in the same manner. This weight minus the weight recorded in Section C.10.9.2(5) equals the weight of the component with the next highest *boiling point*.

   Note: The component should be added with the next highest *boiling point* so that the weight is less than that selected. By adding small additions, the component can be brought up to the selected weight. The cylinder and contents should reach ambient laboratory temperature before making the final weighing.

7) Repeat Section C.10.9.2(5) except that the refrigerant added here is the component with the next highest *boiling point* and the tare weight for calculating the component with the next highest *boiling point* added is the weight in Section C.10.9.2(5). Repeat this step until all selected components are added to the steel cylinder.
8) After the last component is added, agitate the cylinder by rolling for a minimum of one hour to mix the contents thoroughly. The weight percent of each component can be calculated from the measured weights of the components added. Record the weight percent of each component and date of preparation on the cylinder label. Record the total weight of refrigerant in the calibration standard cylinder.

   Note: The blend calibration standard can continue in service until the liquid phase in the cylinder decreases to 60% of the loading capacity (0.6 · liquid density · cylinder volume in mL) when the remaining liquid phase is discarded and a new standard prepared. This is done to prevent the vapor/liquid equilibrium changing, thereby changing the composition of the liquid phase. Record the minimum cylinder weight on the cylinder tag.

9) Preparing a vapor phase standard by either adding a known volume of vapor phase and using the ideal gas law to calculate the weight of each component or by adding a liquid phase and using the liquid density to calculate each component weight can be used as alternates for Section C.10.9.2(1) through Section C.10.9.2(7).

C.10.9.3. Determination of Component Response Factors

1) Set up the chromatography data system for an area normalization response factor calibration.
2) Analyze the calibration standard in triplicate using the chromatographic conditions described in Section C.10.9.1. Load the sample injection device by slowly and completely vaporizing the liquid phase. For example, by bubbling the vapor into water through flexible polymer tubing and then puncturing the tubing with the syringe needle or using the apparatus as in Figure 8.
3) Perform the necessary functions to have the data system determine each component response factor that is then stored.
4) Response factors for each component are calculated as shown in Equation 36 through Equation 38.

$$ARF_{component_A} = \frac{weight\%\ of\ component_A\ in\ calibration\ standard}{A_{component_A}} \qquad \textbf{36}$$

$$ARF_{component_B} = \frac{weight\%\ of\ component_B\ in\ calibration\ standard}{A_{component_B}} \quad \textbf{37}$$

$$ARF_{component_i} = \frac{weight\%\ of\ component_i\ in\ calibration\ standard}{A_{component_i}} \quad \textbf{38}$$

Where:

A = peak area of component (average of three determinations)
ARF = absolute response factor
$component_i$ = third component or greater

Then, using component *i* as the reference peak, the RRF can be determined using Equation 39 and Equation 40.

$$RRF_{component_B} = \frac{ARF_{component_B}}{ARF_{component_i}} \quad \textbf{39}$$

$$RRF_{component_A} = \frac{ARF_{component_A}}{ARF_{component_i}} \quad \textbf{40}$$

RRF values are computed to the nearest 0.0001 unit.

Note: The largest peak in the calibration standard chromatogram is selected as the reference peak (RRF = 1.0).

C.10.9.4. Sampling

Submitted sample cylinders shall contain liquid phase for analysis.

Note: Eighty percent liquid full should be used for analysis.

Special handling for low *critical temperature* refrigerants R-503 and R-508: A vapor phase sample shall be used to determine non-condensables and volatile impurities, including other refrigerants. The vapor phase sample is obtained by regulating the sample container temperature to 5K or more above the refrigerant *critical temperature*. *Critical temperatures*: R-503 = 19.5°C; R-508A = 13.5°C; and R-508B = 14.0°C.

C.10.9.5. Sample Analysis

Analyze the sample using the chromatographic conditions described in Section C.10.9.1.

1) The sample taken into the syringe for injection into the gas chromatograph is vaporized liquid phase from the sample cylinder. The vapor can be obtained by completely vaporizing the liquid through soft plastic tubing into water and taking the vapor sample by piercing the tubing wall with the syringe needle. An alternative apparatus for vaporizing liquid sample into a glass gas sample bulb allowing repeat injections of the same sample is shown in Figure 8.
2) See example gas chromatograms in Appendix D.

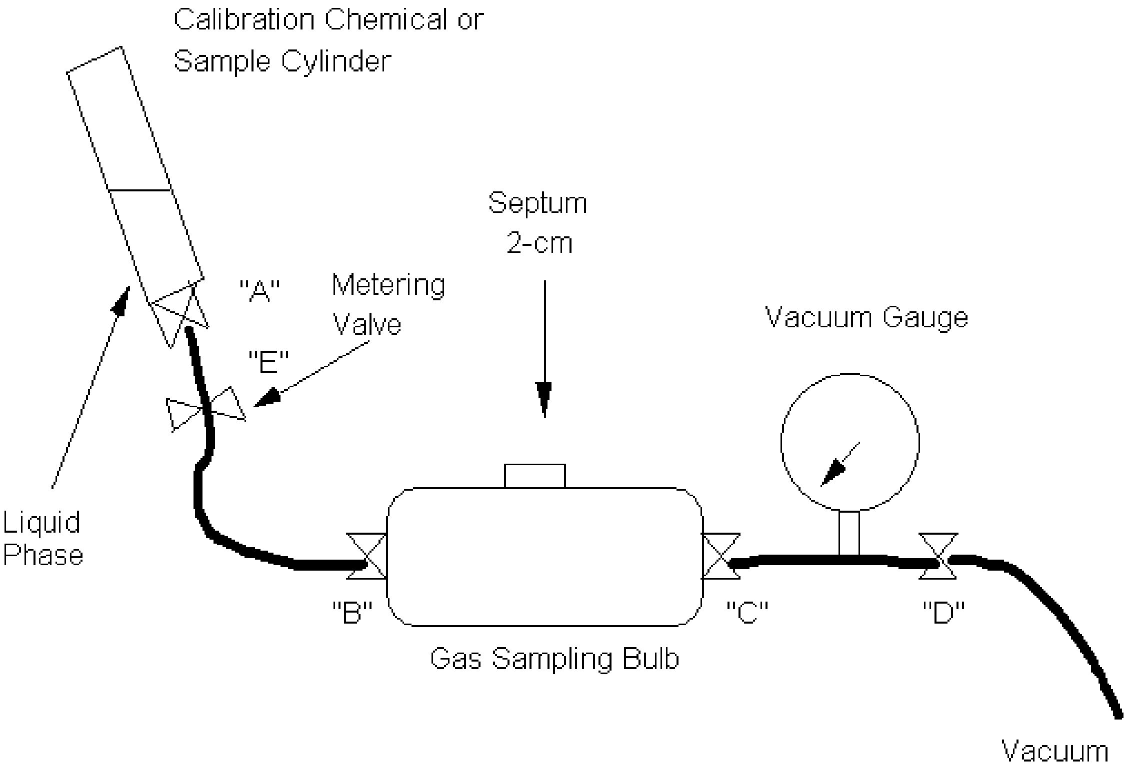


Figure 8 Apparatus Used for Calibration Standard Preparation and for Cylinder Sampling

C.10.9.6. Calculations

1) The weight percentage of each component is calculated as shown in Equation 41.

$$W_i = \frac{RRF_i \cdot A_i \cdot 100}{\sum(A_i \cdot RRF_i)} \qquad \textbf{41}$$

Where:

A_i = peak area of component *i*
RRF_i = Relative response factor for component *i*
W_i = weight percent of component *i*
$\sum(A_i \cdot RRF_i)$ = sum of all component peak areas times their respective relative response factors

Note: The largest peak in the calibration standard chromatogram is selected as the reference peak (RRF= 1.0).

2) Record the sample component concentrations to the nearest 0.01%.

APPENDIX D. GAS CHROMATOGRAM FIGURES – INFORMATIVE

D.1. Purpose

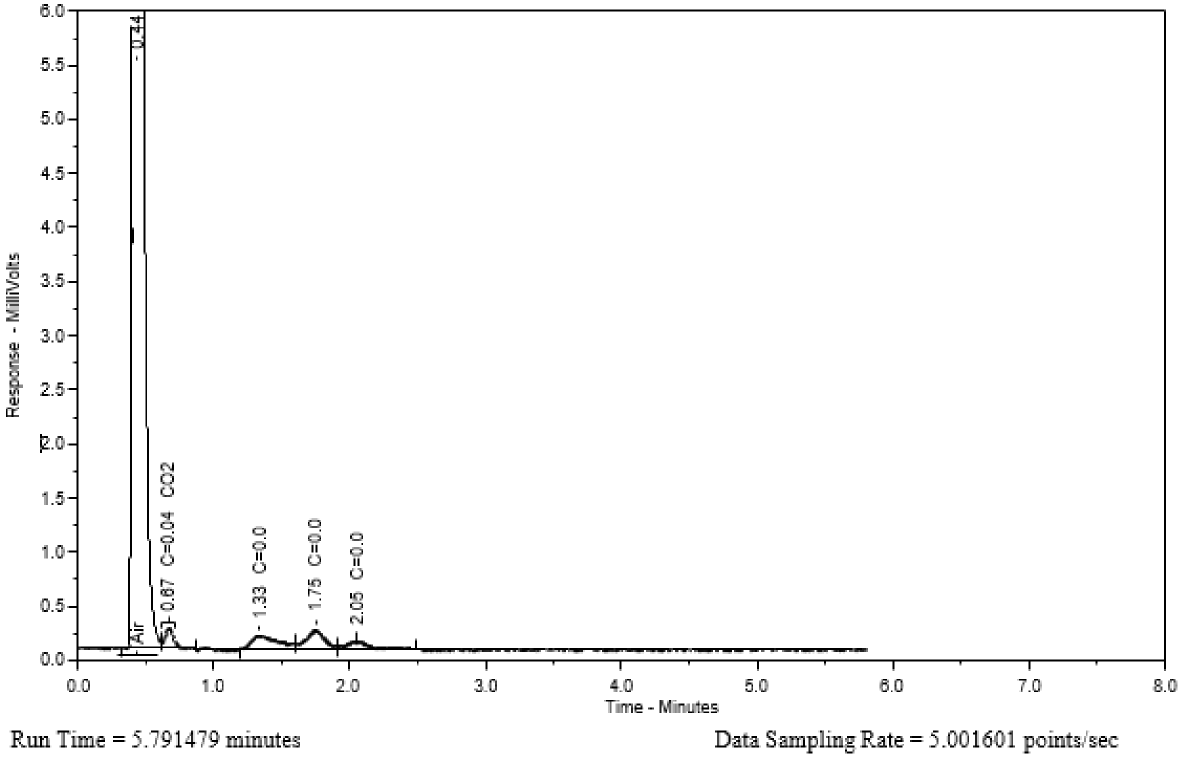
This appendix provides figures for the gas chromatograms used with Appendix C.

For all figures:

Ret. Time = Retention Time
Comp. = Component

D.2. Gas Chromatogram of NCG

Figure 9 shows the gas chromatogram of *NCG*.



Run Time = 5.791479 minutes

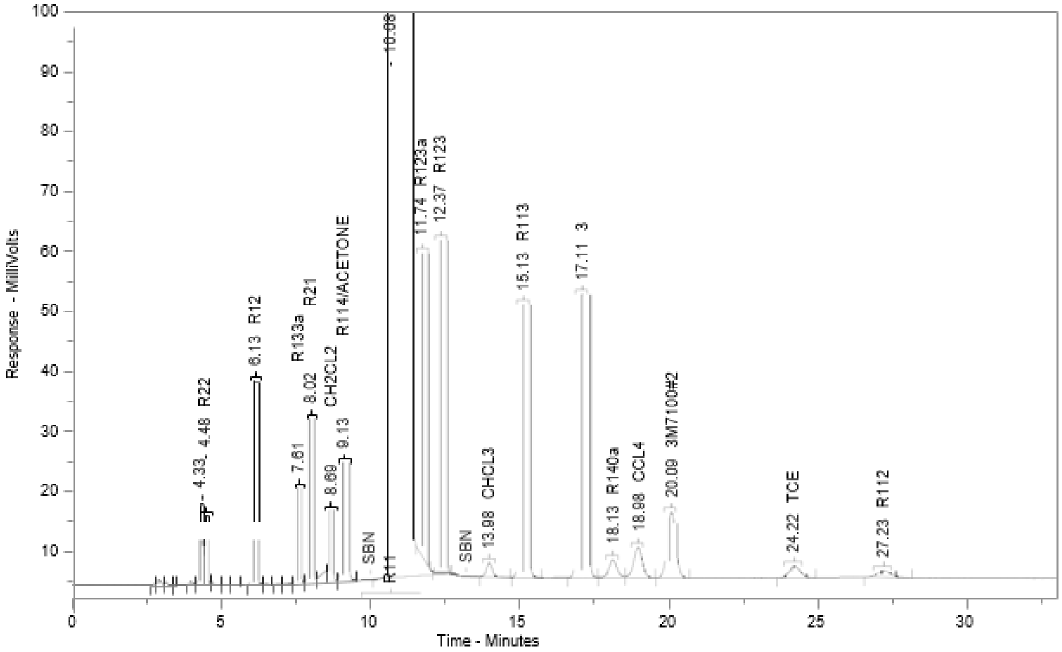
Data Sampling Rate = 5.001601 points/sec

Ret. Time	Component
0.44	Air
0.67	CO2
1.33	
1.75	
2.05	

Figure 9 Gas Chromatogram of NCG

D.3. Gas Chromatogram of R-11

Figure 10 shows the gas chromatogram of R-11.



Run Time = 32.99667 minutes

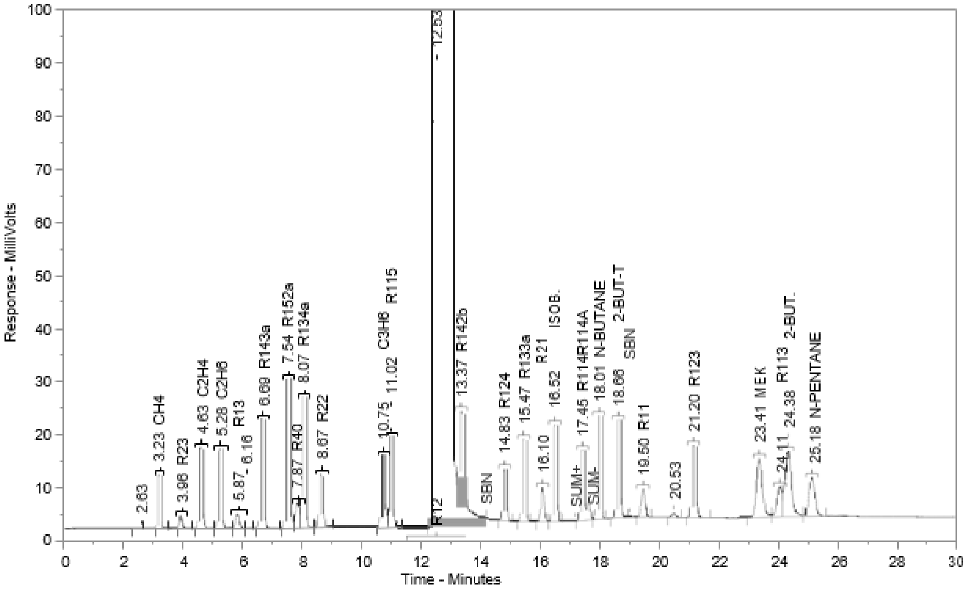
Data Sampling Rate = 5 points/sec

Ret. Time	Component
4.33	
4.48	R22
6.13	R12
7.61	R133a
8.02	R21
8.69	CH2CL2
9.13	R114/ACETONE
10.68	R11
11.74	R123a
12.37	R123
13.98	CHCL3
15.13	R113
17.11	3M7100#1
18.13	R140a
18.98	CCL4
20.09	3M7100#2
24.22	TCE
27.23	R112

Figure 10 Gas Chromatogram of R-11

D.4. Gas Chromatogram of R-12

Figure 11 shows the gas chromatogram of R-12.



Run Time = 30 minutes

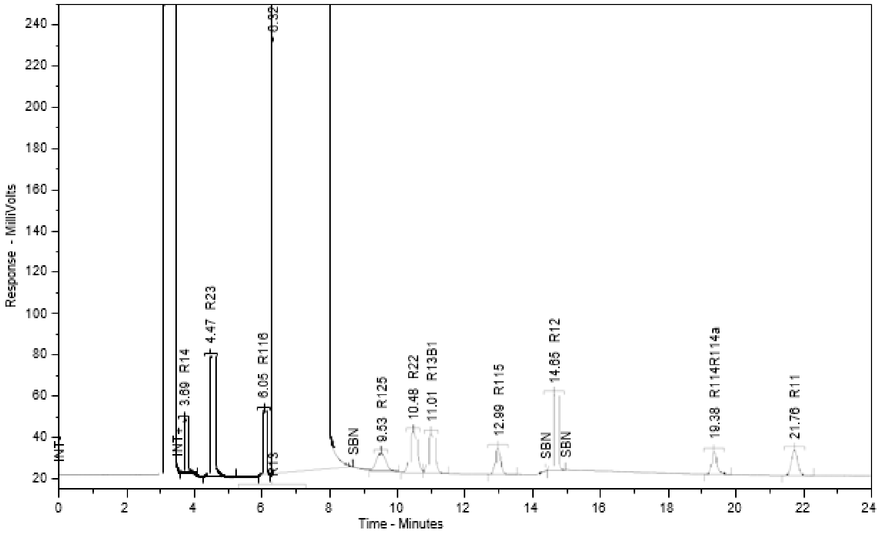
Data Sampling Rate = 5 points/sec

Ret. Time	Component
2.63	
3.23	CH4
3.96	R23
4.63	C2H4
5.28	C2H6
5.87	R13
6.16	
6.69	R143a
7.54	R152a
7.87	R40
8.07	R134a
8.67	R22
10.75	C3H6
11.02	R115
12.53	R12
13.37	R142b
14.83	R124
15.47	R133a
16.10	R21
16.52	ISOB.
17.45	R114R114A
18.01	N-BUTANE
18.66	2-BUT-T
19.50	R11
20.53	
21.20	R123
23.41	MEK
24.11	R113
24.38	2-BUT.
25.18	N-PENTANE

Figure 11 Gas Chromatogram of R-12

D.5. Gas Chromatogram of R-13

Figure 12 shows the gas chromatogram of R-13.



Run Time = 24 minutes

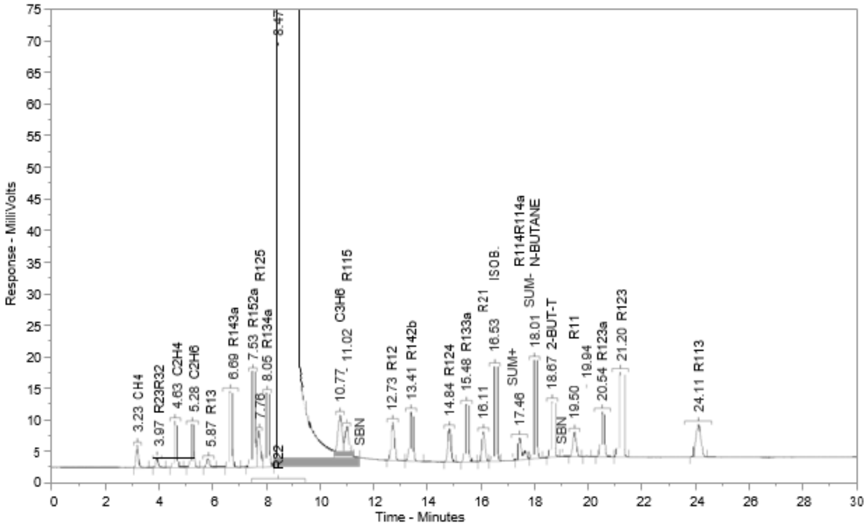
Data Sampling Rate = 5 points/sec

Ret. Time	Component
3.69	R14
4.47	R23
6.05	R116
6.32	R13
9.53	R125
10.48	R22
11.01	R13B1
12.99	R115
14.65	R12
19.38	R114R114a
21.76	R11

Figure 12 Gas Chromatogram of R-13

D.6. Gas Chromatogram of R-22 (Packed)

Figure 13 shows the gas chromatogram of R-22 (Packed).



