

TITLE OF THE INVENTION

RECOVERY, RECYCLE, AND REUSE OF THERMAL FLUIDS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority of U.S. Provisional Application 63/541,524 filed September 29, 2023, and U.S. Provisional Application 63/564,035 filed March 12, 2024, the disclosure of each of which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present disclosure relates to systems and processes of thermal fluid recovery, recycle, and reuse. More specifically, the present disclosure relates to systems and processes of recovery, recycle, and reuse of spent single, azeotropic, near azeotropic or zeotropic thermal fluids onsite.

BACKGROUND OF THE INVENTION

[0003] Thermal fluid or refrigerant reclamation has long attracted significant attention due to regulatory requirements and increasing emphasis on circularity, emissions reduction, and resource efficiency. An efficient and effective reclamation process benefits both the environment and the global economy. Indeed, in the absence of such a reclamation process, the thermal fluids would have to be destroyed or otherwise disposed of, such as by thermal oxidation, which is very energy intensive and results in a loss of product to the circular economy.

[0004] One common area of thermal fluid on-site recycling is automotive refrigerant. Due to environmental pressures, the current predominant automotive refrigerant, 1,1,1,2-tetrafluoroethane ($\text{CF}_3\text{-CH}_2\text{F}$; HFC-134a), a hydrofluorocarbon (HFC), is being phased out in favor of lower global warming potential (GWP) refrigerants with $\text{GWP} < 150$. The hydrofluoroolefin (HFO) 2,3,3,3-tetrafluoropropene ($\text{CF}_3\text{-CF=CH}_2$; HFO-1234yf) meets the low GWP requirement, but it has a slightly different boiling point versus the incumbent refrigerant, HFC-134a. The boiling point of HFC-134a is -26.074°C and the boiling point of HFO-1234yf is -29.485°C per REFPROP version 10.0.

[0005] Historically, on-site refrigerant recovery has been limited to single-compound fluids. Used or spent automotive refrigerant is conventionally collected from vehicles at an automobile service shop or automobile dealership and sent off-site for reclamation. Reclamation requires sending the used or spent refrigerants to a reclamation site for further processing, including purification, removal of non-absorbable gases (NAG), residual oils, moisture and composition adjustments for blends.

[0006] During the reclamation process, the used or spent refrigerants are often combined in a mixed tank at the reclamation site. To obtain pure components, a large distillation system containing at least one distillation column may be required, in addition to technical processes such as fractional distillation or extraction distillation, all of which may be energy-intensive, labor-intensive, and time-consuming. Furthermore, refrigerant reclamation may inadvertently increase life cycle CO₂ emissions due to fugitive process emissions or transportation emissions.

[0007] Therefore, onsite recovery has many advantages when used for automotive systems and stationary systems versus off-site reclamation. SAE has provided and continues to provide guidance on how to ensure adequate quality of recovered, recycled refrigerant for recharging in automotive systems through the SAE J standards. SAE has been a keystone in the circular economy by developing and recovery, recycle, recharge (RRR) equipment that negates the need to collect refrigerant and ship to off-site location for processing. RRR machines are widely used and accepted as an automotive industry best practice.

[0008] Recently there were instances of recovered, recycled refrigerant, that met SAE J standard quality but contained a polymeric contaminant due to excessive air and/or peroxide contaminants. The instant invention solves certain problems associated with on-site RRR of thermal fluids by employing an additive that increases the fluid stability and further enables the fluids to be used with traditional and modified on-site RRR equipment.

SUMMARY OF THE INVENTION

[0009] In an example embodiment, a process of thermal fluid recovery, recycle, and reuse includes recovering a thermal fluid including at least one refrigerant

compound from at least one thermal management device as a recovered thermal fluid. Examples of the thermal management device include, but are not limited to, automotive or stationary heat pump systems, automotive or stationary refrigeration systems, and automotive or stationary air conditioning systems. In one embodiment, the process is preferably utilized in connection with automotive heat pump or automotive air conditioning systems.

[0010] The process also includes recycling the recovered thermal fluid. The recycling includes testing the recovered thermal fluid for composition and level of impurities. The recycling also includes purifying the recovered thermal fluid to reduce the level of impurities as needed and adjusting the composition of the recovered thermal fluid as needed to provide a recycled thermal fluid meeting predetermined purity and composition criteria for a predetermined thermal fluid type. The recycling further includes validating that the recycled thermal fluid has greater than about 95 wt%, about 96 wt%, about 97 wt%, about 98 wt%, about 99 wt%, or about 99.5 wt% organic purity. The process further includes reusing the thermal fluid. The reusing includes charging the recycled thermal fluid to a thermal management device. The process occurs onsite.

[0011] Other features and advantages of the present invention will be apparent from the following more detailed description, taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 schematically shows a recovery, recycle, and reuse system in an embodiment of the present disclosure.

[0013] Wherever possible, the same reference numbers will be used throughout the drawings to represent the same parts.

DETAILED DESCRIPTION OF THE INVENTION

[0014] In exemplary embodiments, an integrated business and engineering process effectively and efficiently recovers used or spent thermal fluids and recycles

and reuses the thermal fluids onsite. The reuse may be for a use similar to or different from the use prior to recovery.

[0015] As used herein, "refrigerant compound" refers to any fluorocarbon (FC), hydrofluorocarbon (HFC), hydrochlorofluorocarbon (HCFC), chlorofluorocarbon (CFC), hydrofluoroolefin (HFO), chlorofluoroolefin (CFO), hydrochlorofluoroolefin (HCFO), hydrocarbon (HC), or carbon dioxide (R-744) that may be used alone or in a blend with other refrigerant compounds as a thermal fluid.

[0016] As used herein, "near-azeotrope" or "azeotrope-like" refer to a composition of two or more refrigerant compounds that behaves like an azeotropic composition (i.e., has constant boiling characteristics or a tendency not to fractionate upon boiling or evaporation). Hence, during boiling or evaporation, the vapor and liquid compositions, if they change at all, change only to a minimal or negligible extent. In contrast, the vapor and liquid compositions of non-azeotrope-like compositions change to a substantial degree during boiling or evaporation. As used herein, "near-azeotrope" refers to a composition exhibiting near-azeotrope behavior.

[0017] As used herein, "near-azeotrope behavior" refers to a behavior exhibiting dew point pressure and bubble point pressure with virtually no pressure differential. In some embodiments, the difference in the dew point pressure and bubble point pressure at a given temperature is 10% or less, alternatively 9% or less, alternatively 8% or less, alternatively 7% or less, alternatively 6% or less, alternatively 5% or less, alternatively 4% or less, alternatively 3% or less, alternatively 2% or less, alternatively 1% or less, or any value, range, or sub-range therebetween.

[0018] As used herein, "thermal fluid" refers to any fluid used for heat transfer in a closed-loop system.