Run Time = 30 minutes

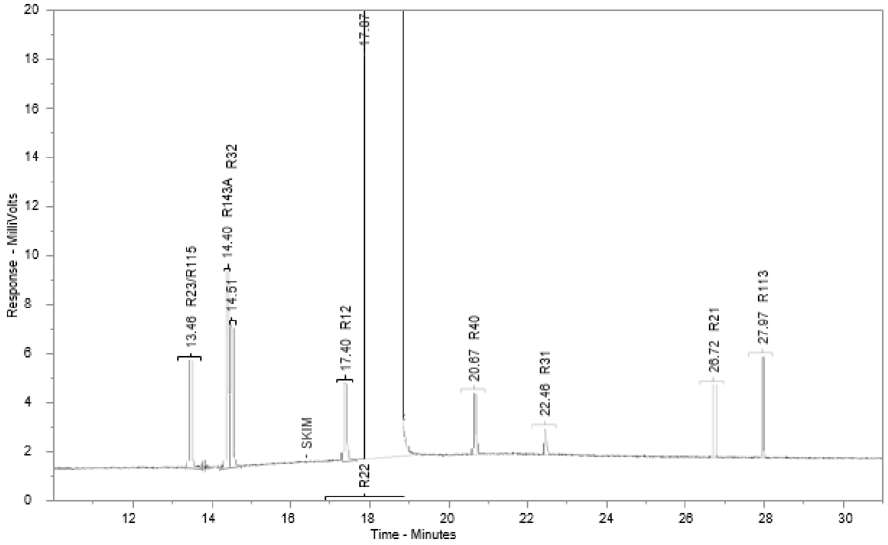
Data Sampling Rate = 5 points/sec

Ret. Time	Component
3.23	CH4
3.97	R23R32
4.63	C2H4
5.28	C2H6
5.87	R13
6.69	R143a
7.53	R152a
7.76	R125
8.05	R134a
8.47	R22
10.77	C3H6
11.02	R115
12.73	R12
13.41	R142b
14.84	R124
15.48	R133a
16.11	R21
16.53	ISOB.
17.46	R114R114a
18.01	N-BUTANE
18.67	2-BUT-T
19.50	R11
19.94	
20.54	R123a
21.20	R123

Figure 13 Gas Chromatogram of R-22 (Packed)

D.7. Gas Chromatogram of R-22 (Capillary)

Figure 14 shows the gas chromatogram of R-22 (Capillary).



Run Time = 31 minutes

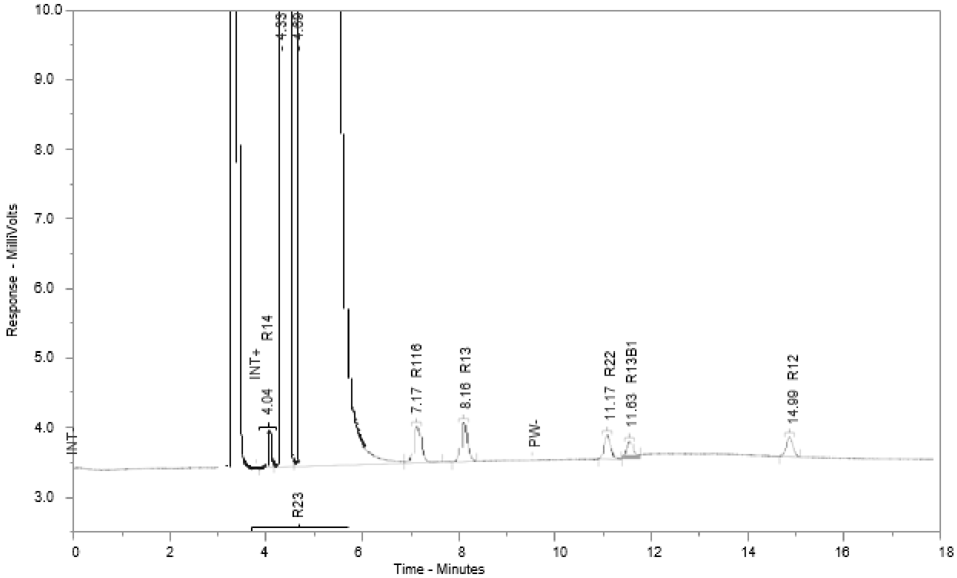
Data Sampling Rate = 20 points/sec

Ret. Time	Component
13.46	R23/R115
14.40	R143A
14.51	R32
17.40	R12
17.87	R22
20.67	R40
22.46	R31
26.72	R21
27.97	R113

Figure 14 Gas Chromatogram of R-22 (Capillary)

D.8. Gas Chromatogram of R-23

Figure 15 shows the gas chromatogram of R-23.



Run Time = 18 minutes

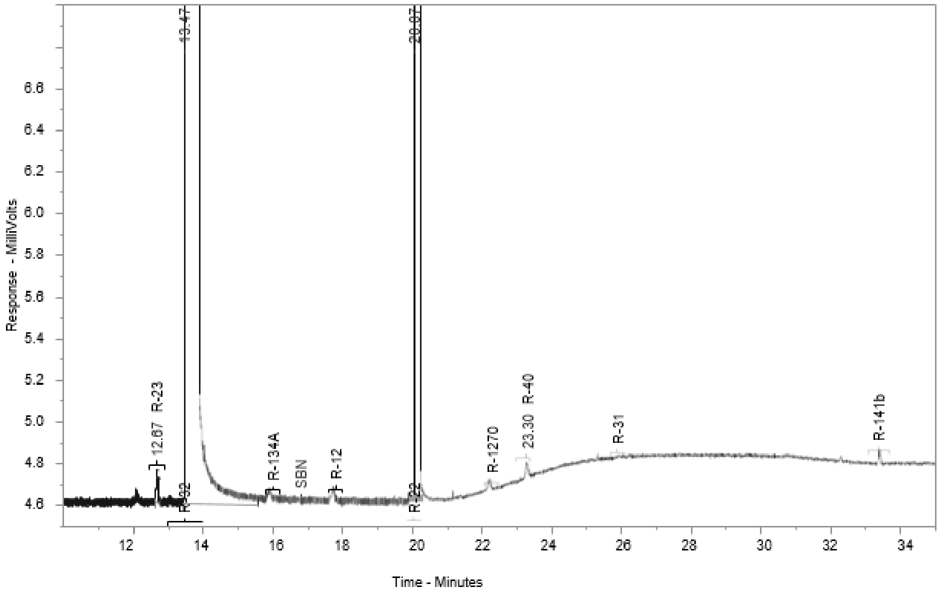
Data Sampling Rate = 5 points/sec

Ret. Time	Component
4.04	R14
4.33	
4.69	R23
7.17	R116
8.16	R13
11.17	R22
11.63	R13B1
14.99	R12

Figure 15 Gas Chromatogram of R-23

D.9. Gas Chromatogram of R-32

Figure 16 shows the gas chromatogram of R-32.



Run Time = 34.99917 minutes

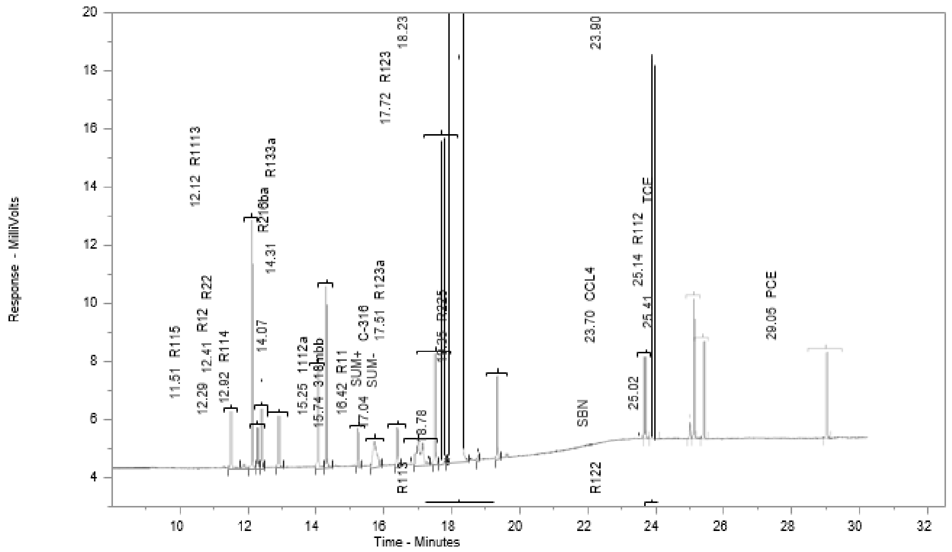
Data Sampling Rate = 20 points/sec

Ret. Time	Component
12.67	R-23
13.47	R-32
20.07	R-22
23.30	R-40

Figure 16 Gas Chromatogram of R-32

D.10. Gas Chromatogram of R-113

Figure 17 shows the gas chromatogram of R-113.



Run Time = 30.27 minutes

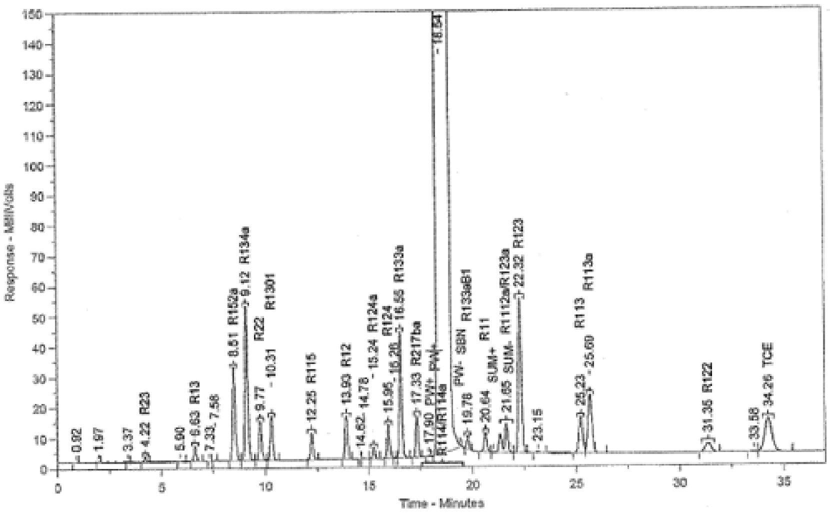
Data Sampling Rate = 20 points/sec

Ret. Time	Component
11.51	R115
12.12	R1113
12.29	R12
12.41	R22
12.92	R114
14.07	R216ba
14.31	R133a
15.25	1112a
15.74	318mbb
16.42	R11
17.04	C-316
17.51	R123a
17.72	R123
18.23	R113
18.78	
19.35	R225
23.70	CCL4
23.90	R122
25.02	
25.14	R112
25.41	TCE
29.05	PCE

Figure 17 Gas Chromatogram of R-113

D.11. Gas Chromatogram of R-114

Figure 18 shows the gas chromatogram of R-114.



Run Time = 37

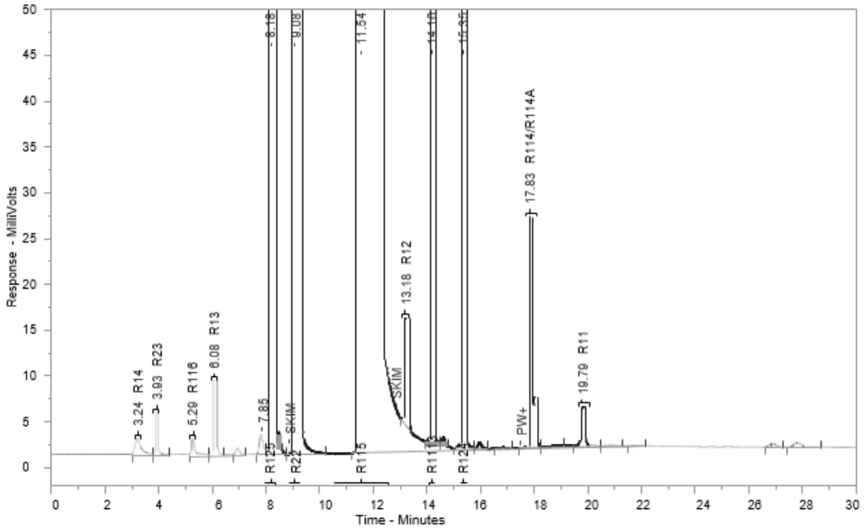
Data Sampling Rate = 5

Ret. Time	Component
0.92	
1.97	
3.37	
4.22	R23
5.90	
6.63	R13
7.33	
7.58	
8.51	R152a
9.12	R134a
9.77	R22
10.31	R1301
12.25	R115
13.93	R12
14.62	
14.78	
15.24	R124a
15.95	R124
16.26	
16.55	R133a
17.33	R217ba
17.90	
18.54	R114/R114a
19.78	R133aB1
20.64	R11
21.65	R1112a/R123a
22.32	R123
23.15	
25.23	R113
25.69	R113a
31.35	R122
33.58	
34.26	TCE

Figure 18 Gas Chromatogram of R-114

D.12. Gas Chromatogram of R-115

Figure 19 shows the gas chromatogram of R-115.



Run Time = 30 minutes

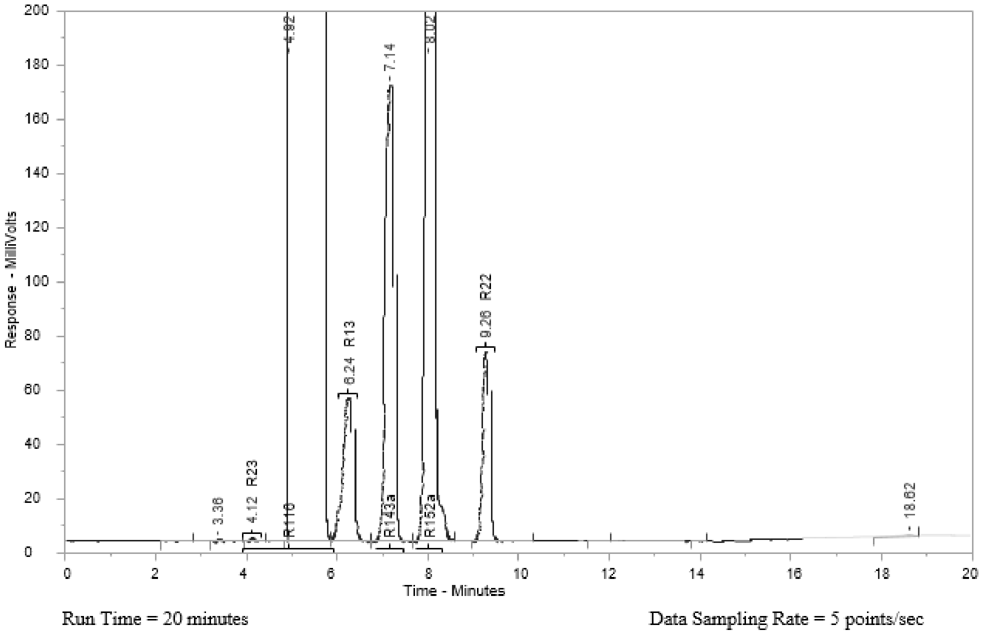
Data Sampling Rate = 5 points/sec

Ret. Time	Component
3.24	R14
3.93	R23
5.29	R116
6.08	R13
7.85	
8.18	R125
9.08	R22
11.54	R115
13.18	R12
14.16	R1113
15.35	R124
17.83	R114/R114A
19.79	R11

Figure 19 Gas Chromatogram of R-115

D.13. Gas Chromatogram of R-116

Figure 20 shows the gas chromatogram of R-116.

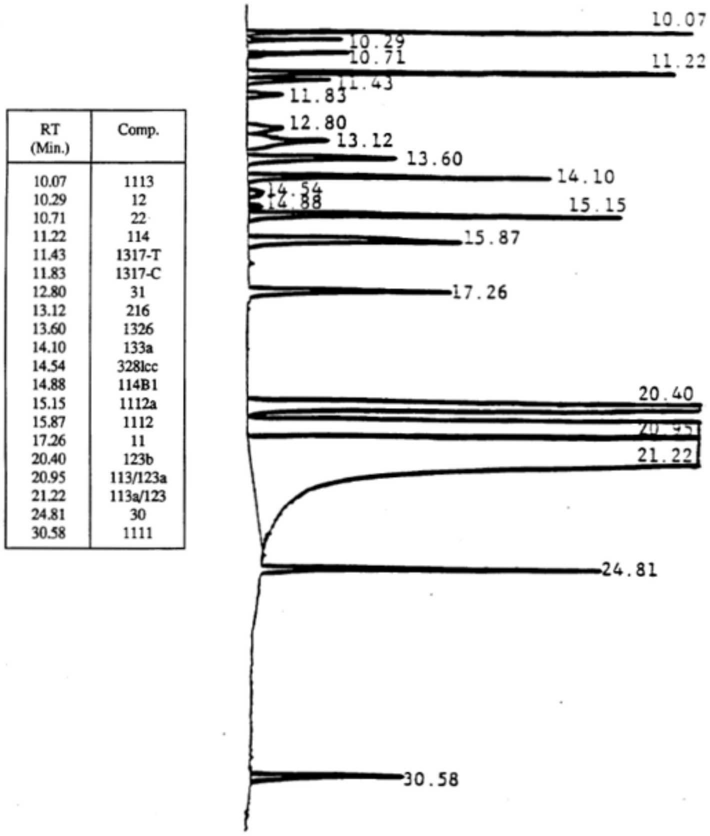


Ret. Time	Component
3.36	
4.12	R23
4.92	R116
6.24	R13
7.14	R143a
8.02	R152a
9.26	R22
18.62	
21.65	R1112a/R123a
22.32	R123
23.15	
25.23	R113
25.69	R113a
31.35	R122
33.58	
34.26	TCE

Figure 20 Gas Chromatogram of R-116

D.14. Gas Chromatogram of R-123 (Packed)

Figure 21 shows the gas chromatogram of R-123 (Packed).

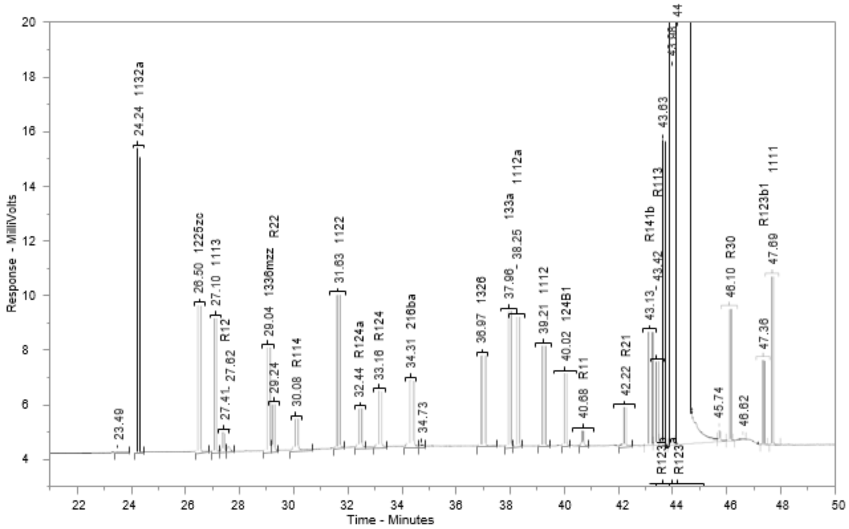


RT (Min.)	Comp.
10.07	1113
10.29	12
10.71	22
11.22	114
11.43	1317-T
11.83	1317-C
12.80	31
13.12	216
13.60	1326
14.10	133a
14.54	328lcc
14.88	114B1
15.15	1112a
15.87	1112
17.26	11
20.40	123b
20.95	113/123a
21.22	113a/123
24.81	30
30.58	1111

Figure 21 Gas Chromatogram of R-123 (Packed)

D.15. Gas Chromatogram of R-123 (Capillary)

Figure 22 shows the gas chromatogram of R-123 (capillary).