[0019] As used herein, "used thermal fluid" refers to a thermal fluid composition having at least about 95 wt% organic purity, preferably at least about 99 wt% organic purity, most preferably at least about 99.5 wt% organic purity, and that has been used as a thermal fluid.

[0020] As used herein, "spent thermal fluid" refers to a thermal fluid composition having less than about 95 wt% organic purity, preferably less than about 99 wt%

organic purity, most preferably less than about 99.5 wt% organic purity, and that has been used as a thermal fluid.

[0021] As used herein, “recovery” refers to a process of collecting or extracting used or spent thermal fluid from a thermal management device, such as a stationary or automotive heat pump system, stationary or automotive refrigeration system or stationary or automotive air-conditioning system, preferably an automotive heat pump system or automotive air-conditioning system.

[0022] As used herein, “recovered thermal fluid” refers to a used or spent thermal fluid drained or otherwise removed from a thermal management device, such as, for example, a stationary or automotive heat pump system, stationary or automotive refrigeration system or stationary or automotive air-conditioning system, preferably an automotive heat pump system or automotive air-conditioning system.

[0023] As used herein, “recycling” refers to a process of converting a recovered thermal fluid to a reusable thermal fluid.

[0024] As used herein, “recycled thermal fluid” refers to a recovered thermal fluid composition, either as recovered or after purification or other processing, having at least about 95 wt% organic purity, preferably at least about 99 wt% organic purity, most preferably at least about 99.5 wt% organic purity and meeting conventional specifications for commercial use or sale as a thermal fluid.

[0025] As used herein, “reusing” refers to a process of supplying a recycled thermal fluid to a thermal management device, such as a stationary or automotive heat pump system, stationary or automotive refrigeration system or stationary or automotive air-conditioning system, preferably an automotive heat pump system or automotive air-conditioning system.

[0026] As used herein, “reused thermal fluid” refers to a recycled thermal product that has been put back into use in a thermal management device, such as a stationary or automotive heat pump system, stationary or automotive refrigeration system or stationary or automotive air-conditioning system, preferably an automotive heat pump system or automotive air-conditioning system, as a thermal fluid.

[0027] As used herein, “onsite” refers to a single site such that a transportation vehicle is not required between recovering, recycling, and reusing.

[0028] As used herein, “organic purity” refers to the degree to which a fluid or fluid composition is free of contaminants such as oil and inorganic materials, such as water, acid, non-absorbable gases (NAGs), particulates/solids, and the like.

[0029] As used herein, “purify” and other forms of that term such as “purification” or “purifying” refer to treating a fluid to separate oils, reduce moisture content and reduce acidity, in a system, such as a RRR machine, wherein the treatment process may optionally involve vapor recovery.

[0030] In some embodiments, “used thermal fluid”, “spent thermal fluid”, “recovered thermal fluid” and/or “recycled thermal fluid”, as used herein, refer to a thermal fluid composition as each is defined above, and optionally further comprising at least one stabilizer, particularly when the thermal fluid composition includes an HFO refrigerant compound, such as R-1234yf. In some embodiments, the stabilizer comprises at least one inhibitor compound that inhibits, if not eliminates, a fluoroethylene from interacting with another compound and forming dimers, oligomers, homopolymers, or polymeric products. In some embodiments, the at least one inhibitor is selected from hydrocarbons such as cyclic monoterpenes (e.g., limonene, pinene, α -pinene, β -pinene, and terpinene); lipophilic organic compounds such as tocopherols (e.g., α -tocopherol) or butylated hydroxytoluene (BHT); phenols or aromatic organic compounds having at least one chemical moiety $-C_6H_4(OH)$ (e.g., benzene-1,4-diol, 4-methoxyphenol); and mixtures thereof. Specific examples of inhibitor compounds may include at least one member selected from limonene (particularly D-limonene), α -terpinene, pinene, α -pinene, β -pinene, α -tocopherol, butylated hydroxytoluene (BHT), 4-methoxyphenol, benzene-1,4-diol, and mixtures thereof. In one embodiment, the thermal fluid composition of any of a “used thermal fluid”, “spent thermal fluid”, “recovered thermal fluid” and/or “recycled thermal fluid”, each as defined above, comprises R-1234yf and at least one stabilizer comprising at least one inhibitor selected from hydrocarbons including at least cyclic monoterpene; lipophilic organic compounds; or phenols, aromatic organic compounds having at least one chemical moiety $-C_6H_4(OH)$, and more particularly selected from limonene (particularly D-limonene), α -terpinene, pinene, α -pinene, β -pinene, α -tocopherol,

butylated hydroxytoluene (BHT), 4-methoxyphenol, benzene-1,4-diol, and mixtures thereof.

[0031] In another embodiment, the stabilizer comprises an acid scavenger, such as, but not limited to, hindered amines and epoxy compounds such as epoxy butene. In one embodiment, the thermal fluid composition of any of a “used thermal fluid”, “spent thermal fluid”, “recovered thermal fluid” and/or “recycled thermal fluid”, each as defined above, comprises at least one refrigerant compound, such as an HFO refrigerant compound, and at least one stabilizer comprising at least one acid scavenger, such as, but not limited to, hindered amines and epoxy compounds such as epoxy butene.

[0032] Further details of the optional stabilizer are provided herein.

[0033] FIG. 1 shows a recovery, recycle, and reuse system for recovering, recycling, and reusing a thermal fluid onsite from a thermal management device 10. Examples of the thermal management device 10 include, but are not limited to, automotive or stationary heat pump systems, automotive or stationary refrigeration systems, and automotive or stationary air conditioning systems. In one embodiment, the thermal management device 10 is preferably an automotive heat pump system or automotive air conditioning system.

[0034] In one embodiment, the system of FIG. 1 may be a Recover, Recycle, Recharge (RRR) machine. The thermal fluid 12 including at least one refrigerant compound is recovered from the thermal management device 10. The recovered thermal fluid 12 may then be tested 14 for composition and purity of the fluid. For example, in one embodiment, the recovered thermal fluid 12 may optionally be sent to a refrigerant identifier 14, which may be either integrated into the system (e.g., RRR machine) or may be a stand-alone device preferably located onsite.

[0035] If the composition of the recovered thermal fluid 12 is determined to be of a first thermal fluid type and of sufficient purity, it is permitted to be recycled. In one embodiment, during the conveyance, the recycled fluid is optionally conveyed through an oil separator (not shown) which separates out the oil to levels <500 ppm oil. The fluid may also optionally be sent through a drier (not shown) such the

resulting moisture is <50 ppm. The final recycled fluid 18 is sent to a first recycled fluid tank 16.