Run Time = 50 minutes

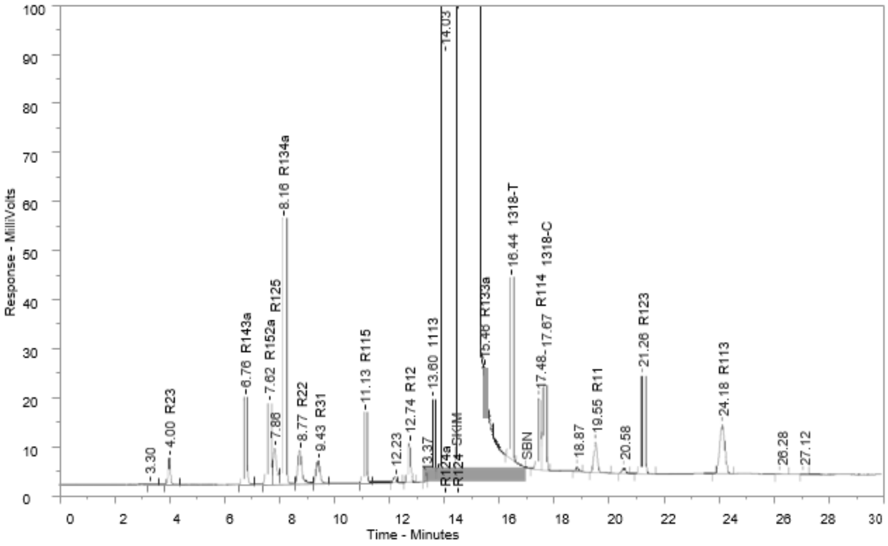
Data Sampling Rate = 5 points/sec

Ret. Time	Component
23.49	
24.24	1132a
26.50	1225zc
27.10	1113
27.41	R12
27.62	
29.04	1336mzz
29.24	R22
30.08	R114
31.63	1122
32.44	R124a
33.16	R124
34.31	216ba
34.73	
36.97	1326
37.96	133a
38.25	1112a
39.21	1112
40.02	124B1
40.68	R11
42.22	R21
43.13	R141b
43.42	R113
43.63	R123b
43.98	R123a
44.16	R123
45.74	
46.10	R30
46.62	
47.36	R123b1
47.69	1111

Figure 22 Gas Chromatogram of R-123 (Capillary)

D.16. Gas Chromatogram of R-124

Figure 23 shows the gas chromatogram of R-124.



Run Time = 30 minutes

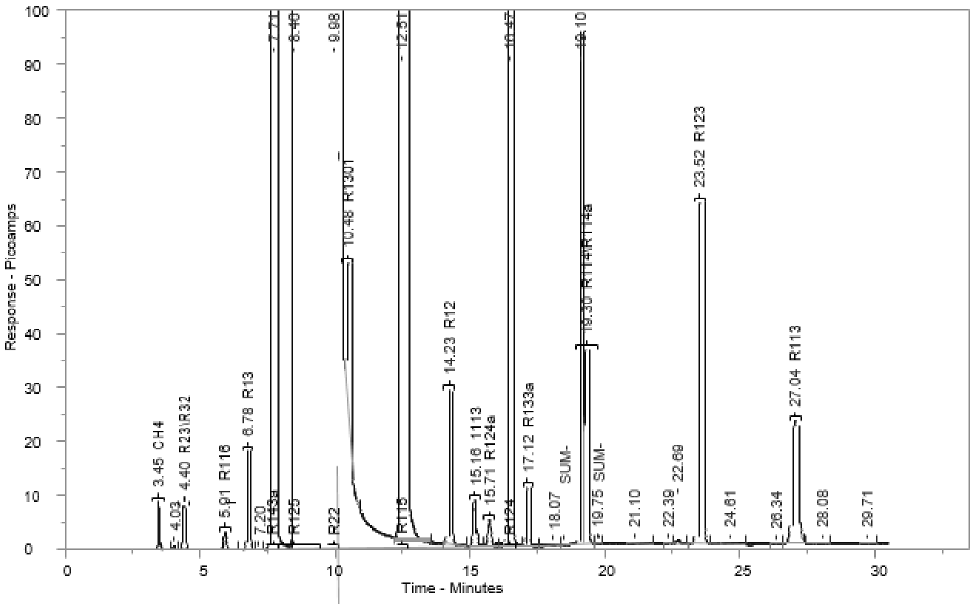
Data Sampling Rate = 5 points/sec

Ret. Time	Component
3.30	
4.00	R23
6.76	R143a
7.62	R152a
7.86	R125
8.16	R134a
8.77	R22
9.43	R31
11.13	R115
12.23	
12.74	R12
13.37	
13.60	1113
14.03	R124a
14.49	R124
15.46	R133a
16.44	1318-T
17.48	R114
17.67	1318-C
18.87	
19.55	R11
20.58	
21.26	R123
24.18	R113
26.28	
27.12	

Figure 23 Gas Chromatogram of R-124

D.17. Gas Chromatogram of R-125

Figure 24 shows the gas chromatogram of R-125.



Run Time = 30.49667 minutes

Data Sampling Rate = 5 points/sec

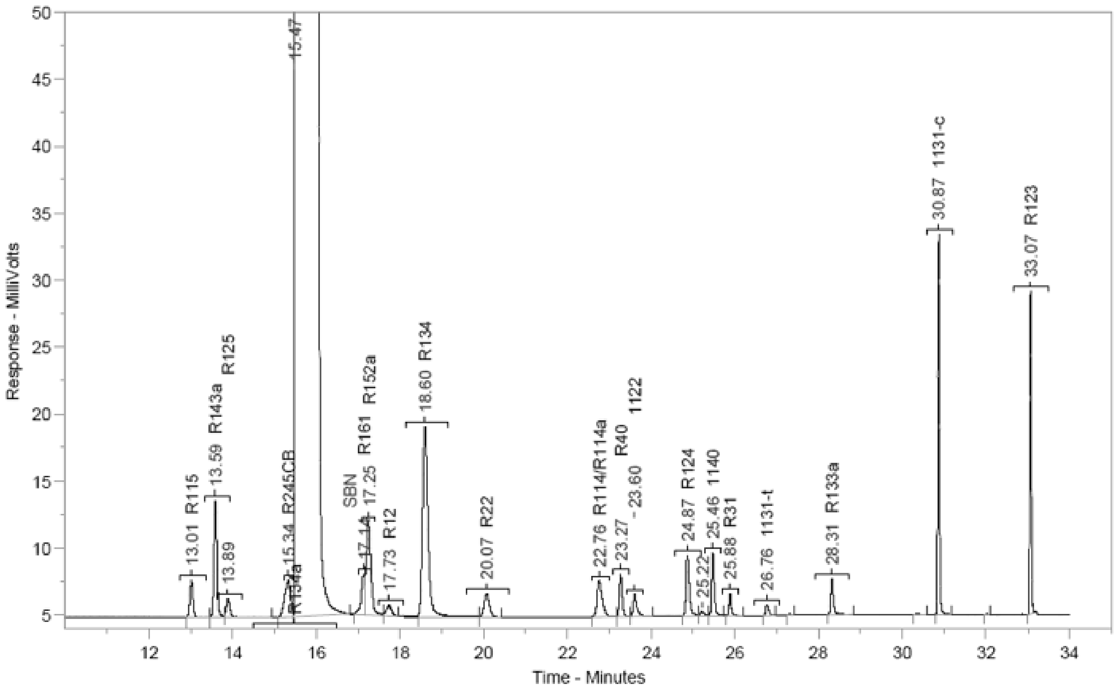
Ret. Time	Component
3.45	CH4
4.03	
4.40	R23\R32
5.91	R116
6.78	R13
7.20	
7.71	R143a
8.46	R125
9.98	R22
10.48	R1301
12.51	R115
14.23	R12
15.16	1113
15.71	R124a
16.47	R124
17.12	R133a
18.07	
19.10	
19.30	R114\R114a
19.75	
21.10	
22.39	
22.69	
23.52	R123
24.61	

Ret. Time	Component
26.34	
27.04	R113
28.08	
29.71	

Figure 24 Gas Chromatogram of R-125

D.18. Gas Chromatogram of R-134a

Figure 25 shows the gas chromatogram of R-134a.



Run Time = 33.99667 minutes

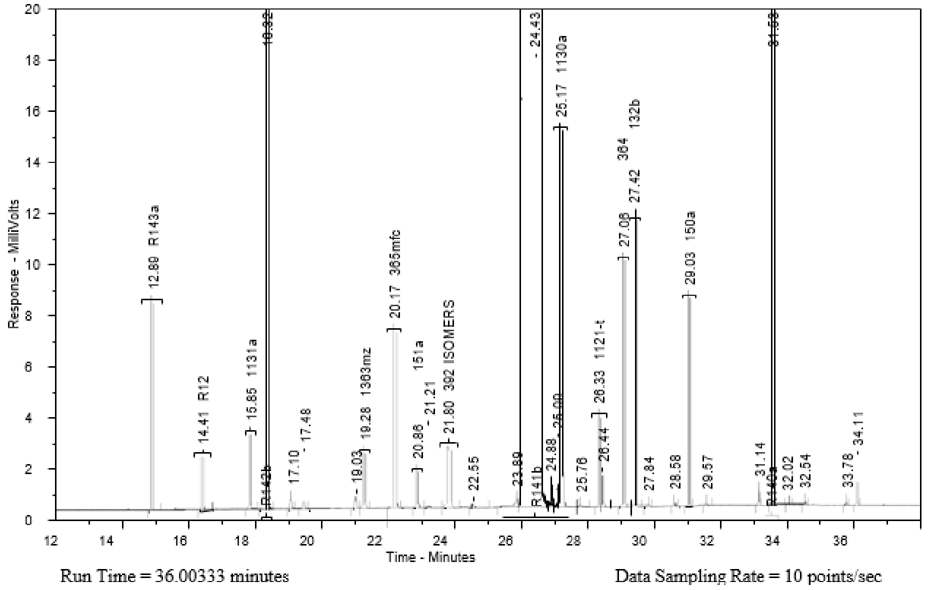
Data Sampling Rate = 20 points/sec

Ret. Time	Component
13.01	R115
13.59	R143a
13.89	R125
15.34	R245CB
15.47	R134a
17.14	R161
17.25	R152a
17.73	R12
18.60	R134
20.07	R22
22.76	R114/R114a
23.27	R40
23.60	1122
24.87	R124
25.22	
25.46	1140
25.88	R31
26.76	1131-t
28.31	R133a
30.87	1131-c
33.07	R123

Figure 25 Gas Chromatogram of R-134a

D.19. Gas Chromatogram of R-141b

Figure 26 shows the gas chromatogram of R-141b.



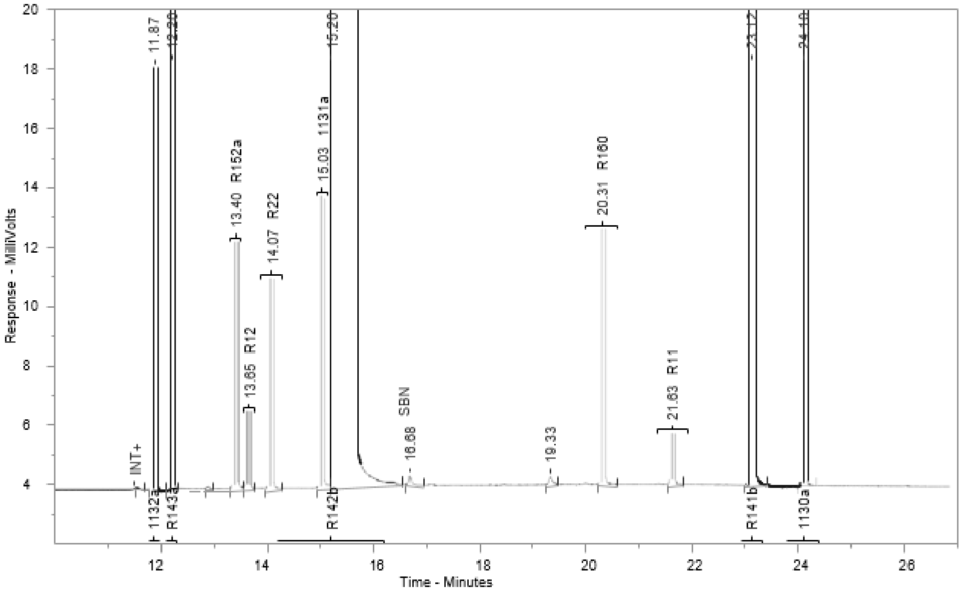
Ret. Time	Component
12.89	R143a
14.41	R12
15.85	1131a
16.32	R142b
17.10	
17.48	
19.03	
19.28	1363mz
20.17	365mfc
20.86	151a
21.21	
21.80	392 ISOMERS
22.55	
23.89	
24.43	R141b
24.88	
25.09	
25.17	1130a
25.76	
26.33	1121-t
26.44	
27.06	364
27.42	132b
27.84	
28.58	
29.03	150a

Ret. Time	Component
29.57	
31.14	
31.53	R140a
32.02	
32.54	
33.78	
34.11	

Figure 26 Gas Chromatogram of R-141b

D.20. Gas Chromatogram of R-142b

Figure 26 shows the gas chromatogram of R-142b.



Run Time = 26.99833 minutes

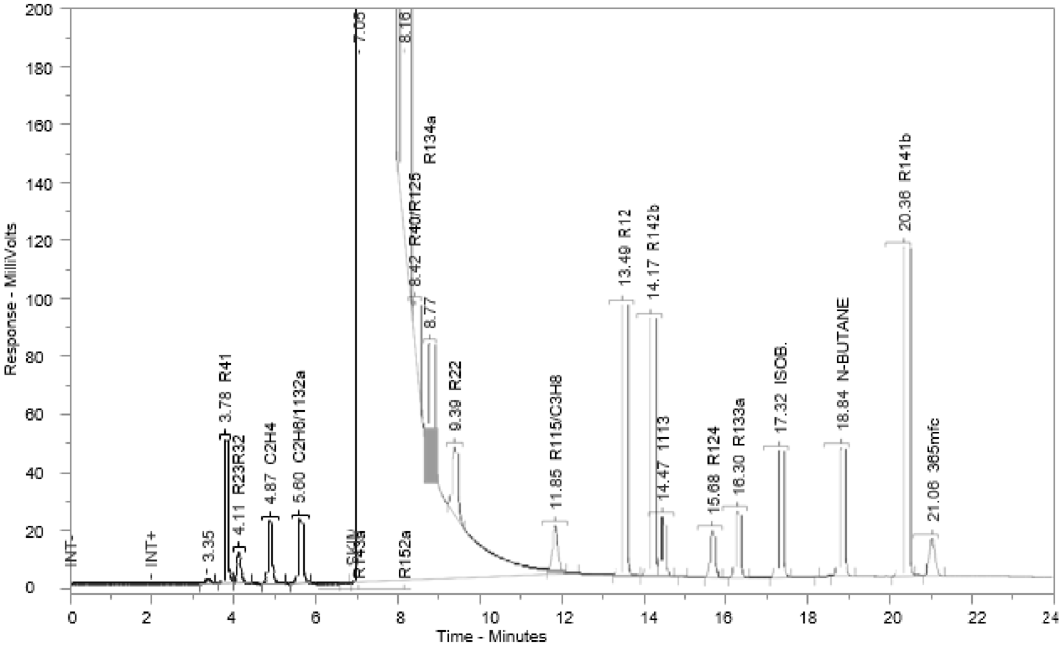
Data Sampling Rate = 10 points/sec

Ret. Time	Component
11.87	1132a
12.20	R143a
13.40	R152a
13.65	R12
14.07	R22
15.03	1131a
15.20	R142b
16.68	
19.33	
20.31	R160
21.63	R11
23.12	R141b
24.10	1130a
32.02	
32.54	
33.78	
34.11	

Figure 27 Gas Chromatogram of R-142b

D.21. Gas Chromatogram of R-143a

Figure 28 shows the gas chromatogram of R-143a.



Run Time = 24 minutes

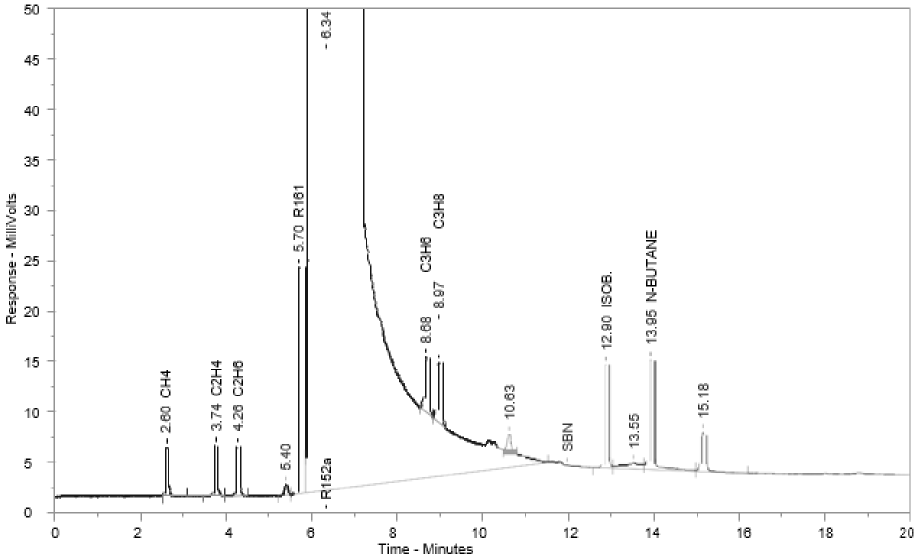
Data Sampling Rate = 5 points/sec

Ret. Time	Component
3.35	
3.78	R41
4.11	R23R32
4.87	C2H4
5.60	C2H6/1132a
7.05	R143a
8.16	R152a
8.42	R40/R125
8.77	R134a
9.39	R22
11.85	R115/C3H8
13.49	R12
14.17	R142b
14.47	1113
15.68	R124
16.30	R133a
17.32	ISOB.
18.84	N-BUTANE
20.36	R141b
21.06	365mfc

Figure 28 Gas Chromatogram of R-143a

D.22. Gas Chromatogram of R-152a

Figure 29 shows the gas chromatogram of R-152a.