[0036] If the composition of the recovered thermal fluid 12 is determined to be of the first thermal fluid type and of insufficient purity, it is sent to a first recovered fluid tank 20, as a recovered first thermal fluid 22. The recovered first thermal fluid 22 may be reclaimed. In one embodiment, the recovered first thermal fluid 22 may be circulated through the system (e.g., an RRR machine) until the desired purity is achieved. For example, the recovered first thermal fluid 22 in the first recovered fluid tank 20 may be purified 24 and retested 26 for sufficient purity either to go back to the first recovered fluid tank 20 as recovered first thermal fluid 22 or to the first recycled fluid tank 16 as first recycled thermal fluid 18. It will be understood by those skilled in the art that the inclusion of separate tanks 20 and 16 for the recovered first thermal fluid 22 and the first recycled thermal fluid 18, respectively, is optional, as the purification and retesting (i.e., reclamation) may occur in a single tank or device 14.

[0037] Alternatively, in another embodiment, the recovered first thermal fluid 22 may be sent off-site for reclamation.

[0038] If the first type of thermal fluid is a blend of more than one refrigerant compound, adjustments to the composition of the thermal fluid may be made by addition of one or more refrigerant compounds at any point to meet the thermal fluid type composition. The first recycled thermal fluid 18 in the first recycled fluid tank 16 may be further tested, purified, or adjusted 28 prior to becoming first reused thermal fluid 30 supplied to a thermal management device 32. Thermal management device 32 may be the same or different than thermal management device 10.

[0039] If the composition of the recovered thermal fluid 12 is determined to be of a second thermal fluid type and of sufficient purity, it is sent to a second recycled fluid tank 36 as a second recycled thermal fluid 38. For example, the first thermal fluid type may be a first type of refrigerant compound or blend thereof (e.g., HFC-134a or a HFC-134a azeotropic, near azeotropic or zeotropic blend) and the second thermal fluid type may be a second type of refrigerant compound or blend thereof (e.g., HFO-1234yf or a HFO-1234yf azeotropic, near azeotropic or zeotropic blend).

[0040] If the composition of the recovered thermal fluid 12 is determined to be of the second thermal fluid type and of sufficient purity, it is permitted to be recycled. In one embodiment, during the conveyance, the recycled fluid is optionally conveyed through an oil separator (not shown) which separates out the oil to levels <500 ppm oil. The fluid may also optionally be sent through a drier (not shown) such the resulting moisture is <50 ppm. The final recycled fluid 38 is sent to a second recycled fluid tank 36.

[0041] If the composition of the recovered thermal fluid 12 is determined to be of the second thermal fluid type and of insufficient purity, it is sent to a second recovered fluid tank 40 as recovered second thermal fluid 42. The recovered second thermal fluid 42 may then be reclaimed. In one embodiment, the recovered second thermal fluid 42 may be circulated through the system (e.g., RRR machine) until the desired purity is achieved. For example, second recovered thermal fluid 42 in the second recovered fluid tank 40 may be purified 44 and retested 46 for sufficient purity either to go back to the second recovered fluid tank 40 as second recovered thermal fluid 42 or to the second recycled fluid tank 36 as second recycled thermal fluid 38. It will be understood by those skilled in the art that the inclusion of separate tanks 40 and 36 for the recovered first thermal fluid 42 and the first recycled thermal fluid 38, respectively, is optional, as the purification and retesting (i.e., reclamation) may occur in a single tank or device 14.

[0042] If the second type of thermal fluid is a blend of more than one refrigerant compound, adjustments to the composition of the thermal fluid may be made by addition of one or more refrigerant compounds at any point to meet the thermal fluid type composition. The second recycled thermal fluid 38 in the second recycled fluid tank 36 may be further tested, purified, or adjusted 48 prior to becoming second reused thermal fluid 50 supplied to a thermal management device 52. Thermal management device 52 may be the same or different than thermal management device 10.

[0043] Although the system of FIG. 1 is configured to receive two different types of thermal fluids, other systems may receive one type or three or more types of thermal fluids.

[0044] In some embodiments, the thermal fluid is recovered from the heat pump system or air-conditioning system of a vehicle or a thermal management device of a portable or transportable system.

[0045] In some embodiments, the vehicle is an automobile and the recovery, recycle, and reuse system is located at an automobile service shop or automobile dealership.

[0046] In some embodiments, the thermal fluid type is of a refrigerant compound. Appropriate refrigerant compounds for systems and methods of the present disclosure may include, but are not limited to, R-11; R-12; R-13; R-22; R-23; R-32; R-50; R-113; R-114; R-115; R-116; R-123; R-124; R-125; R-134a; R-134; R-141b; R-142b; R-143a; R-152a; R-170; R-218; R-227ea; R-236fa; R-245fa; R-290; R-600; R-600a; R-601; R-601a; R-610; R-1130(E); R-1132(E); R-1132(Z); R-1336mzz(E); R-1233zd(E); R-1233zd(Z); R-1233xf; R-1234yf; R-1234ze(Z); R-1234ze(E); R-1252zc; R-1243yc; R-1270; and R-1336mzz(Z). In some embodiments, the thermal fluid comprises <5000 ppm, <2000 ppm, <1000 ppm, <500 ppm, <100 ppm, <50 ppm, <10 pm, or <5 ppm, or <1 ppm of HFO-Z-1132.

[0047] These refrigerants are as referenced in the ANSI/American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 34 with Addenda, which is also incorporated by reference in its entirety herein. The compositions of certain blends can be found in "Factsheet 1: Update on New Refrigerants Designations and Safety Classifications", ASHRAE, April 2023 or at <https://www.ashrae.org/technical-resources/standards-and-guidelines/ashrae-refrigerant-designations>, which are also incorporated by reference in its entirety herein.

[0048] In some embodiments, the refrigerant compound is R-134a.

[0049] In some embodiments, the refrigerant compound is R-1234yf.

[0050] In some embodiments, the refrigerant compound is dichlorodifluoromethane (CCl₂F₂; R-12).

[0051] In some embodiments, the refrigerant compound is 1,3,3,3-tetrafluoropropene (CF₃-CH=CHF; R-1234ze).

[0052] In some embodiments, the thermal fluid type is a zeotropic, near-azeotropic or azeotropic blend of two or more thermal fluids.