Run Time = 20 minutes

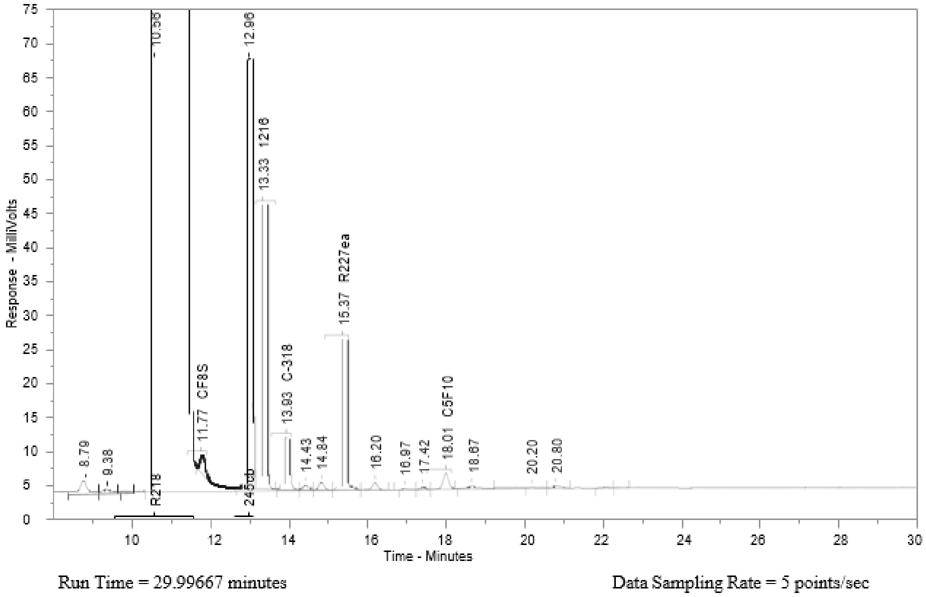
Data Sampling Rate = 5 points/sec

Ret. Time	Component
2.60	CH4
3.74	C2H4
4.26	C2H6
5.40	
5.70	R161
6.34	R152a
8.68	C3H6
8.97	C3H8
10.63	
12.90	ISOB.
13.55	
13.95	N-BUTANE
15.18	

Figure 29 Gas Chromatogram of R-152a

D.23. Gas Chromatogram of R-218

Figure 30 shows the gas chromatogram of R-218.



Run Time = 29.99667 minutes

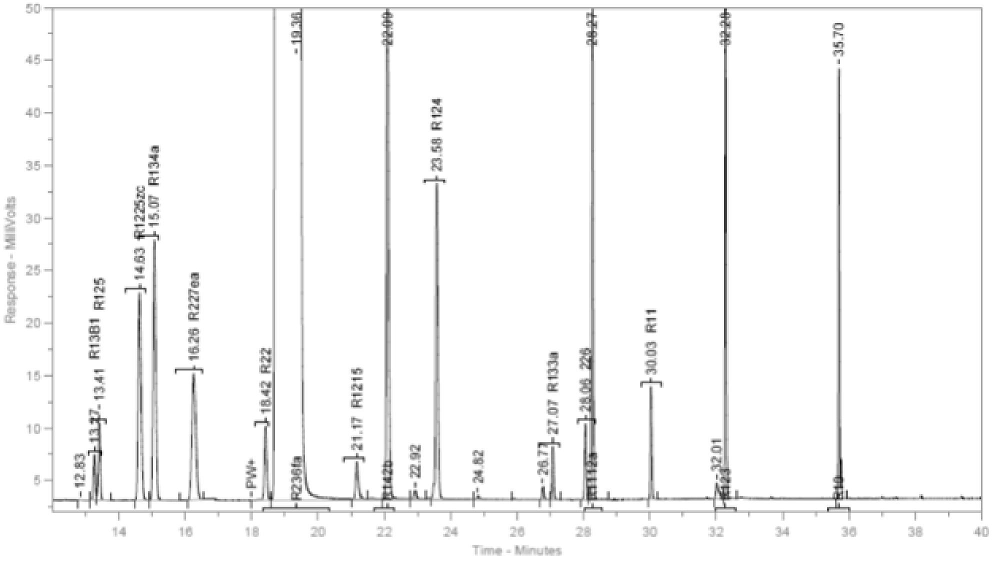
Data Sampling Rate = 5 points/sec

Ret. Time	Component
3.42	
5.63	
8.79	
9.38	
10.56	R218
11.77	CF8S
12.96	245cb
13.33	1216
13.93	C-318
14.43	
14.84	
15.37	R227ea
16.20	
16.97	
17.42	
18.01	C5F10
18.67	
20.20	
20.80	

Figure 30 Gas Chromatogram of R-218

D.24. Gas Chromatogram of R-236fa

Figure 31 shows the gas chromatogram of R-236fa.



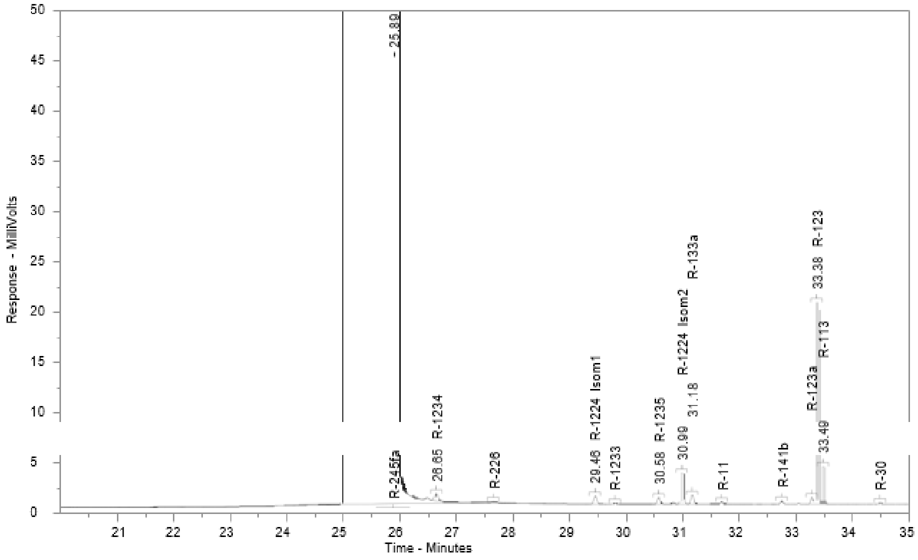
Run Time = 39.99667 Data Sampling Rate = 10

Ret. Time	Component
13.27	R13B1
13.41	R125
14.63	R1225zc
15.07	R134a
16.26	R227ea
18.42	R22
19.36	R236fa
21.17	R1215
22.09	R142b
23.58	R124
27.07	R133a
28.06	226
28.27	R1112a
30.03	R11
32.28	R123
35.70	R10

Figure 31 Gas Chromatogram of R-236fa

D.25. Gas Chromatogram of R-245fa

Figure 32 shows the gas chromatogram of R-245fa.



Run Time = 34.99667 minutes

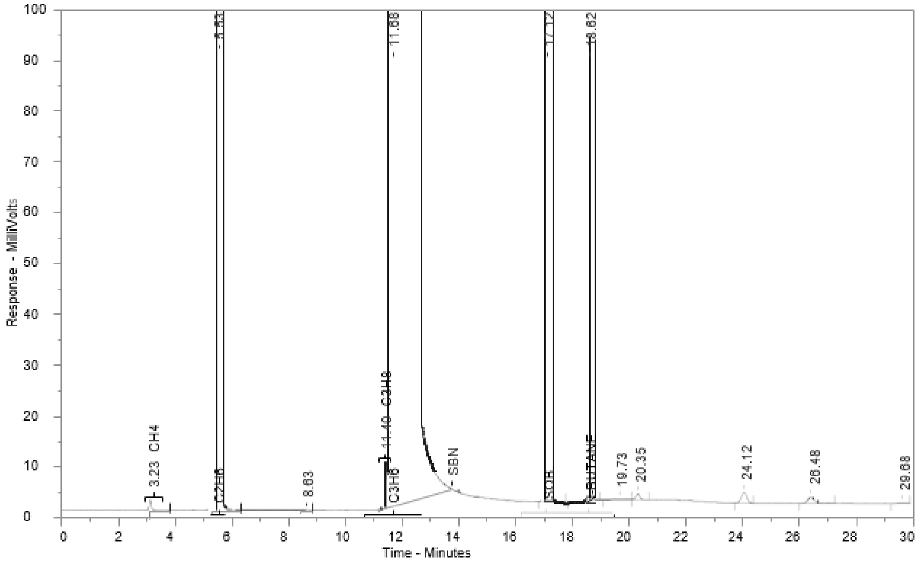
Data Sampling Rate = 10 points/sec

Ret. Time	Component
25.89	R-245fa
26.65	R-1234
29.46	R-1224 Isom1
30.58	R-1235
30.99	R-1224 Isom2
31.18	R-133a
33.38	R-123
33.49	R-113

Figure 32 Gas Chromatogram of R-245fa

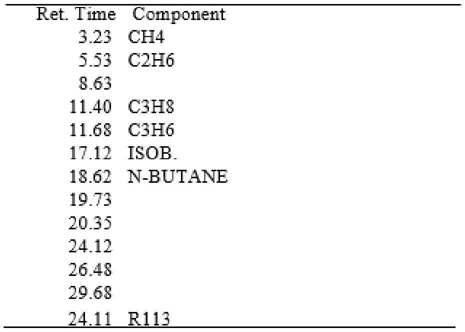
D.26. Gas Chromatogram of R-290

Figure 33 shows the gas chromatogram of R-290.



Run Time = 30 minutes

Data Sampling Rate = 5 points/sec

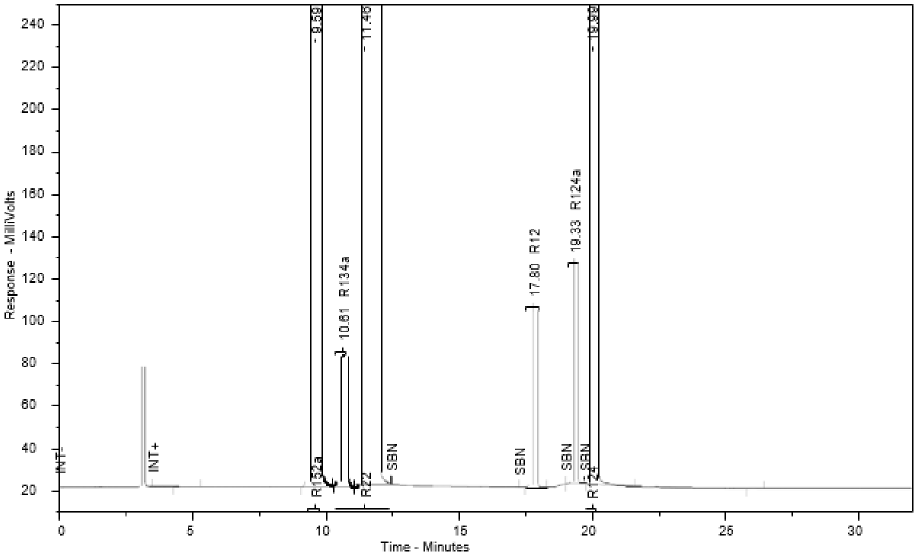


Ret. Time	Component
3.23	CH4
5.53	C2H6
8.63	
11.40	C3H8
11.68	C3H6
17.12	ISOB.
18.62	N-BUTANE
19.73	
20.35	
24.12	
26.48	
29.68	
24.11	R113

Figure 33 Gas Chromatogram of R-290

D.27. Gas Chromatogram of R-401

Figure 34 shows the gas chromatogram of R-401.



Run Time = 31.99667 minutes

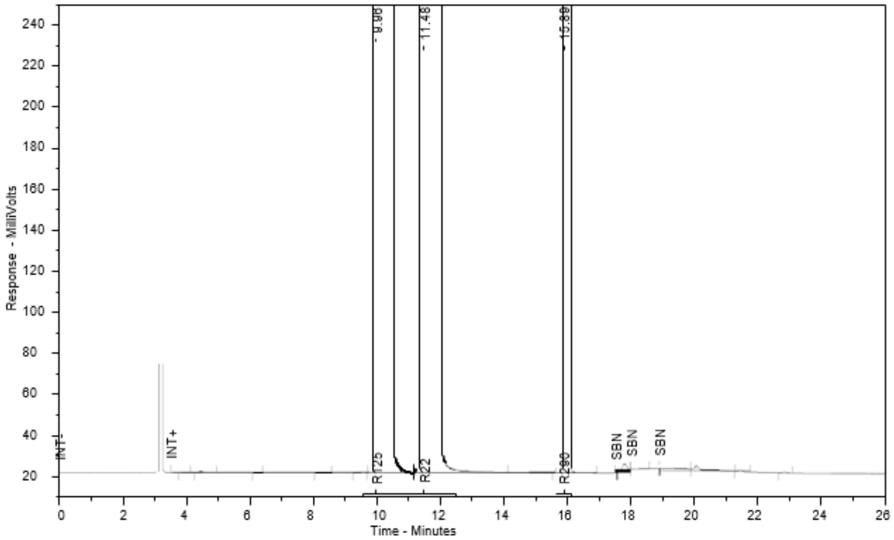
Data Sampling Rate = 5 points/sec

Ret. Time	Component
9.59	R152a
10.61	R134a
11.46	R22
17.80	R12
19.33	R124a
19.99	R124

Figure 34 Gas Chromatogram of R-401

D.28. Gas Chromatogram of R-402

Figure 35 shows the gas chromatogram of R-402.



Run Time = 25.99333 minutes

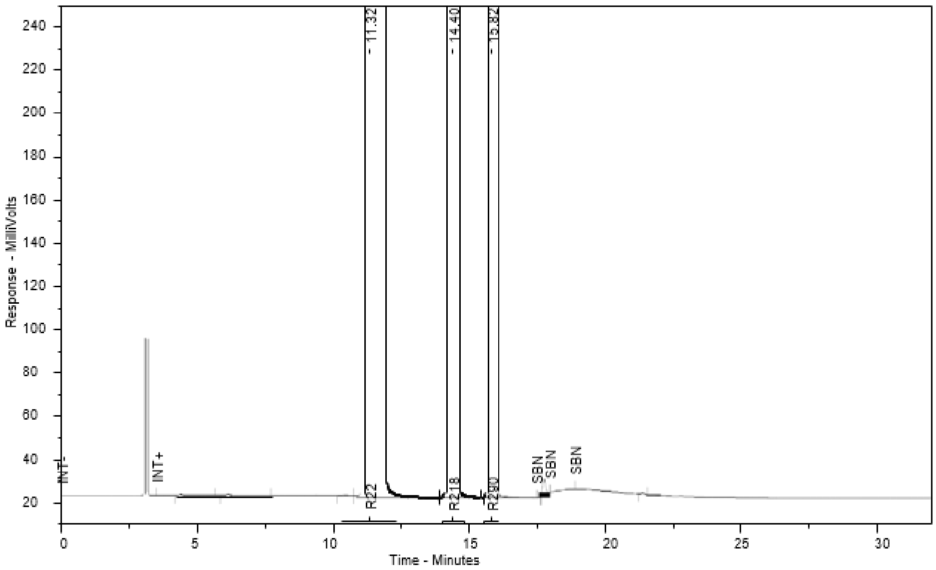
Data Sampling Rate = 5 points/sec

Ret. Time	Component
9.96	R125
11.48	R22
15	

Figure 35 Gas Chromatogram of R-402

D.29. Gas Chromatogram of R-403

Figure 36 shows the gas chromatogram of R-403.



Run Time = 31.99667 minutes

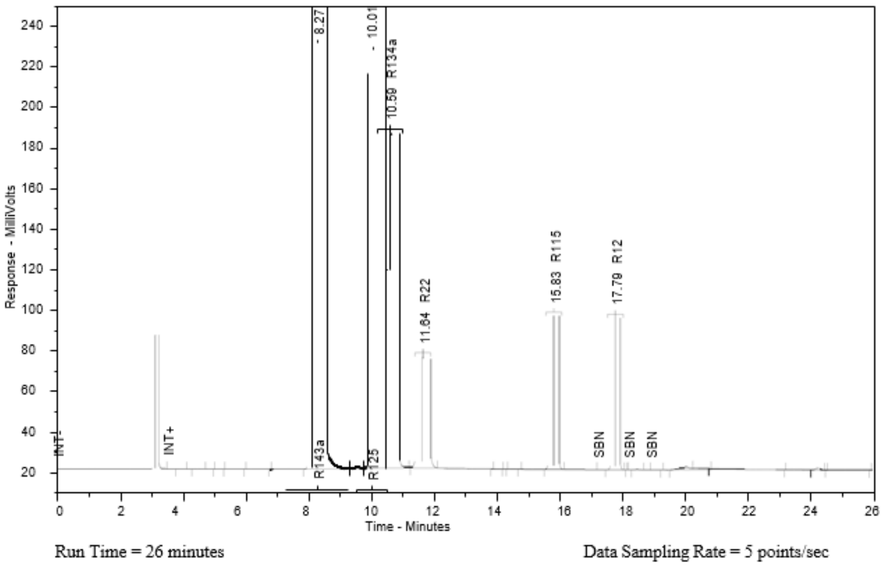
Data Sampling Rate = 5 points/sec

Ret. Time	Component
11.32	R22
14.40	R218
15.82	R290

Figure 36 Gas Chromatogram of R-403

D.30. Gas Chromatogram of R-404

Figure 37 shows the gas chromatogram of R-404.

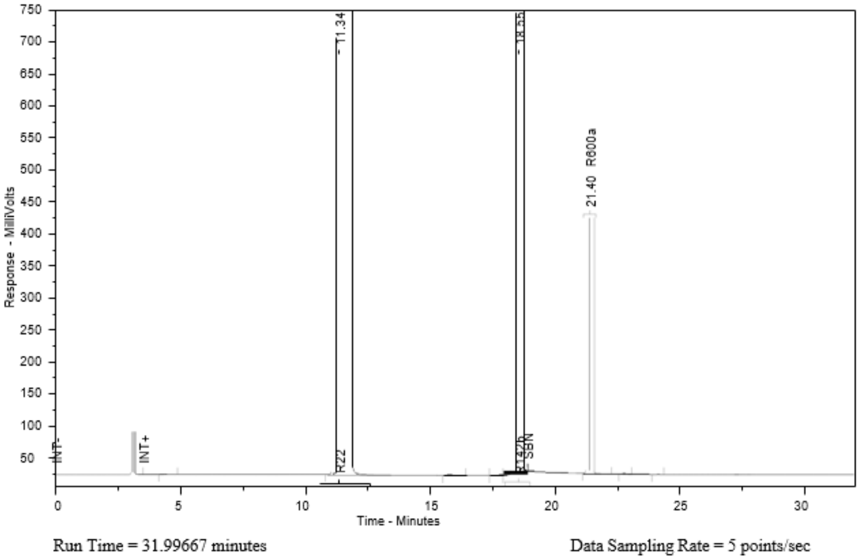


Ret. Time	Component
8.27	R143a
10.01	R125
10.59	R134a
11.64	R22
15.83	R115
17.79	R12

Figure 37 Gas Chromatogram of R-404

D.31. Gas Chromatogram of R-406

Figure 38 shows the gas chromatogram of R-406.

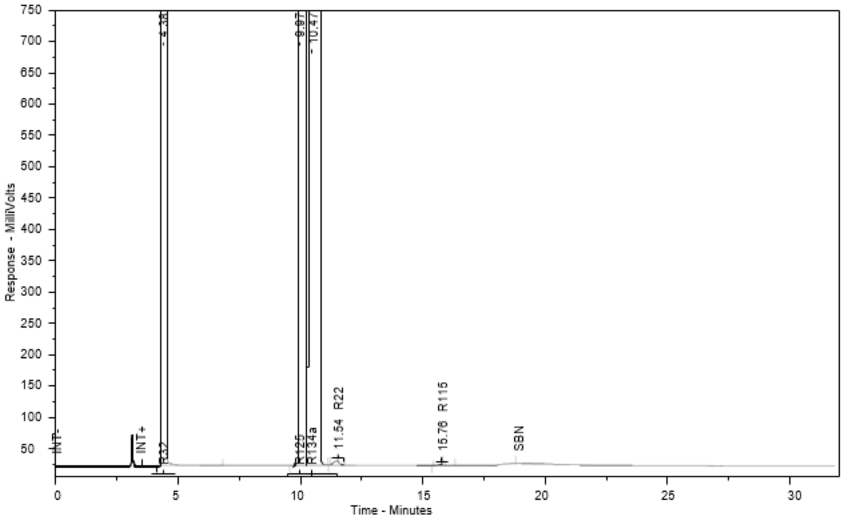


Ret. Time	Component
11.34	R22
18.55	R142b
21.40	R600a

Figure 38 Gas Chromatogram of R-406

D.32. Gas Chromatogram of R-407

Figure 39 shows the gas chromatogram of R-407.