[0053] In some embodiments, the thermal fluid type includes one or more of the following refrigerant compounds: R-12, 2,2-dichloro-1,1,1-trifluoroethane ($\text{CF}_3\text{-CHCl}_2$; R-123), R-134a, R-134, 1,1-difluoroethane ($\text{CHF}_2\text{-CH}_3$; R-152a), R-227ea, (E)-1,2-dichloroethylene (CHCl=CHCl ; t-DCE, R-1130(E)), R-1234yf, R-1132(E), R-1132(Z), R-32, R-1233zd(E), R-1233zd(Z), R-1233xf, R-1224yd(Z), R-1224yd(E), (E)-1,3,3,3-tetrafluoropropene ($\text{CF}_3\text{-CH=CHF}$; R-1234ze(E)), (Z)-1,3,3,3-tetrafluoropropene ($\text{CF}_3\text{-CH=CHF}$; R-1234ze(Z)), (E)-1,1,1,4,4,4-hexafluoro-2-butene ($\text{CF}_3\text{-CH=CH-CF}_3$; R-1336mzz(E)), or (Z)-1,1,1,4,4,4-hexafluoro-2-butene ($\text{CF}_3\text{-CH=CH-CF}_3$; R-1336mzz(Z)). In some embodiments, the thermal fluid comprises <5000 ppm, <2000 ppm, <1000 ppm, <500 ppm, <100 ppm, <50 ppm, <10 ppm, or <5 ppm, or <1 ppm of HFO-Z-1132.

[0054] Appropriate zeotropic blend thermal fluid types for systems and methods of the present disclosure may include, but are not limited to, 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-432A; R-433A; R-433B; R-433C; R-434A; R-435A; R-436A; R-436B; R-437A; R-438A; R-439A; R-440A; R-441A; R-442A; R-443A; 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-458A; R-459A; R-459B; R-460A; R-460B; R-461A; R-462A; R-463A; R-464A; R-470A; R-476A; R-482A; R-491A; R-471B; R-471A; R-474A; and R-479A.

[0055] In one embodiment, thermal fluid blends for systems and methods of the present disclosure preferably include blends suitable for use in automotive thermal management devices, such as heat pump or air-conditioning systems. Examples of such blends include, but are not limited to, R-444A, R-456A, R-474A, R-457C (7.5%

R-32/78% HFO-1234yf/14.5% HFC-152a), R-457D (4% R-32/82% HFO-1234yf/14% HFC-152a), R-491A (35% HFO-1132E/65% HFC-152a), a blend of HFO-E-1132 and HFO-1252zc, a blend of R-32, HFO-1252zc and HFO-E-1234ze, or a blend of HFO-E-1132 and HFO-1243yc. In some embodiments, the thermal fluid comprises <5000 ppm, <2000 ppm, <1000 ppm, <500 ppm, <100 ppm, <50 ppm, <10 ppm, or <5 ppm, or <1 ppm of HFO-Z-1132.

[0056] Appropriate azeotropic blend thermal fluid types for systems and methods of the present disclosure may include, but are not limited to, R-410A; 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; R-516A; R-516B; R-1132a and CO₂; R-1132(E) and R-32; R-1132(Z) and R-1234yf; R-1234yf and R-134a; R-1234yf and R-1234ze(E); R-1234ze(E) and R-134a; R-1234ze(E) and R-152a; R-1233zd(E) and R-1234ze(Z); R-1234ze(E) and R-227ea; and R-1336mzz(E) and R-1234ze(Z). In some embodiments, the thermal fluid comprises <5000 ppm, <2000 ppm, <1000 ppm, <500 ppm, <100 ppm, <50 ppm, <10 ppm, or <5 ppm, or <1 ppm of HFO-Z-1132.

[0057] In some embodiments, the thermal fluid type is R-410A, R-512A, R-513A, R-513B, R-514A, R-515A, R-515B, or R-516A. The compositions of these thermal fluid types are shown in Table 1.

TABLE 1
COMPOSITIONS OF AZEOTROPIC AND
NEAR- AZEOTROPIC THERMAL FLUID TYPES

Name	C1	Wt%	C2	Wt%	C3	Wt%
R-512A	R-134a	5.0	R-152a	95.0		
R-513A	R-1234yf	56.0	R-134a	44.0		
R-513B	R-1234yf	58.5	R-134a	41.5		
R-514A	R-1336mzz(Z)	74.7	t-DCE	25.3		
R-515A	R-1234ze	88.0	R-227ea	12.0		
R-515B	R-1234ze	91.1	R-227ea	8.9		
R-516A	R-1234yf	77.5	R-134a	8.5	R-152a	14.0
R-410A	R-32	50.0	R-125	R-125		

[0058] In some embodiments, the first recycled thermal fluid and/or the second recycled thermal fluid comprises R-134a and one or more additional compounds selected from HFC-134, HCFC-124, HCFO-1122, HFC-143a, HCFC-31, HFC-32, HFC-125, CFC-114, CFC-114a and HFO-1234yf.

[0059] In some embodiments, the first recycled thermal fluid and/or the second recycled thermal fluid comprises R-1234yf and one or more additional compounds selected from R-32, R-1225zc, R-1225ye(Z), R-1225yf(E), R-245cb, R-245eb, R-1243zf, F-40, R-244bb, R-254eb, R-134a, R-134, R-152a, R-2223, R-1234ze(E), R-1233zd(E), R-1233zd(Z), R-1233xf, R-124, R-1131a, R-1132(E), R-142b, and R-1131(E).

[0060] In some embodiments, the first recycled thermal fluid and/or the second recycled thermal fluid comprises R-134a and R-1234yf and (i) one or more additional compounds selected from HFC-134, HCFC-124, HCFO-1122, HFC-143a, HCFC-31, HFC-32, HFC-125, CFC-114, CFC-114a and HFO-1234yf, and (ii) one or more additional compounds selected from R-1225cz, R-1225ye(Z), R-1225yf(E), R-245cb, R-245eb, R-1243zf, F-40, R-244bb, R-254eb, R-134a, R-152a, R-2223, R-1234ze(E), R-1233zd(E), R-1233zd(Z), R-1233xf, R-124, R-1131a, R-142b, and R-1131(E).

[0061] In some embodiments, the first recycled thermal fluid and/or the second recycled thermal fluid comprises R-1234ze(E) and one or more additional compounds selected from R-134a, R-1225zc, R-1234yf, R-245cb, R-236fa, R-1234ze(Z), R-1225ye(E), R-1225ye(Z), R-245fa, R-124, R-114, R-152a, R-1243zf, R-2223, R-1234zc, R-1233zd(E), R-1233zd(Z), R-1233xf and R-263fb.

[0062] In some embodiments, the first recycled thermal fluid and/or the second recycled thermal fluid comprises R-227ea and one or more additional compounds selected from R-236fa, R-124, R-217ba, R-1225zc and R-1225ye(Z).

[0063] In some embodiments, the first recycled thermal fluid and/or the second recycled thermal fluid comprises R-1132(E) and one or more additional compounds selected from R-32, R-1234ze(E) and R-1234yf.

[0064] In some embodiments, the recovering to remove the thermal fluid from a thermal management device is by a recovery system, which may include a

combination of a recovery compressor, an air-cooled condenser, and/or a fan from which compressed and condensed refrigerant may be sent for testing for composition and/or impurities or to a recovery tank. The thermal fluid recovery may be configured to recover a wide variety or only a limited number of thermal fluids or refrigerant compounds. A recovery system may utilize a single circuit for a single thermal fluid type or multiple circuits for multiple fluid types.