Run Time = 31.99667 minutes

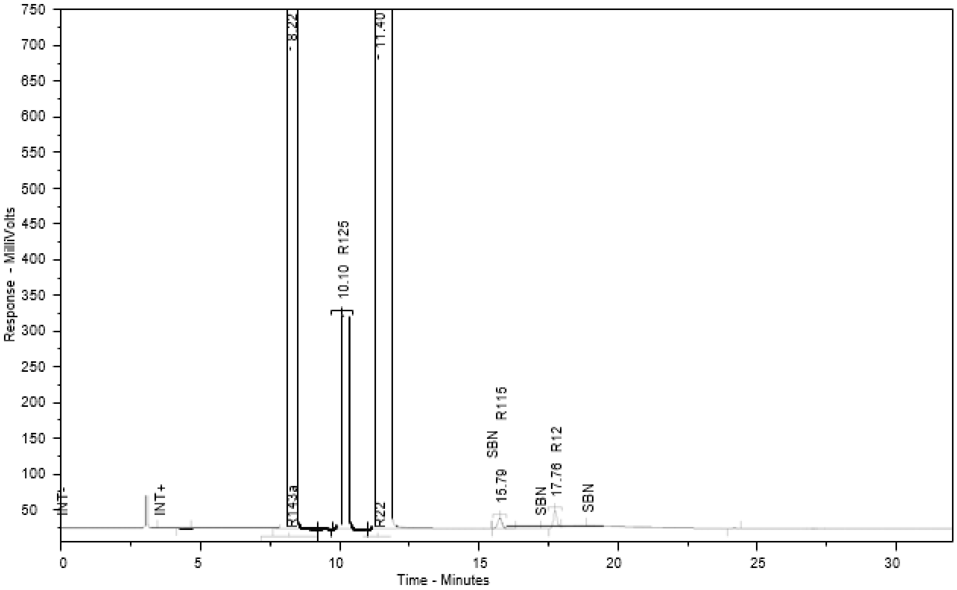
Data Sampling Rate = 5 points/sec

Ret. Time	Component
4.38	R32
9.97	R125
10.47	R134a
11.54	R22
15.76	R115

Figure 39 Gas Chromatogram of R-407

D.33. Gas Chromatogram of R-408

Figure 40 shows the gas chromatogram of R-408.



Run Time = 31.99667 minutes

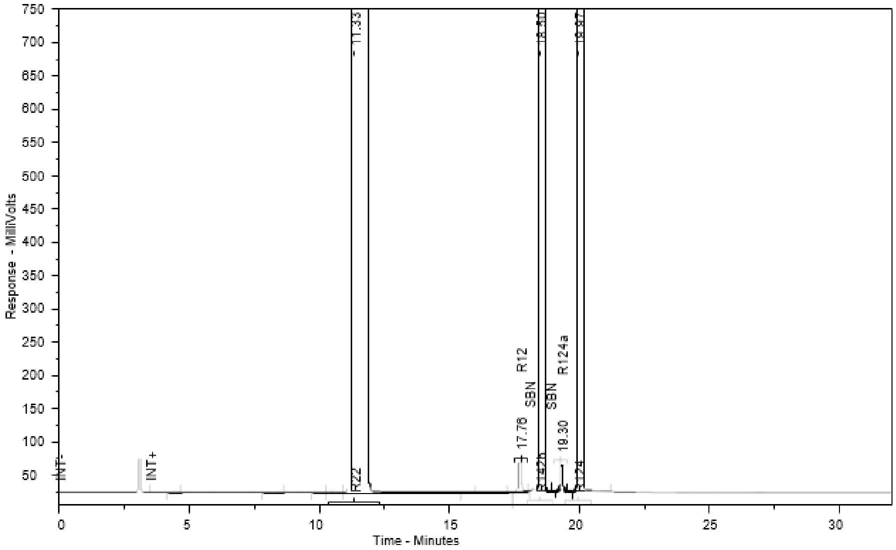
Data Sampling Rate = 5 points/sec

Ret. Time	Component
8.22	R143a
10.10	R125
11.40	R22
15.79	R115
17.76	R12

Figure 40 Gas Chromatogram of R-408

D.34. Gas Chromatogram of R-409

Figure 41 shows the gas chromatogram of R-409.



Run Time = 32 minutes

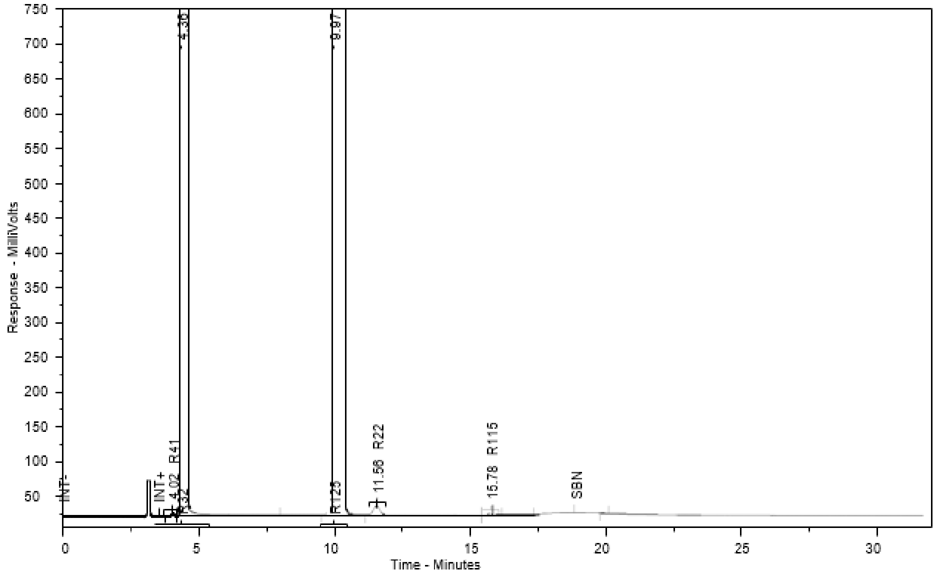
Data Sampling Rate = 5 points/sec

Ret. Time	Component
11.33	R22
17.76	R12
18.50	R142b
19.30	R124a
19.97	R124

Figure 41 Gas Chromatogram of R-409

D.35. Gas Chromatogram of R-410

Figure 42 shows the gas chromatogram of R-410.



Run Time = 31.99667 minutes

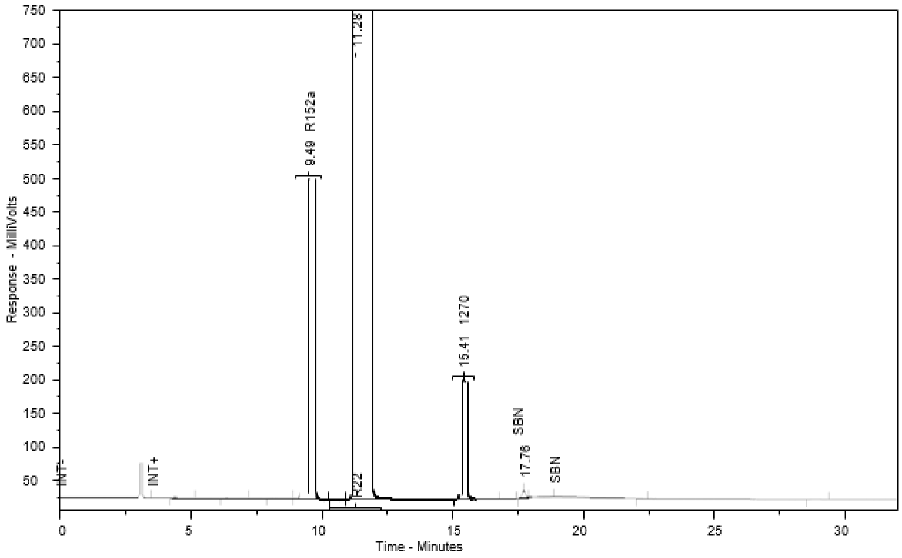
Data Sampling Rate = 5 points/sec

Ret. Time	Component
4.02	R41
4.36	R32
9.97	R125
11.56	R22
15.78	R115

Figure 42 Gas Chromatogram of R-410

D.36. Gas Chromatogram of R-411

Figure 43 shows the gas chromatogram of R-411.



Run Time = 31.99667 minutes

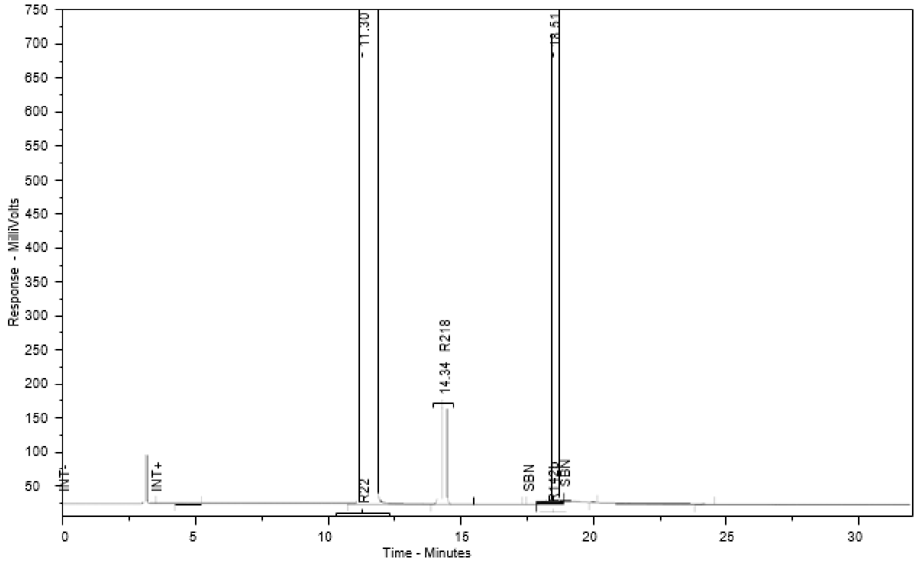
Data Sampling Rate = 5 points/sec

Ret. Time	Component
9.49	R152a
11.28	R22
15.41	1270
17.76	

Figure 43 Gas Chromatogram of R-411

D.37. Gas Chromatogram of R-412

Figure 44 shows the gas chromatogram of R-412.



Run Time = 31.99333 minutes

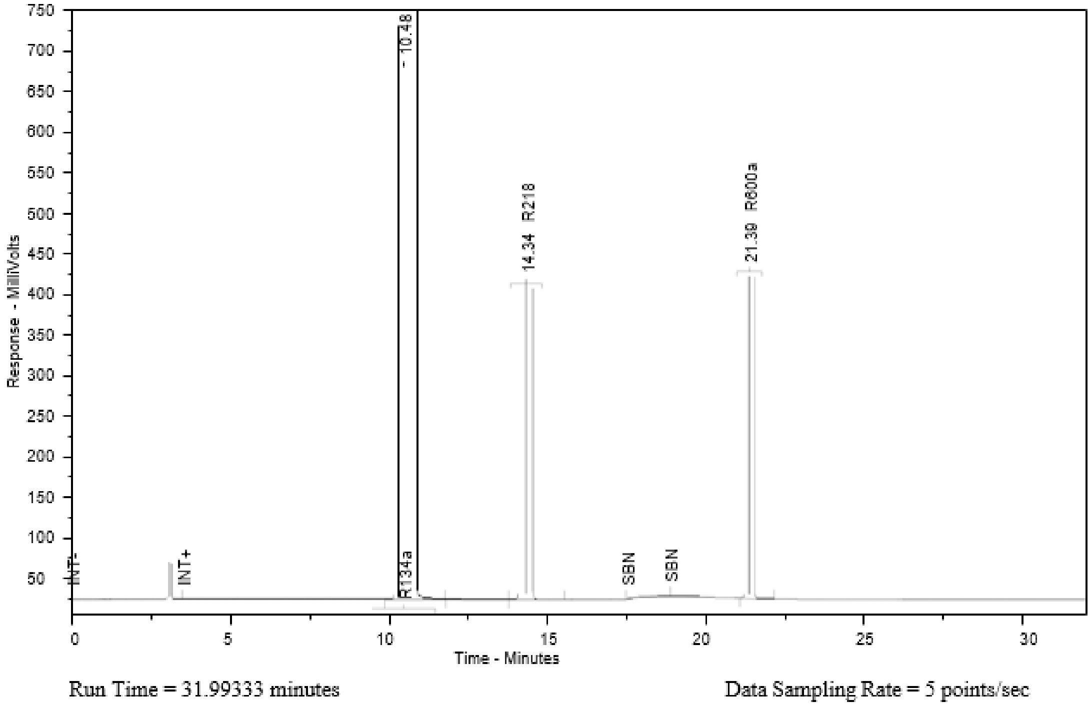
Data Sampling Rate = 5 points/sec

Ret. Time	Component
11.30	R22
14.34	R218
18.51	R142b

Figure 44 Gas Chromatogram of R-412

D.38. Gas Chromatogram of R-413

Figure 45 shows the gas chromatogram of R-413.

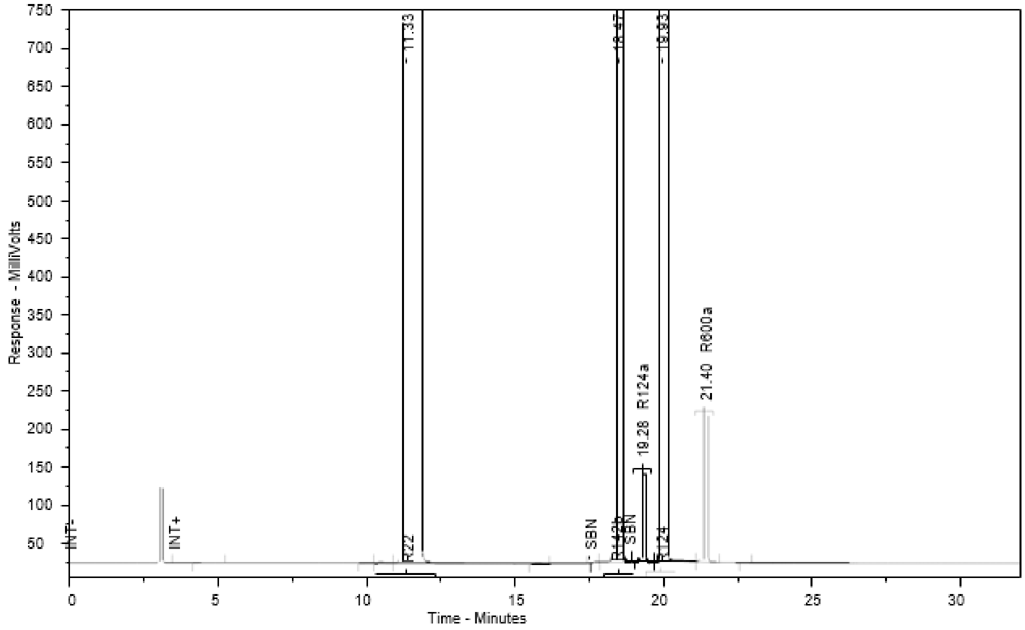


Ret. Time	Component
10.48	R134a
14.34	R218
21.39	R600a

Figure 45 Gas Chromatogram of R-413

D.39. Gas Chromatogram of R-414

Figure 46 shows the gas chromatogram of R-414.



Run Time = 31.99333 minutes

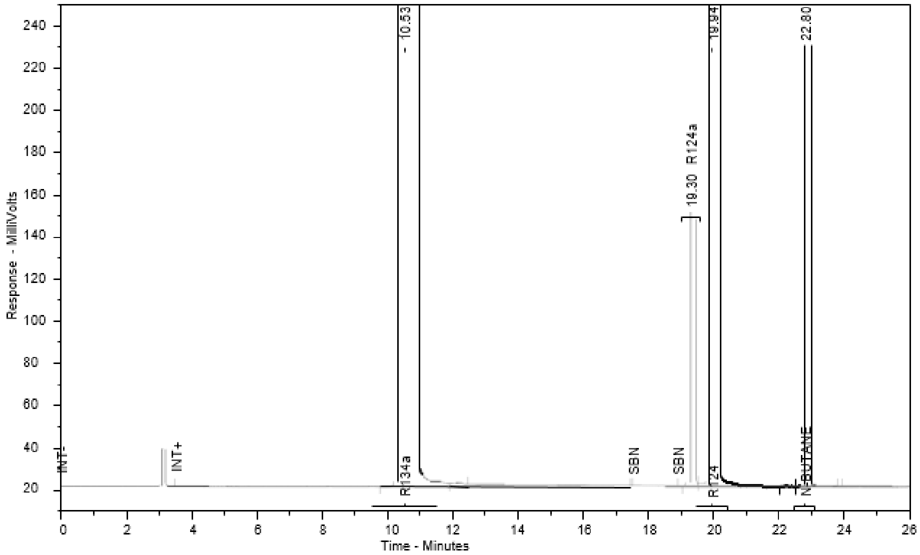
Data Sampling Rate = 5 points/sec

Ret. Time	Component
11.33	R22
18.47	R142b
19.28	R124a
19.93	R124
21.40	R600a

Figure 46 Gas Chromatogram of R-414

D.40. Gas Chromatogram of R-416

Figure 47 shows the gas chromatogram of R-416.



Run Time = 25.99667 minutes

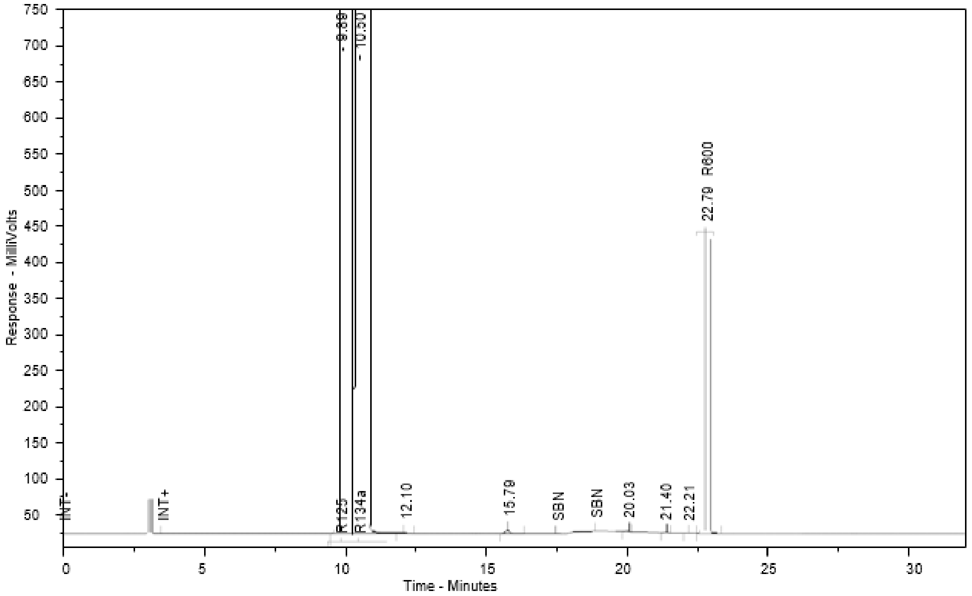
Data Sampling Rate = 5 points/sec

Ret. Time	Component
10.53	R134a
19.30	R124a
19.94	R124
22.80	N-BUTANE

Figure 47 Gas Chromatogram of R-416

D.41. Gas Chromatogram of R-417

Figure 48 shows the gas chromatogram of R-417.



Run Time = 31.99667 minutes

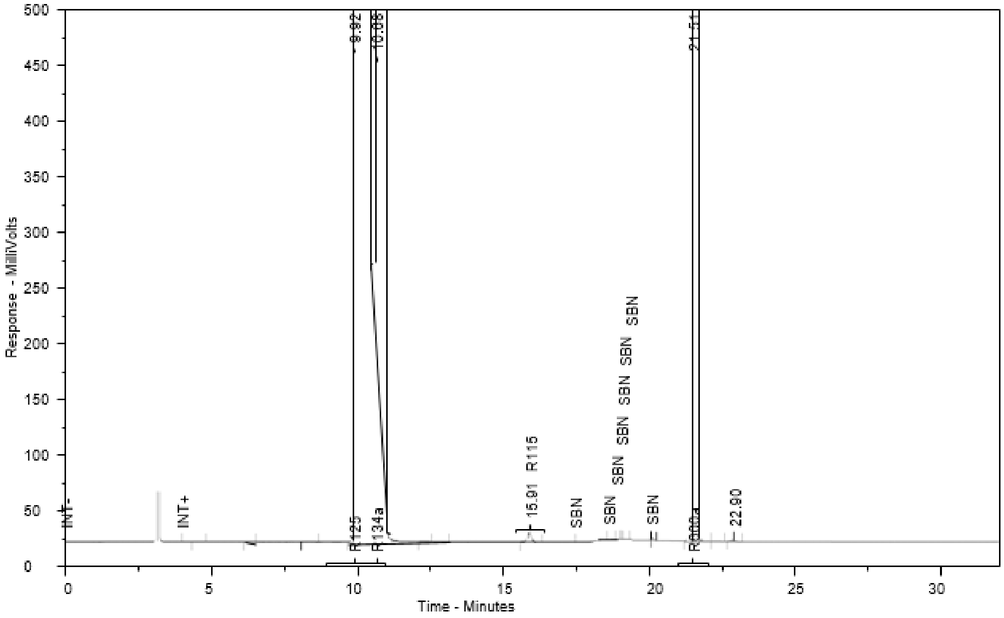
Data Sampling Rate = 5 points/sec

Ret. Time	Component
9.89	R125
10.50	R134a
12.10	
15.79	
20.03	
21.40	
22.21	
22.79	R600

Figure 48 Gas Chromatogram of R-417

D.42. Gas Chromatogram of R-422

Figure 49 shows the gas chromatogram of R-422.



Run Time = 31.99667 minutes

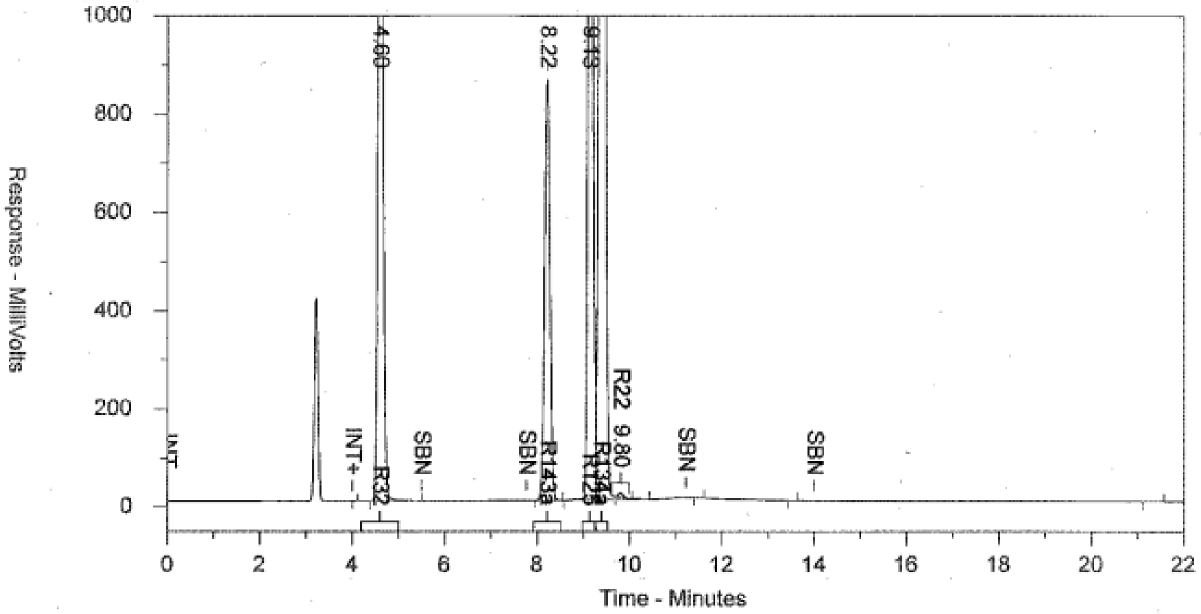
Data Sampling Rate = 5 points/sec

Ret. Time	Component
9.92	R125
10.68	R134a
15.91	R115
21.51	R600a
22.90	

Figure 49 Gas Chromatogram of R-422

D.43. Gas Chromatogram of R-427

Figure 50 shows the gas chromatogram of R-427.



Run Time = 21.99667

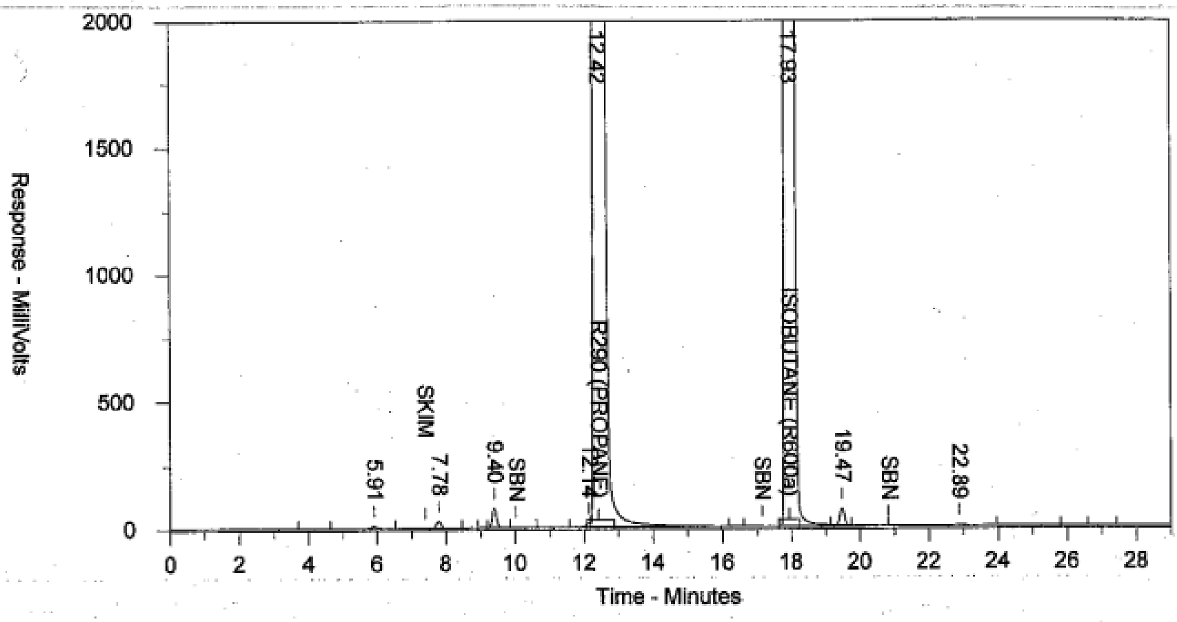
Data Sampling Rate = 5

Ret. Time	Component
4.60	R32
8.22	R143a
9.13	R125
9.38	R134a
9.80	R22

Figure 50 Gas Chromatogram of R-427

D.44. Gas Chromatogram of R-436

Figure 51 shows the gas chromatogram of R-436.



Run Time = 28.99333

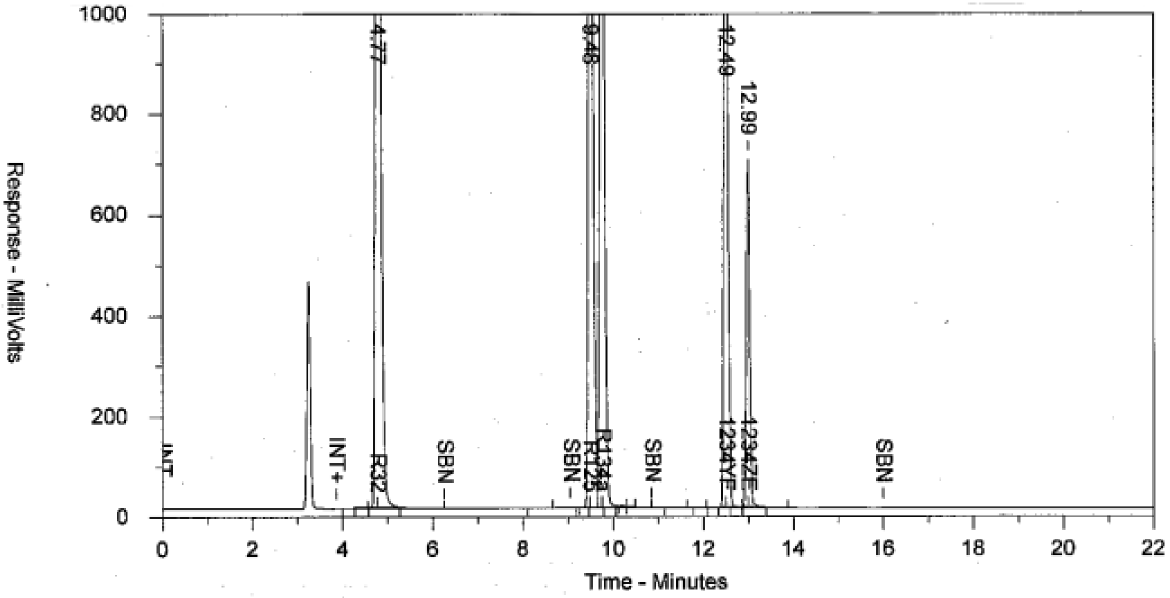
Data Sampling Rate = 5

Ret. Time	Component
5.91	
7.78	
9.40	
12.14	
12.42	R290 (PROPANE)
17.93	ISOBUTANE (R600a)
19.47	
22.89	

Figure 51 Gas Chromatogram of R-436

D.45. Gas Chromatogram of R-448

Figure 52 shows the gas chromatogram of R-448.



Run Time = 21.99667

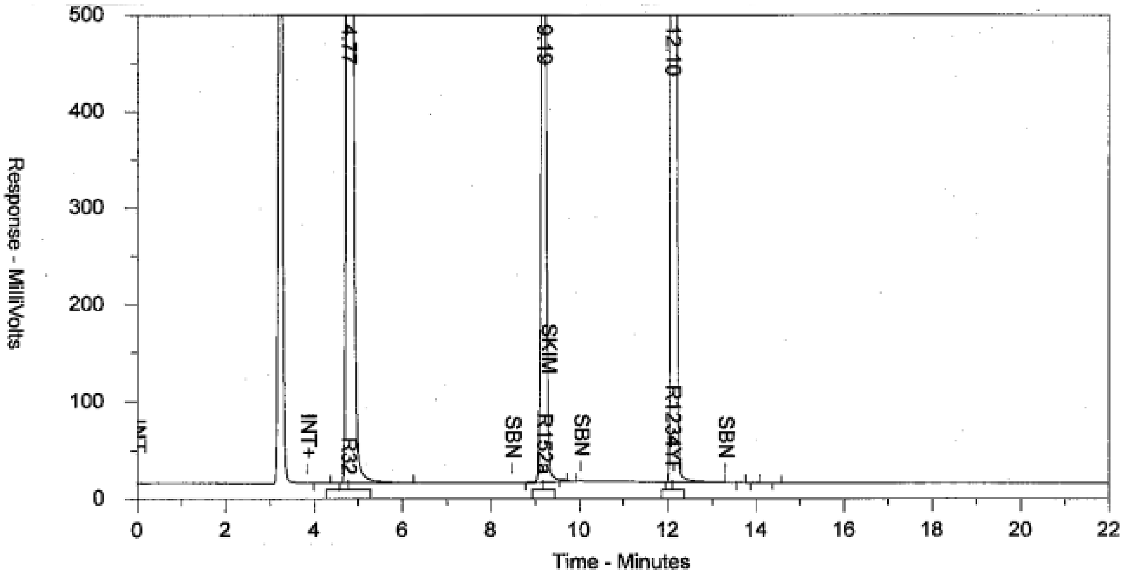
Data Sampling Rate = 5

Ret. Time	Component
4.77	R32
9.48	R125
9.75	R134a
12.49	1234YF
12.99	1234ZE

Figure 52 Gas Chromatogram of R-448

D.46. Gas Chromatogram of R-457

Figure 53 shows the gas chromatogram of R-457.



Run Time = 21.99333

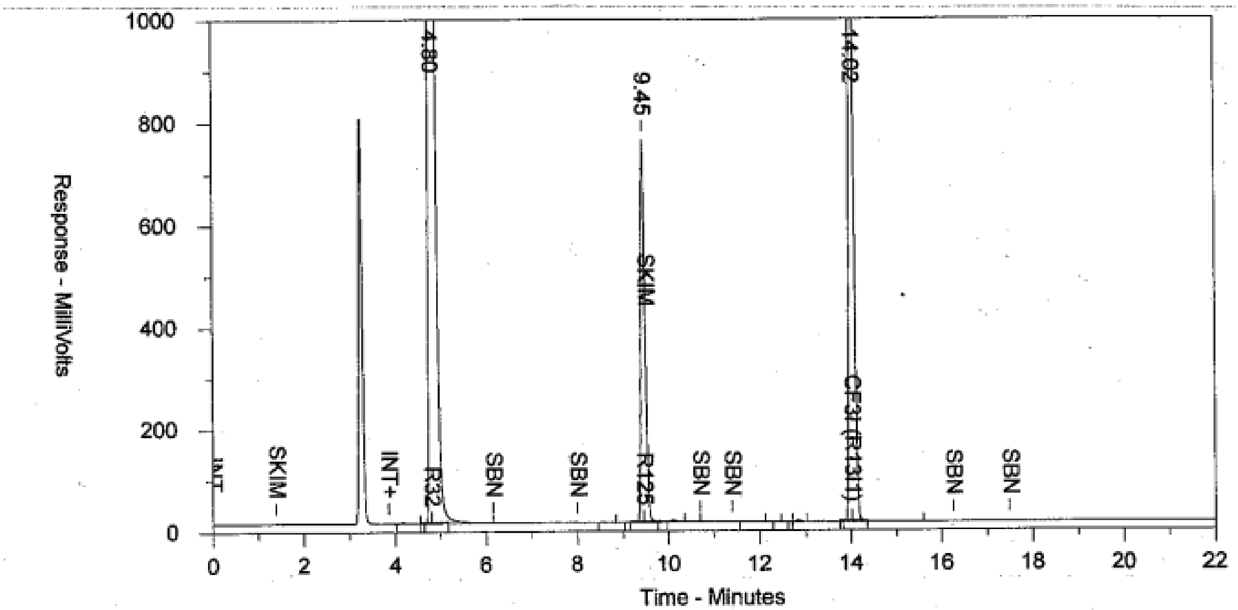
Data Sampling Rate = 5

Ret. Time	Component
4.77	R32
9.19	R152a
12.10	R1234YF

Figure 53 Gas Chromatogram of R-457

D.47. Gas Chromatogram of R-466

Figure 54 shows the gas chromatogram of R-466.



Run Time = 22

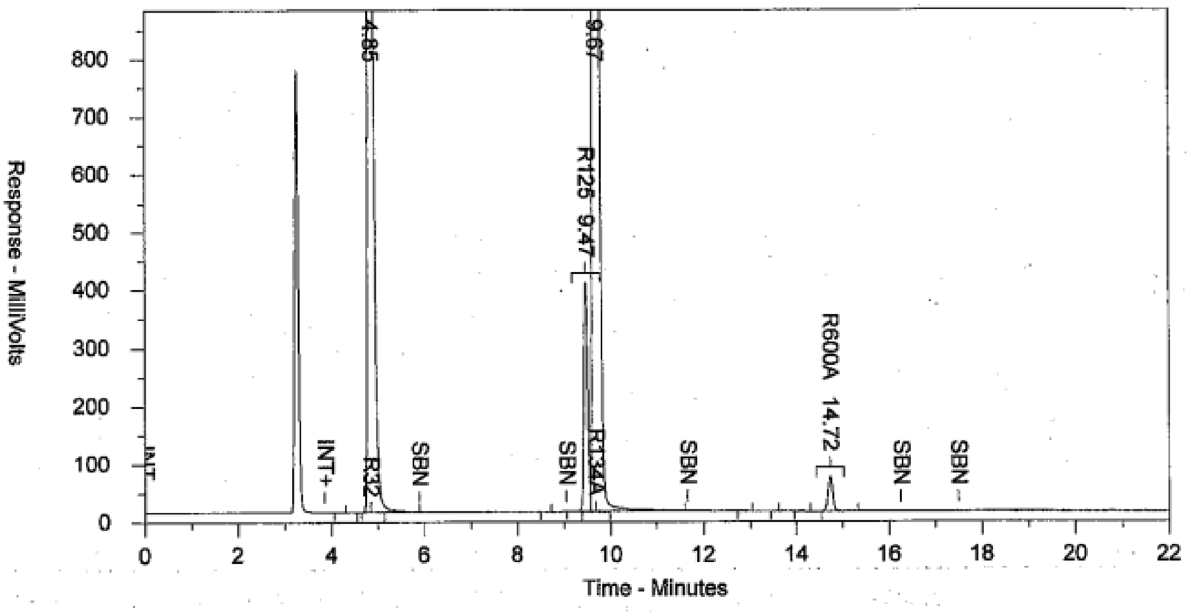
Data Sampling Rate = 5

Ret. Time	Component
4.80	R32
9.45	R125
14.02	CF3I (R13I1)

Figure 54 Gas Chromatogram of R-466

D.48. Gas Chromatogram of R-467

Figure 55 shows the gas chromatogram of R-467.



Run Time = 21.99333

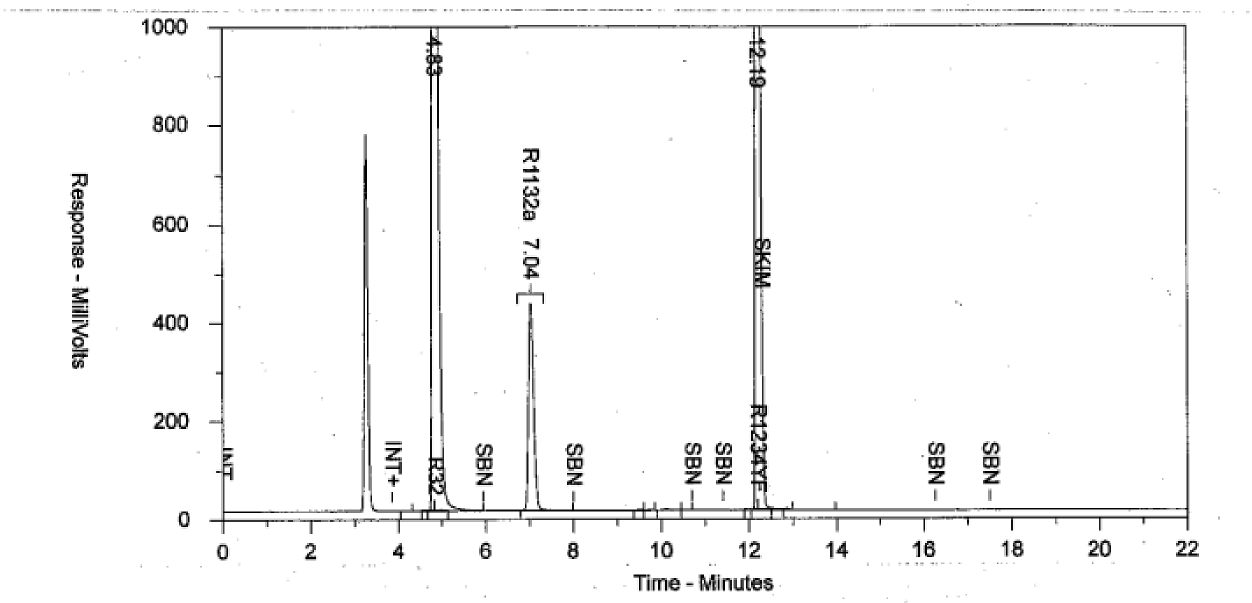
Data Sampling Rate = 5

Ret. Time	Component
4.85	R32
9.47	R125
9.67	R134A
14.72	R600A

Figure 55 Gas Chromatogram of R-467

D.49. Gas Chromatogram of R-468C

Figure 56 shows the gas chromatogram of R-468C.