[0065] In some embodiments, the recycling includes testing the recovered thermal fluid, purifying the recovered thermal fluid as needed, adjusting the composition of the recovered thermal fluid as needed, and stabilizing the recovered thermal fluid as needed. In some embodiments, the recycling includes validating the recycled recovered thermal fluid as a recycled thermal fluid.

[0066] In some embodiments disclosed herein, a RRR machine may be connected to one of more of systems for adding stabilizer to the recovered thermal fluid, and/or removing the stabilizer of a stabilized recovered thermal fluid, or may be attached to a stabilizer injection kit for dosing stabilizer into the system.

[0067] In some embodiments, the testing includes determining the composition and/or the amount of organic purity of the recovered thermal fluid. In some embodiments, a refrigerant analyzer performs the testing. The analyzer determines the composition and purity of the recovered thermal fluid. In some embodiments, the analyzer determines the type of recovered thermal fluid and purity as it is being recovered from a thermal management device. The analyzer may alternatively determine the type and purity of a consolidated composition of recovered thermal fluids. If the analyzed thermal fluid is determined to be organically pure e.g., at least about 95 wt%, or about 96 wt%, or about 97 wt%, or about 98 wt%, or about 99 wt%, or about 99.5 wt%) and of a thermal fluid type by the analyzer, the thermal fluid may be transferred to an appropriate recycled thermal fluid tank. If, however, there are impurities (or the organic purity is less than about 95 wt%, or about 96 wt%, or about 97 wt%, or about 98 wt%, or about 99 wt%, or about 99.5 wt%), such as, air, unknown fluids, or incorrect thermal fluid, found in the analyzed thermal fluid by the analyzer, the recovered thermal fluid may be sent for reclamation. Fluids which contain higher amounts of oil or moisture may be reduced by the RRR equipment to

acceptable levels. Again, if refrigerants with high oil, moisture or other contaminants cannot be reduced, the refrigerant may be sent off-site for reclamation.

[0068] In some embodiments, the purifying includes removing one or more impurities from the recovered thermal fluid. In some embodiments, the purifying includes removing acids, moisture and high boiling residues by, for example, a filter, filter drier, absorbent bed(s) or absorbent column(s). The absorbent may be one or the combination of alumina, molecular sieves, silica gel, zeolites, and the like. In some embodiments, the purifying includes a process to remove NAG.

[0069] If the purity does not meet the appropriate standards for a recycled thermal fluid after purification, the recovered thermal fluid may be returned for further purifying or sent to a reclamation site for reclamation.

[0070] Optionally, in some embodiments, the purifying is performed by a regenerator. The regenerator can include at least a compressor, a separator, a filter dryer, and may further include a distiller, a diluter, or a reformulator. In some embodiments, the compressor is driven to circulate the thermal fluid in a refrigerant circuit such that a voltage is applied to reduce or remove oil, such as the refrigerating machine oil, in the thermal fluid. In some embodiments, the separator is a type of oil separator. In some embodiments, the filter dryer reduces or removes water and acid included in the thermal fluid. The regenerator can also determine information on the appropriateness of the oil, water, and acid included in the thermal fluid after the regeneration processing and compile the thermal fluid composition, the weight, and the like. After appropriate purification, the thermal fluid meets AHRI Standard 700 purity specifications.

[0071] In embodiments where the recovered thermal fluid includes at least one HFO refrigerant compound, the stabilizing may include adding a stabilizer package to the thermal fluid, such as described in U.S. Patent Application Publication No. 2021/0108119, the disclosure of which is incorporated by reference herein in its entirety. In some embodiments, the stabilizer package includes an effective amount of at least one inhibitor such that the thermal fluid remains substantially free of oligomeric, homopolymeric, or other polymeric products derived from the thermal fluid. In some embodiments, the inhibitor is added as a neat component to the thermal fluid. In some embodiments, the at least one inhibitor is selected from

hydrocarbons such as cyclic monoterpenes (e.g., limonene, pinene, α -pinene, β -pinene and terpinene); lipophilic organic compounds such as tocopherols (e.g., α -tocopherol) or butylated hydroxytoluene (BHT); phenols or aromatic organic compounds having at least one chemical moiety $-C_6H_4(OH)$ (e.g., benzene-1,4-diol, 4-methoxyphenol); and mixtures thereof. Specific examples of inhibitor compounds may include at least one member selected from limonene (particularly D-limonene), α -terpinene, pinene, α -pinene, β -pinene, α -tocopherol, butylated hydroxytoluene (BHT), 4-methoxyphenol, benzene-1,4-diol, and mixtures thereof. In one embodiment, the inhibitor composition includes a liquid at a temperature from about -80°C to about 180°C , about -70°C to about 170°C , and in some cases about -60°C to about 160°C . By "stabilized" it is meant to refer to a composition including an effective amount of at least one inhibitor compound that inhibits, if not eliminates, a fluoroethylene from interacting with another compound and forming dimers, oligomers, homopolymers, or polymeric products.

[0072] In some embodiments, the stabilizer package includes an effective amount of at least one acid scavenger. Examples of the acid scavengers that may be included in the present compositions include, but are not limited to, the stabilizers and/or the epoxide component of the stabilizers disclosed in U.S. Patent No. 8,535,555 and the acid scavengers disclosed in International Application Publication No. WO 2020/222864, the disclosure of each of which is incorporated herein by reference in its entirety.

[0073] In some embodiments, the acid scavenger may comprise one or more epoxides, one or more amines and/or one or more hindered amines, such as, for example but not limited to, epoxybutane.

[0074] In some embodiments, the inhibitor is premixed with the HFO compound. In some embodiments, the stabilizer package further includes a dye, such as described in International Application Publication No. WO 2023/141098, the disclosure of which is incorporated by reference herein in its entirety. In some embodiments, the dye is an ultraviolet dye that absorbs light in the ultraviolet or near ultraviolet region of the electromagnetic spectrum. Any compatible dye can be included in the inventive compositions. Appropriate compatible dyes may include, but are not limited to, at least one compound containing a fluorescein species selected from the derivatives of

6-hydroxy-3H-xanthen-3-one and having an absorbance peak from about 425 to about 433 nm, another absorbance peak from about 292 to about 295 nm, and, in some cases, a third absorbance peak from about 243 to about 250 nm. Absorbance peaks may be measured using UV-Vis. Compatible dyes may also be characterized using Fourier-transform infrared (FTIR) spectroscopy as having peaks between about 700 to about 800 cm^{-1} , about 1000 to about 1100 cm^{-1} , about 1200 to about 1300 cm^{-1} , and/or about 1400 to about 1600 cm^{-1} . The amount of dye can range from about 30 to about 0.001 wt%, alternatively about 20 to about 0.001 wt%, alternatively about 5 to about 0.001 wt%, or any value, range, or sub-range therebetween, based on the total weight of the composition. The dye, lubricant, HFO, and inhibitor, among other components of the stabilizer package, can be combined in any suitable sequence. In some embodiments, dye is solubilized in lubricant, followed by addition of HFO containing an inhibitor. In some embodiments, dye is solubilized in lubricant containing inhibitor, followed by addition of HFO.

[0075] In some embodiments, where the recovered or recycled thermal fluid is a blend of two or more refrigerant compounds, adjustments to the composition of the recovered or recycled thermal fluid may be made by addition of one or more refrigerant compounds at any point to meet the desired thermal fluid type composition. Preferably, this is done on-site with the system of FIG. 1.

[0076] In some embodiments, the validating includes confirming that the recovered thermal fluid has an organic purity greater than about 95 wt%, or about 96 wt%, or about 97 wt%, or about 98 wt%, or about 99 wt%, or about 99.5 wt%, and meets predetermined standards for a recycled thermal fluid. In the case of thermal fluids of or including R-134a and/or R-1234yf, the recycled thermal fluid meets Society of Automotive Engineers (SAE) J2099 standards, which includes less than 1.5 % NAG, by volume, less than 500 ppm (parts per million) by weight high boiling residue, and less than 50 ppm by weight moisture.

[0077] In some embodiments, the recycled and reused thermal fluid meets the standards of, *Standard for Specifications for Refrigerants*, Air-Conditioning, Heating & Refrigeration Institute (AHRI), AHRI 700, which is incorporated by reference in its entirety herein. AHRI 700 specifies acceptable levels of contaminants (purity

requirements) for fluorocarbon, hydrocarbon, and carbon dioxide refrigerants regardless of source and lists acceptable test methods.

EXAMPLES

[0078] The invention will be described in greater detail by way of specific examples. The following examples are offered for illustrative purposes and are not intended to limit the invention in any manner. Those of skill in the art will readily recognize a variety of non-critical parameters which can be changed or modified to yield essentially the same results. Those skilled in the art will also recognize that the activities mentioned in the Examples, including but not limited to testing, identification, validation, purification and the like, may be carried out using a RRR machine or another type of testing and treatment device which is suitable for use on-site (e.g., a portable or transportable device).

Example 1

[0079] An automobile arrives at an automobile service shop for service. It is determined that the air-conditioning thermal fluid in the automobile needs to be replaced. The air-conditioning thermal fluid is recovered from the automobile and determined to be of the type R-134a.

[0080] The recovered thermal fluid is optionally tested onsite for purity. The recovered thermal fluid is optionally combined onsite with other recovered thermal fluid of the same type and purified onsite to reduce the levels of acidity, moisture, and high boiling residue below predetermined values. The recovered thermal fluid is validated onsite as meeting requirements for a recycled thermal fluid of type R-134a.

[0081] The recycled thermal fluid is stored onsite until needed by an automobile being serviced at the automobile service shop that needs its type R-134a air-conditioning thermal fluid replaced. The recycled thermal fluid is reused by being added onsite to the automobile's air-conditioning system after its spent air-conditioning thermal fluid is recovered.

Example 2

[0082] An automobile arrives at an automobile service shop for service. It is determined that the air-conditioning (or heat pump) thermal fluid in the automobile needs to be replaced. The air-conditioning thermal fluid is recovered from the automobile and determined to be of the type R-1234yf.

[0083] The recovered thermal fluid is optionally tested onsite for purity. The recovered thermal fluid is combined onsite with other recovered thermal fluid of the same type and purified onsite to reduce the levels of acidity, moisture, NAG, and high boiling residue below predetermined values. The recovered thermal fluid is validated onsite as meeting requirements for a recycled thermal fluid of type R-1234yf. Optionally a stabilizer package is added to the recycled thermal fluid.

[0084] The recycled thermal fluid is stored onsite until needed by an automobile being serviced at the automobile service shop that needs its type R-1234yf air-conditioning thermal fluid replaced. The recycled thermal fluid is reused by being added onsite to the automobile's air-conditioning system after its spent air-conditioning thermal fluid is recovered.

Example 3

[0085] An automobile arrives at an automobile service shop for service. It is determined that the air-conditioning (or heat pump) thermal fluid in the automobile needs to be replaced. The air-conditioning thermal fluid is recovered from the automobile and determined to be of the mixture of R-1234yf and R-134a.

[0086] The recovered thermal fluid is optionally tested onsite for purity. The recovered thermal fluid is combined onsite with other recovered thermal fluid of the same type and purified onsite to reduce the levels of acidity, moisture, NAG, and high boiling residue below predetermined values. The recovered thermal fluid is validated onsite as meeting requirements for a recycled thermal fluid of R-1234yf and R-134a. Optionally a stabilizer package is added to the recycled thermal fluid.

[0087] The recycled thermal fluid is stored onsite until needed by an automobile being serviced at the automobile service shop that needs its type R-1234yf and R134a air-conditioning thermal fluid replaced. The recycled thermal fluid is reused by

being added onsite to the automobile's air-conditioning system after its spent air-conditioning thermal fluid is recovered.

Example 4

[0088] It is determined that the air-conditioning thermal fluid in a refrigeration and air conditioning system needs to be replaced. The air-conditioning thermal fluid is recovered from the system and determined to be of the type R-513A.

[0089] The recovered thermal fluid is optionally tested onsite for purity. The recovered thermal fluid is optionally combined onsite with other recovered thermal fluid of the same type and purified onsite to reduce the levels of acidity moisture, NAG, and high boiling residue below predetermined values. The recovered thermal fluid is optionally tested onsite for composition and determined to require addition of R-1234yf or R-134a, which is added to the recovered thermal fluid. The recovered thermal fluid is validated onsite as meeting requirements for a recycled thermal fluid of type R-513A. Optionally a stabilizer package is added to the recycled thermal fluid.

[0090] The recycled thermal fluid is put back to the same unit from which it is recovered. The recycled thermal fluid is reused by being added onsite to the same air-conditioning system after its spent air-conditioning thermal fluid is recovered.

Example 5

[0091] It is determined that the air-conditioning thermal fluid in the refrigeration and air conditioning system needs to be replaced. The air-conditioning thermal fluid is recovered from the system and determined to be of the type R-515B.

[0092] The recovered thermal fluid is optionally tested onsite for purity and determined to be of sufficient purity. The recovered thermal fluid is optionally combined onsite with other recovered thermal fluid of the same type and purified onsite to reduce the levels of acidity, moisture, NAG, and high boiling residue below predetermined values. The recovered thermal fluid is optionally tested onsite for composition and determined to require addition of R-1234ze or R-227ea, which is added to the recovered thermal fluid. The recovered thermal fluid is validated onsite as meeting requirements for a recycled thermal fluid of type R-515B.