Run Time = 21.99667

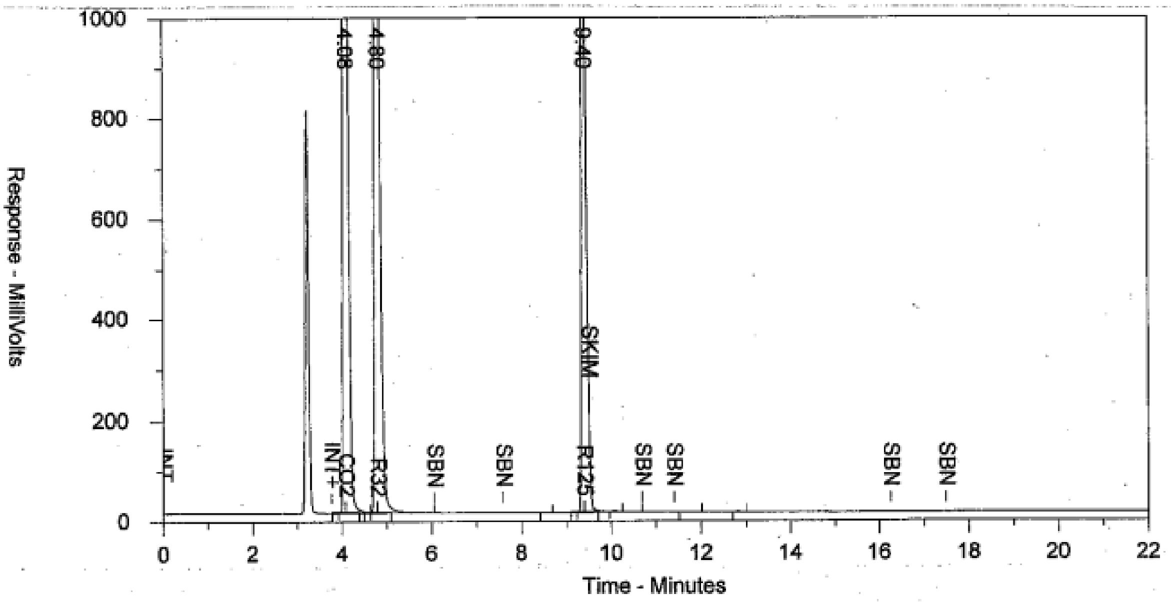
Data Sampling Rate = 5

Ret. Time	Component
4.83	R32
7.04	R1132a
12.19	R1234YF

Figure 56 Gas Chromatogram of R-468C

D.50. Gas Chromatogram of R-469

Figure 57 shows the gas chromatogram of R-469.



Run Time = 21.99333

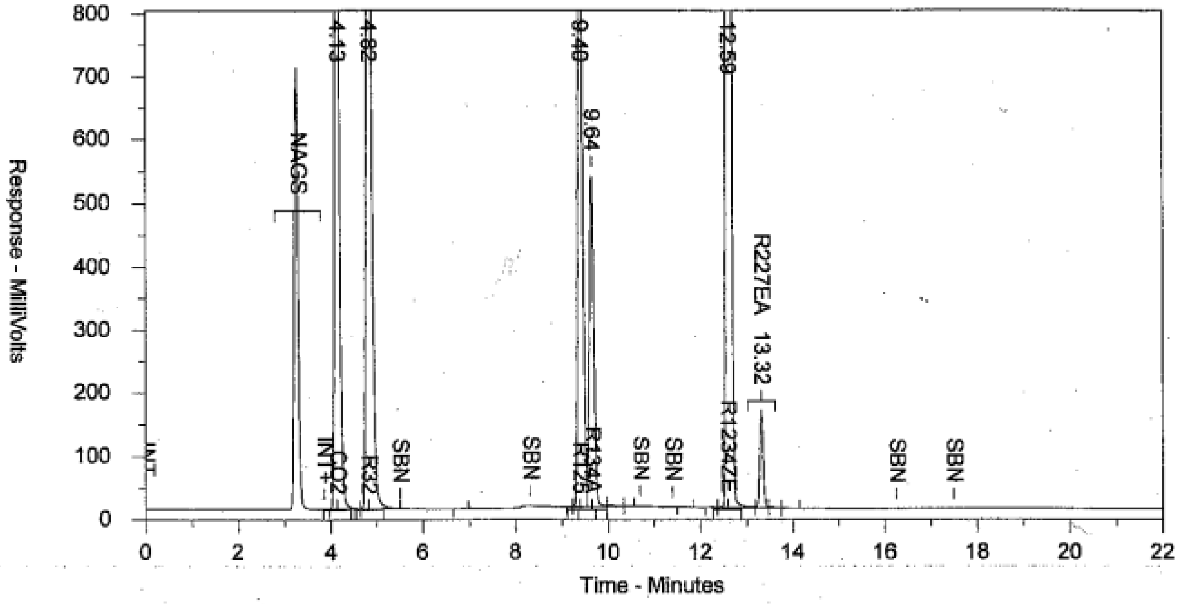
Data Sampling Rate = 5

Ret. Time	Component
4.08	CO2
4.80	R32
9.40	R125

Figure 57 Gas Chromatogram of R-469

D.51. Gas Chromatogram of R-470A

Figure 58 shows the gas chromatogram of R-470A.



Run Time = 21.99333

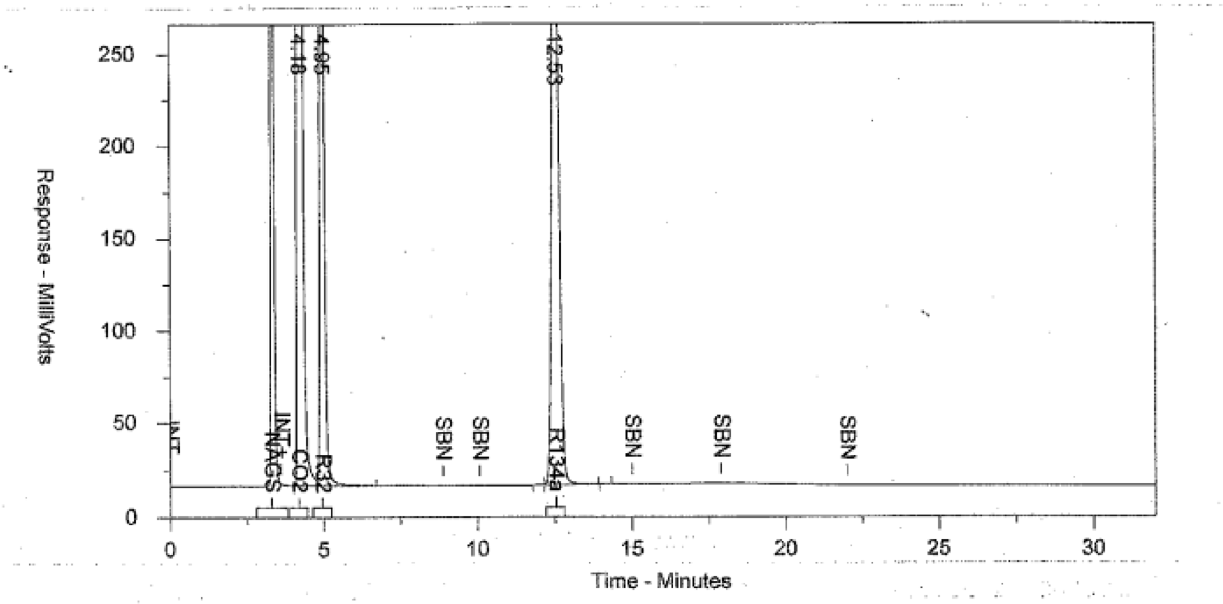
Data Sampling Rate = 5

Ret. Time	Component
4.13	CO2
4.82	R32
9.40	R125
9.64	R134A
12.59	R1234ZE
13.32	R227EA

Figure 58 Gas Chromatogram of R-470A

D.52. Gas Chromatogram of R-472A

Figure 59 shows the gas chromatogram of R-472A.



Run Time = 31.99333

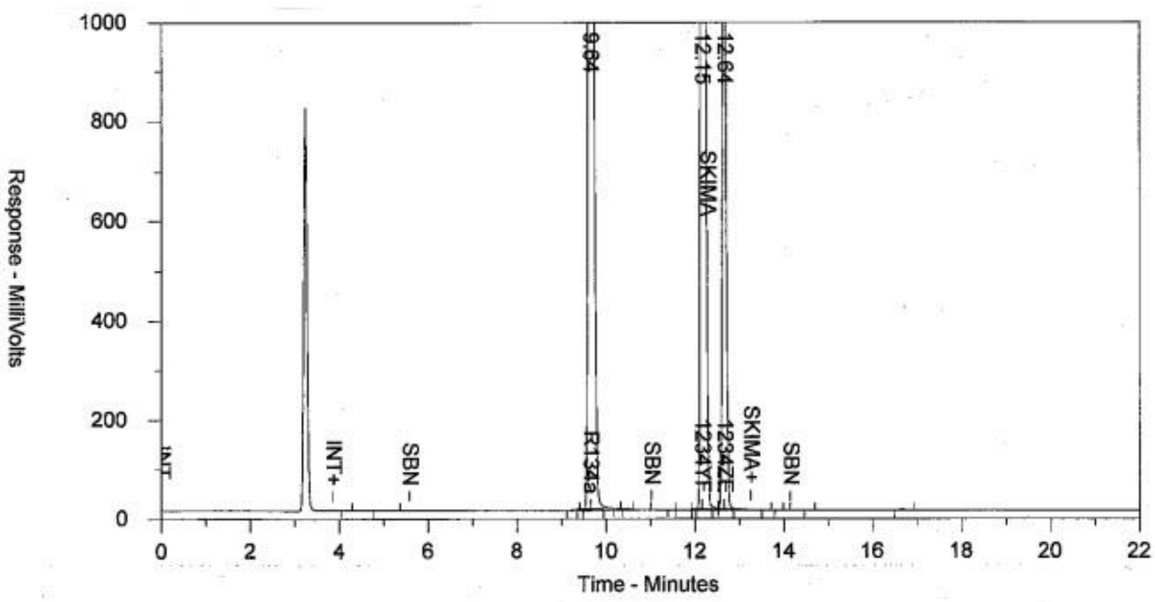
Data Sampling Rate = 5

Ret. Time	Component
4.18	CO2
4.95	R32
12.53	R134a

Figure 59 Gas Chromatogram of R-472A

D.53. Gas Chromatogram of R-475

Figure 60 shows the gas chromatogram of R-475.



Run Time = 21.99333

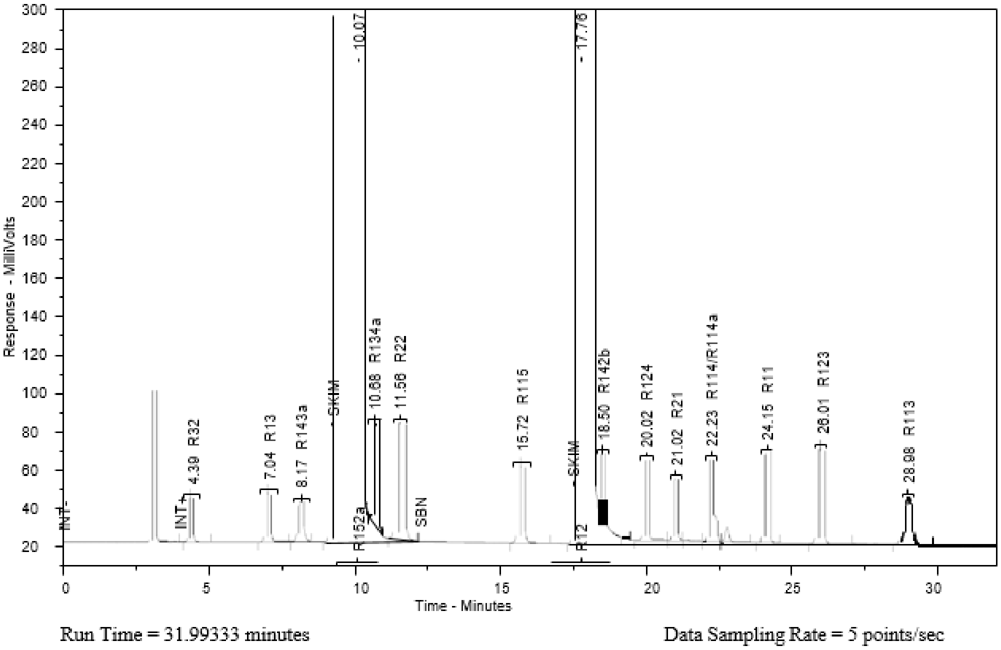
Data Sampling Rate = 5

Ret. Time	Component
9.64	R134a
12.15	1234YF
12.64	1234ZE

Figure 60 Gas Chromatogram of R-475

D.54. Gas Chromatogram of R-500

Figure 61 shows the gas chromatogram of R-500.

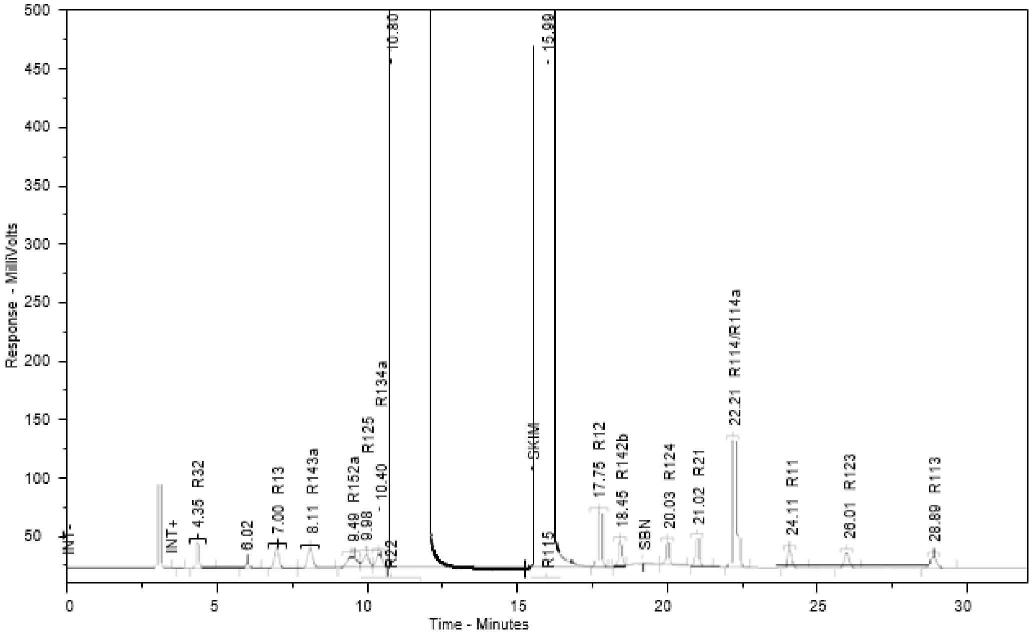


Ret. Time	Component
4.39	R32
7.04	R13
8.17	R143a
10.07	R152a
10.68	R134a
11.56	R22
15.72	R115
17.76	R12
18.50	R142b
20.02	R124
21.02	R21
22.23	R114/R114a
24.15	R11
26.01	R123
28.98	R113

Figure 61 Gas Chromatogram of R-500

D.55. Gas Chromatogram of R-502

Figure 62 shows the gas chromatogram of R-502.



Run Time = 31.99667 minutes

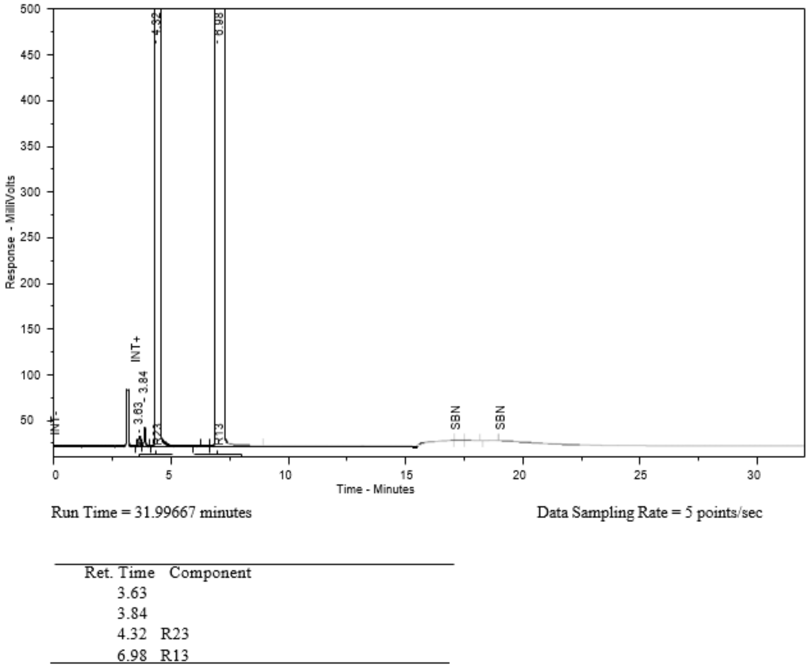
Data Sampling Rate = 5 points/sec

Ret. Time	Component
4.35	R32
6.02	
7.00	R13
8.11	R143a
9.49	R152a
9.98	R125
10.40	R134a
10.80	R22
15.99	R115
17.75	R12
18.45	R142b
20.03	R124
21.02	R21
22.21	R114/R114a
24.11	R11
26.01	R123
28.89	R113

Figure 62 Gas Chromatogram of R-502

D.56. Gas Chromatogram of R-503

Figure 63 shows the gas chromatogram of R-503.



Run Time = 31.99667 minutes

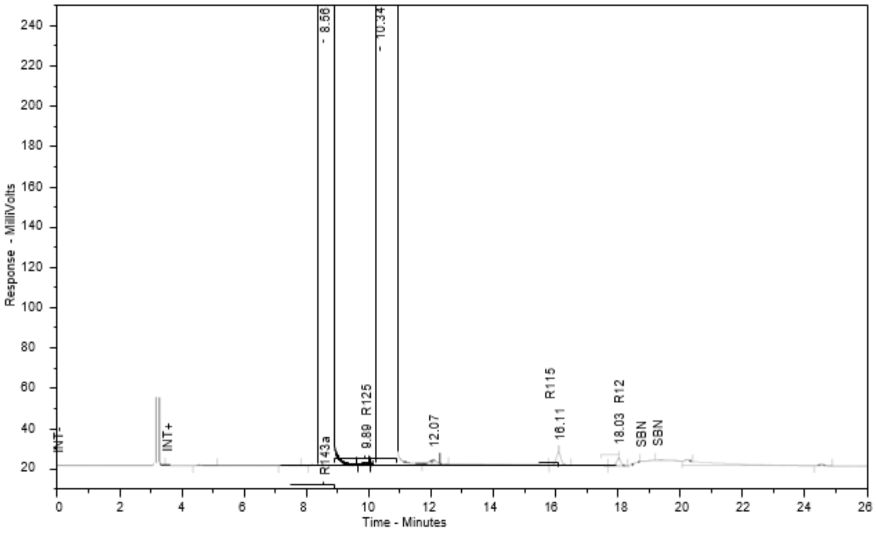
Data Sampling Rate = 5 points/sec

Ret. Time	Component
3.63	
3.84	
4.32	R23
6.98	R13

Figure 63 Gas Chromatogram of R-503

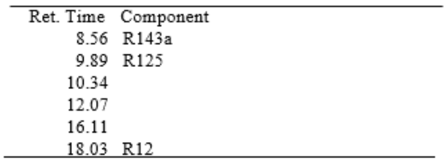
D.57. Gas Chromatogram of R-507

Figure 64 shows the gas chromatogram of R-507.



Run Time = 26 minutes

Data Sampling Rate = 5 points/sec

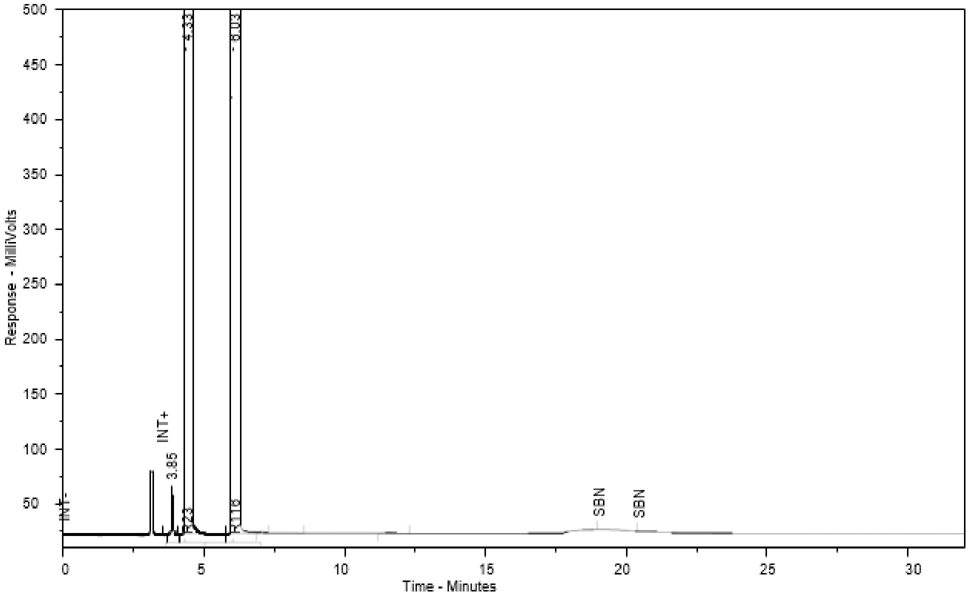


Ret. Time	Component
8.56	R143a
9.89	R125
10.34	
12.07	
16.11	
18.03	R12

Figure 64 Gas Chromatogram of R-507

D.58. Gas Chromatogram of R-508

Figure 65 shows the gas chromatogram of R-508.



Run Time = 32 minutes

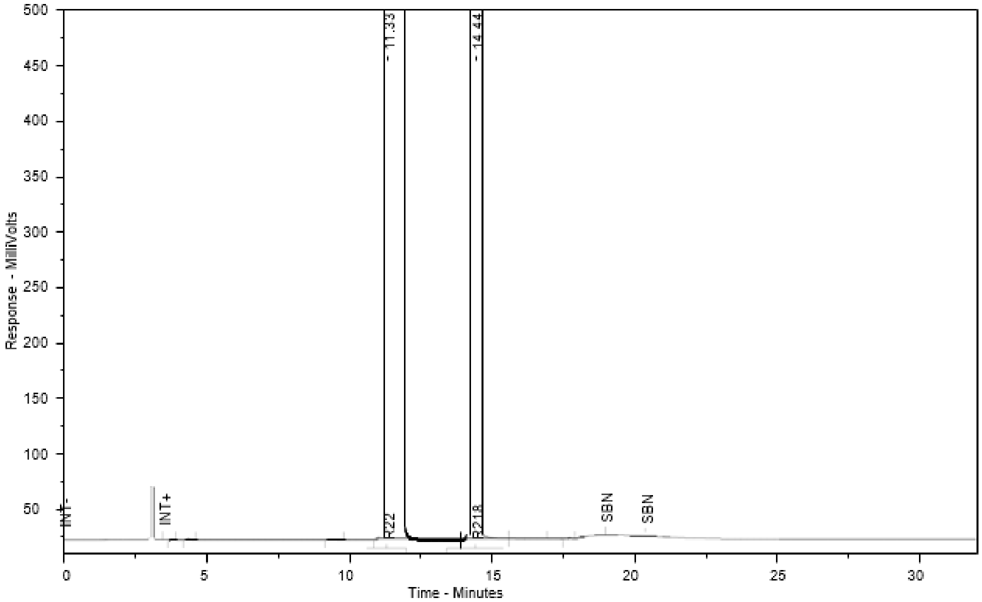
Data Sampling Rate = 5 points/sec

Ret. Time	Component
3.85	
4.33	R23
6.03	R116

Figure 65 Gas Chromatogram of R-508

D.59. Gas Chromatogram of R-509

Figure 66 shows the gas chromatogram of R-509.



Run Time = 31.99667 minutes

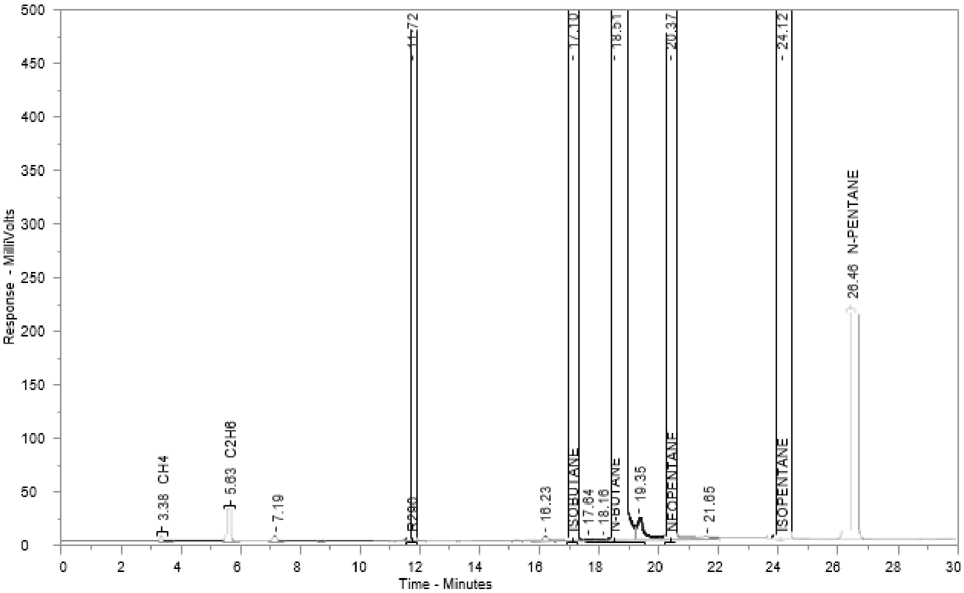
Data Sampling Rate = 5 points/sec

Ret. Time	Component
11.33	R22
14.44	R218
32.02	
32.54	
33.78	
34.11	

Figure 66 Gas Chromatogram of R-509

D.60. Gas Chromatogram of R-600

Figure 67 shows the gas chromatogram of R-600.



Run Time = 29.99 minutes

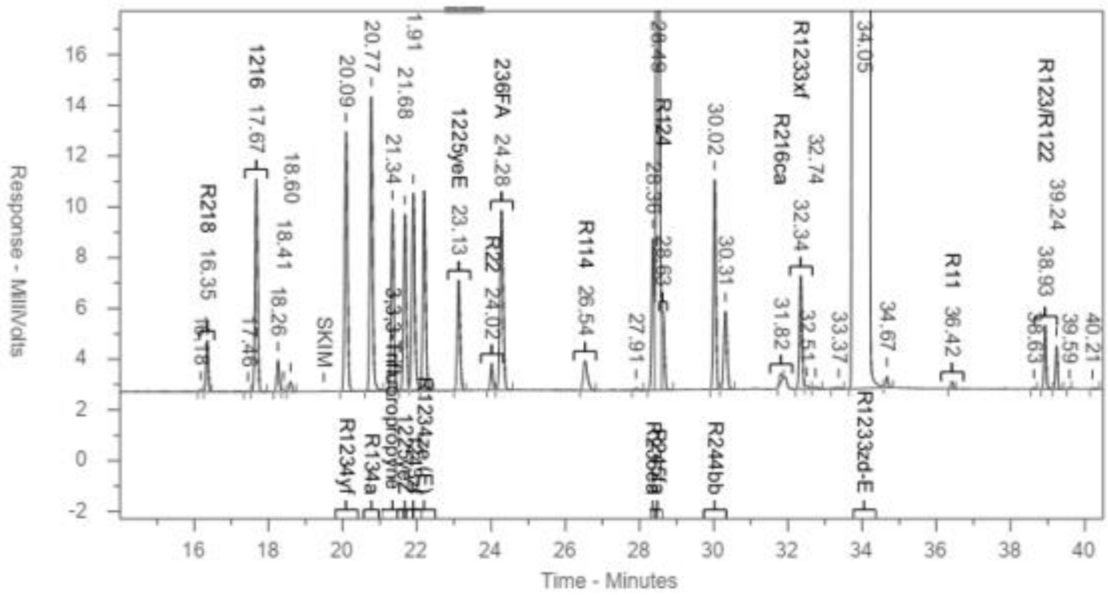
Data Sampling Rate = 5 points/sec

Ret. Time	Component
3.38	CH4
5.63	C2H6
7.19	
11.72	R290
16.23	
17.10	ISOBUTANE
17.64	
18.16	
18.51	N-BUTANE
19.35	
20.37	NEOPENTANE
21.65	
24.12	ISOPENTANE
26.46	N-PENTANE

Figure 67 Gas Chromatogram of R-600

D.61. Gas Chromatogram of R-1233zd

Figure 68 shows the gas chromatogram of R-1233zd.



Run Time = 40.49667 minutes

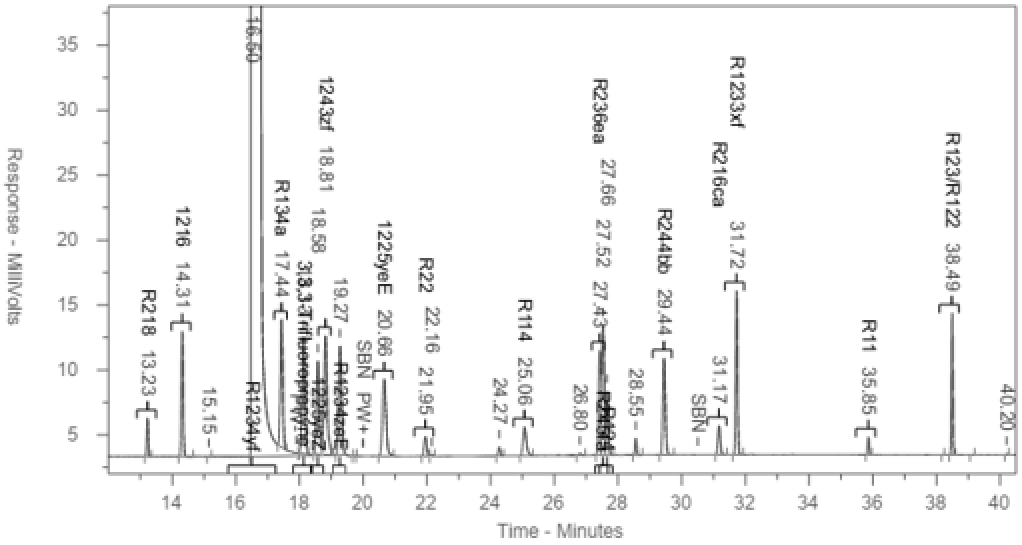
Data Sampling Rate = 5 points/sec

Ret. Time	Component
16.18	
16.35	R218
17.46	
17.67	1216
18.26	
18.41	
18.60	
20.09	R1234yf
20.77	R134a
21.34	3,3,3-Trifluoropropyne
21.68	1225yeZ
21.91	1243zf
22.20	R1234ze (E)
23.13	1225yeE
24.02	R22
24.28	236FA
26.54	R114
27.91	
28.36	R236ea
28.49	R245fa

Figure 68 Gas Chromatogram of R-1233zd

D.62. Gas Chromatogram of R-1234yf

Figure 69 shows the gas chromatogram of R-1234yf.



Run Time = 40.5 minutes

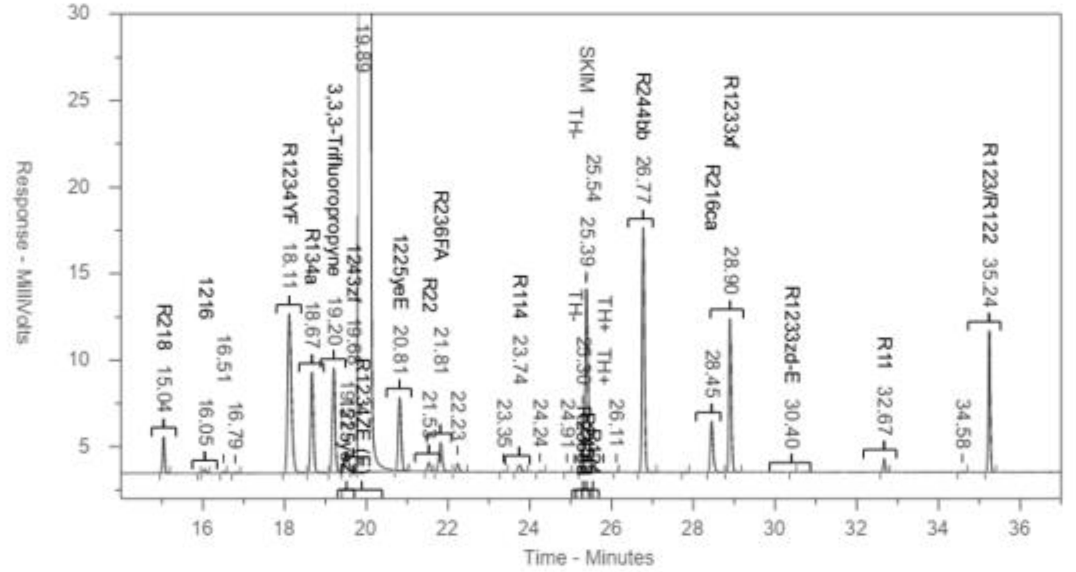
Data Sampling Rate = 10 points/sec

Ret. Time	Component
13.23	R218
14.31	1216
15.15	
16.50	R1234yf
17.44	R134a
18.13	3,3,3-Trifluoropropyne
18.58	1225yeZ
18.81	1243zf
19.27	R1234zeE
20.66	1225yeE
21.95	R22
22.16	
24.27	
25.06	R114
26.80	
27.43	R236ea
27.52	R245fa
27.66	R124
28.55	
29.44	R244bb

Figure 69 Gas Chromatogram of R-1234yf

D.63. Gas Chromatogram of R-1234ze

Figure 70 shows the gas chromatogram of R-1234ze.



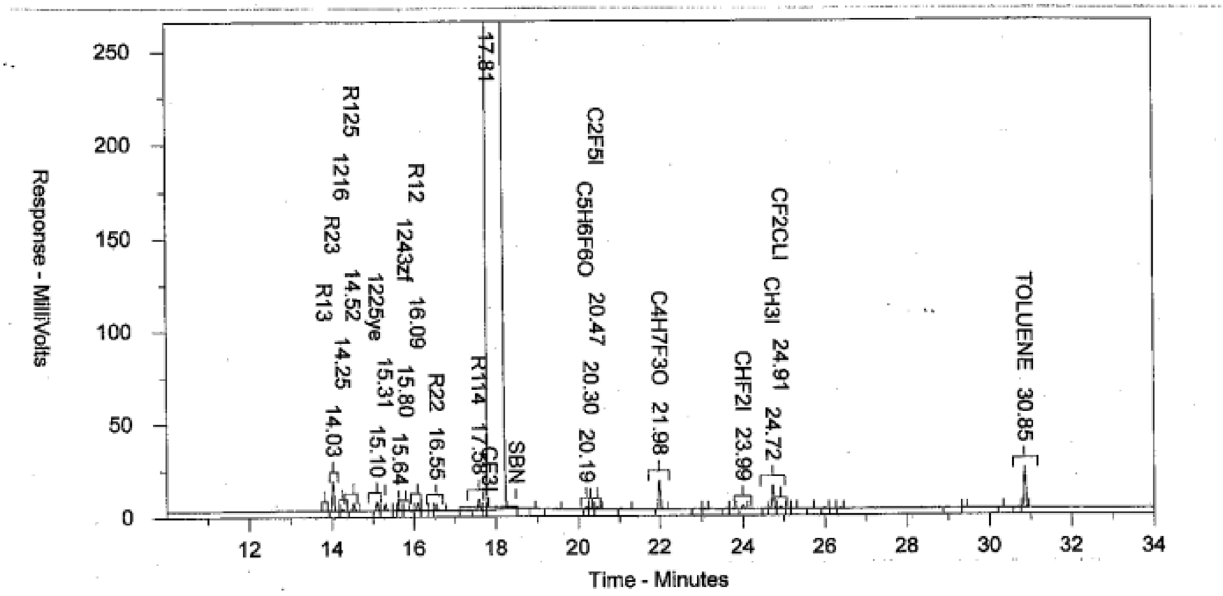
Run Time = 40.49667 Data Sampling Rate = 5 points/sec

Ret. Time	Area	Resp. F	Wt. %	Component
15.04	7593	9.375916E-07	0.0096	R218
16.05	1091	3.322259E-07	0.0005	1216
16.51	242	1.415021E-07	0.0000	
16.79	180	1.415021E-07	0.0000	
18.11	58685	2.184536E-07	0.0174	R1234YF
18.67	28786	2.313106E-07	0.0090	R134a
19.20	28136	1.495269E-07	0.0057	3,3,3-Trifluoropropyne
19.51	6939	3.793551E-07	0.0036	1225yeZ
19.68	1954	1.040583E-07	0.0003	1243zf
19.89	520800300	1.415021E-07	99.8424	R1234ZE (E)
20.81	20534	1.867106E-07	0.0052	1225yeE
21.53	2488	9.932808E-07	0.0033	R22
21.81	9441	1.024832E-07	0.0013	R236FA
22.23	2287	1.415021E-07	0.0004	
23.35	253	1.415021E-07	0.0000	
23.74	2541	1.354606E-06	0.0047	R114
24.24	356	1.415021E-07	0.0001	
24.91	149	1.415021E-07	0.0000	
25.30	12313	6.028471E-07	0.0101	R236ea
25.39	52881	2.614092E-07	0.0187	R245fa

Figure 70 Gas Chromatogram of R-1234ze

D.64. Gas Chromatogram of R-13I1

Figure 71 shows the gas chromatogram of R-13I1.



Run Time = 33.995

Data Sampling Rate = 10

Ret. Time	Component
14.03	R23
14.25	1216
14.52	R125
15.10	1225ye
15.31	
15.64	
15.80	1243zf
16.09	R12
16.55	R22
17.58	R114
17.81	CF3I
20.19	C5H6F6O
20.30	
20.47	C2F5I
21.98	C4H7F3O
23.99	CHF2I
24.72	CH3I
24.91	CF2CLI
30.85	TOLUENE

Figure 71 Gas Chromatogram of R-13I1