[0093] The recycled thermal fluid is put back to the same unit from which it is recovered. The recycled thermal fluid is reused by being added onsite to the same air-conditioning system after its spent air-conditioning thermal fluid is recovered.

Example 6

[0094] It is determined that the air-conditioning thermal fluid in the refrigeration and air conditioning system needs to be replaced. The air-conditioning thermal fluid is recovered from the system and determined to be of the type R-410A.

[0095] The recovered thermal fluid is optionally tested onsite for purity and determined to be of sufficient purity. The recovered thermal fluid is optionally combined onsite with other recovered thermal fluid of the same type and purified onsite to reduce the levels of acidity, moisture, NAG, and high boiling residue below predetermined values. The recovered thermal fluid is optionally tested onsite for composition and determined to require addition of R-32 or R-125, which is added to the recovered thermal fluid. The recovered thermal fluid is validated onsite as meeting requirements for a recycled thermal fluid of type R-410A.

[0096] The recycled thermal fluid is put back to the same unit from which it is recovered. The recycled thermal fluid is reused by being added onsite to the same air-conditioning system after its spent air-conditioning thermal fluid is recovered.

Example 7

[0097] An automobile arrives at an automobile service shop for service. It is determined that the air-conditioning or heat pump thermal fluid in the automobile needs to be replaced. The air-conditioning or heat pump thermal fluid is recovered from the automobile and determined to be of the type R-444A.

[0098] The recovered thermal fluid is optionally tested onsite for purity. The recovered thermal fluid is optionally combined onsite with other recovered thermal fluid of the same type and purified onsite to reduce the levels of acidity, moisture, and high boiling residue below predetermined values. The recovered thermal fluid is optionally tested onsite for composition and determined to require addition of R-1234ze and/or R-152a and/or R-32, which is added to the recovered thermal fluid.

The recovered thermal fluid is validated onsite as meeting requirements for a recycled thermal fluid of type R-444A.

[0099] The recycled thermal fluid is stored onsite until needed by an automobile being serviced at the automobile service shop that needs its type R-444A thermal fluid replaced. The recycled thermal fluid is reused by being added onsite to the automobile's air-conditioning or heat pump system after its spent thermal fluid is recovered.

Example 8

[0100] An automobile arrives at an automobile service shop for service. It is determined that the air-conditioning or heat pump thermal fluid in the automobile needs to be replaced. The air-conditioning or heat pump thermal fluid is recovered from the automobile and determined to be of the type R-474A.

[0101] The recovered thermal fluid is optionally tested onsite for purity. The recovered thermal fluid is optionally combined onsite with other recovered thermal fluid of the same type and purified onsite to reduce the levels of acidity, moisture, and high boiling residue below predetermined values. The recovered thermal fluid is optionally tested onsite for composition and determined to require addition of R-1132(E) and/or R-1234yf and/or R-32, which is added to the recovered thermal fluid. The recovered thermal fluid is validated onsite as meeting requirements for a recycled thermal fluid of type R-474A.

[0102] The recycled thermal fluid is stored onsite until needed by an automobile being serviced at the automobile service shop that needs its type R-474A air-conditioning or heat pump thermal fluid replaced. The recycled thermal fluid is reused by being added onsite to the automobile's air-conditioning or heat pump system after its spent thermal fluid is recovered.

Example 9

[0103] An automobile arrives at an automobile service shop for service. It is determined that the air-conditioning or heat pump thermal fluid in the automobile needs to be replaced. The air-conditioning or heat pump thermal fluid is recovered from the automobile and determined to be of the type R-491A.

[0104] The recovered thermal fluid is optionally tested onsite for purity. The recovered thermal fluid is optionally combined onsite with other recovered thermal fluid of the same type and purified onsite to reduce the levels of acidity, moisture, and high boiling residue below predetermined values. The recovered thermal fluid is optionally tested onsite for composition and determined to require addition of R-1132(E) and/or R-152a, which is added to the recovered thermal fluid. The recovered thermal fluid is validated onsite as meeting requirements for a recycled thermal fluid of type R-491A.

[0105] The recycled thermal fluid is stored onsite until needed by an automobile being serviced at the automobile service shop that needs its type R-491A air-conditioning or heat pump thermal fluid replaced. The recycled thermal fluid is reused by being added onsite to the automobile's air-conditioning or heat pump system after its spent thermal fluid is recovered.

OTHER EMBODIMENTS

[0106] Embodiment 1: a process of thermal fluid recovery, recycle, and reuse, the process comprising: recovering a thermal fluid comprising at least one refrigerant compound from at least one thermal management device as a recovered thermal fluid at a site; recycling the recovered thermal fluid onsite, wherein the recycling comprises testing the recovered thermal fluid for composition and level of impurities, purifying the recovered thermal fluid to reduce the level of impurities as needed and adjusting the composition of the recovered thermal fluid as needed to provide a recycled thermal fluid meeting predetermined purity and composition criteria for a predetermined thermal fluid type, and validating that the recycled thermal fluid has greater than 98 wt% organic purity; and reusing the thermal fluid onsite, wherein the reusing comprises charging the recycled thermal fluid to a thermal management device; wherein the process occurs onsite.

[0107] Embodiment 2: the process of embodiment 1, wherein the recycling further comprises combining the recovered thermal fluid with additional recovered thermal fluid of the same predetermined thermal fluid type.

[0108] Embodiment 3: the process of any of embodiments 1-2, wherein the purifying comprises filtering the recovered thermal fluid.

[0109] Embodiment 4: the process of any of embodiments 1-3, wherein the purifying reduces a moisture content of the recovered thermal fluid.

[0110] Embodiment 5: the process of any of embodiments 1-4, wherein the purifying reduces a high boiling residue content of the recovered thermal fluid.

[0111] Embodiment 6: the process of any of embodiments 1-5, wherein the purifying reduces a non-absorbable gases level in the recovered thermal fluid.

[0112] Embodiment 7: the process of any of embodiments 1-6, wherein the purifying reduces a non-absorbable gases content below 1.5 vol%, a high boiling residue content below 500 parts-per-million by weight, and a moisture content below 50 parts-per-million by weight.

[0113] Embodiment 8: the process of any of embodiments 1-7, wherein the recycling further comprises adding at least one inhibitor to the recovered thermal fluid to stabilize the recovered thermal fluid.

[0114] Embodiment 9: the process of any of embodiments 1-8, wherein the recycling further comprises adding at least one dye to the recovered thermal fluid.

[0115] Embodiment 10: the process of any of embodiments 1-9, wherein the at least one thermal management device comprises a plurality of air-conditioning systems of a plurality of automobiles.

[0116] Embodiment 11: the process of any of embodiments 1-10, wherein a location of the onsite is selected from the group consisting of an automobile service shop and automobile dealership.

[0117] Embodiment 12: the process of any of embodiments 1-11, wherein the at least one refrigerant compound is selected from the group consisting of R-12, R-123, R-134a, R-134, R-152a, R-227ea, R-1130(E), R-1234yf, R-1132(E), R-1132(Z), R-32, R-1233zd(E), R-1233zd(Z), R-1233xf, R-1234ze(E), R-1234ze(Z), R-1336mzz(E), and R-1336mzz(Z).

[0118] Embodiment 13: the process of any of embodiments 1-12, wherein the predetermined thermal fluid type is selected from the group consisting of R-134a and R-1234yf.

[0119] Embodiment 14: the process of any of embodiments 1-13, wherein the recycled thermal fluid comprises R-134a and one or more additional compounds selected from HFC-134, HCFC-124, HCFO-1122, HFC-143a, HCFC-31, HFC-32, HFC-125, CFC-114, CFC-114a and 1234yf.

[0120] Embodiment 15: the process of any of embodiments 1-14, wherein the recycled thermal fluid comprises R-1234yf and one or more additional compounds selected from R-1225zc, R-1225ye(Z), R-1225yf(E), R-245cb, R-245eb, R-32, R-1243zf, F-40, R-244bb, R-254eb, R-134a, R-152a, R-2223, R-1234ze(E), R-1233zd(E), R-1233zd(Z), R-1233xf, R-124, R-1131a, R-1132(E), R-142b and R-1131(E).

[0121] Embodiment 16: the process of any of embodiments 1-15, wherein the recycled thermal fluid comprises R-134a and R-1234yf and (i) one or more additional compounds selected from the group consisting of HFC-134, HCFC-124, HCFO-1122, HFC-143a, HCFC-31, HFC-32, HFC-125, CFC-114, CFC-114a and 1234yf, and (ii) one or more additional compounds selected from the group consisting of R-1225zc, R-1225ye(Z), R-1225yf(E), R-245cb, R-245eb, R-1243zf, F-40, R-244bb, R-254eb, R-134a, R-152a, R-2223, R-1234ze(E), R-1233zd(E), R-1233zd(Z), R-1233xf, R-124, R-1131a, R-142b R-1131(E).

[0122] Embodiment 17: the process of any of embodiments 1-16, wherein the recycled thermal fluid comprises (i) R-1234ze(E) and one or more additional compounds selected from the group consisting of R-134a, R-1225zc, R-1234yf, R-245cb, R-236fa, R-1234ze(Z), R-1225ye(E), R-1225ye(Z), R-245fa, R-124, R-114, R-152a, R-1243zf, R-2223, R-1234zc, R-1233zd(E), R-1233zd(Z), R-1233xf, and R-263fb; or (ii) R-1132(E) and one or more additional compounds selected from R-32, R-1234ze(E) and R-1234yf.

[0123] Embodiment 18: the process of any of embodiments 1-17, wherein the recycled thermal fluid comprises R-227ea and one or more additional compounds selected from the group consisting of R-236fa, R-124, R-217ba, R-1225zc and R-1225ye(Z).

[0124] Embodiment 19: the process of any of embodiments 1-18, wherein the predetermined thermal fluid type is selected from the group consisting of R-410A, R-512A, R-513A, R-513B, R-514A, R-515A, R-515B, and R-516A.

[0125] Embodiment 20: the process of any of embodiments 1-19, wherein the at least one refrigerant compound is selected from R-1234yf, R-1234ze(E), R-1233zd(E), R-1233zd(Z), R-1233xf, R-1224yd(Z), R-1224yd(E), R-1234ze(Z), R-1336mzz(E), and R-1336mzz(Z).

[0126] Embodiment 21: the process of any of embodiments 1-20, wherein the process is performed by a recover, recycle, recharge (RRR) machine.

[0127] Embodiment 22: the process of any of embodiments 1-21, wherein the at least one refrigerant compound is a hydrofluoroolefin.

[0128] Embodiment 23: the process of any of embodiments 1-22, wherein the recycling further comprises adding at least one inhibitor to the recovered thermal fluid to stabilize the recovered thermal fluid.

[0129] Embodiment 24: the process of embodiment 23, wherein the at least one inhibitor is selected from the group consisting of hydrocarbons including at least cyclic monoterpene; lipophilic organic compounds; and phenols, aromatic organic compounds having at least one chemical moiety -C₆H₄(OH), including benzene-1,4-diol, specifically at least one member selected from the group consisting of D-limonene, pinene, α-pinene, β-pinene, α-terpinene, α-tocopherol, butylated hydroxytoluene, 4-methoxyphenol, benzene-1,4-diol, and mixtures thereof.

[0130] Embodiment 25: the process of any of embodiments 1-24, wherein the recovered thermal fluid and/or the recycled thermal fluid optionally comprises at least one inhibitor selected from the group consisting of hydrocarbons including at least cyclic monoterpene; lipophilic organic compounds; and phenols, aromatic organic compounds having at least one chemical moiety -C₆H₄(OH), preferably at least one member selected from the group consisting of D-limonene, pinene, α-pinene, β-pinene, α-terpinene, α-tocopherol, butylated hydroxytoluene, 4-methoxyphenol, benzene-1,4-diol, and mixtures thereof

[0131] Embodiment 26: the process of embodiment 25, wherein the at least one refrigerant compound is a hydrofluoroolefin, preferably R-1234yf.

[0132] Embodiment 27: the process of any of embodiments 1-24, wherein the recovered thermal fluid and/or the recycled thermal fluid optionally comprises at least one acid scavenger.

[0133] Embodiment 28: a reused thermal fluid formed by the process of any of embodiments 1-27.

[0134] While this specification contains many specific implementation details, these should not be construed as limitations on the scope of any inventions or of what may be claimed, but rather as descriptions of features specific to particular implementations of particular inventions. Certain features that are described in this specification in the context of separate implementations can also be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation can also be implemented in multiple implementations separately or in any suitable sub-combination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a sub-combination or variation of a sub-combination.

[0135] Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the implementations described above should not be understood as requiring such separation in all implementations, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products.

[0136] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary

skill in the art to which example embodiments belong. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0137] While the disclosure has been described with reference to a preferred embodiment, it will be understood by those skilled in the art that various changes may be made, and equivalents may be substituted for elements thereof without departing from the scope of the disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the disclosure without departing from the essential scope thereof. While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

CLAIMS

What is claimed is:

1. A process of thermal fluid recovery, recycle, and reuse, the process comprising:
 - recovering a thermal fluid comprising at least one refrigerant compound from at least one thermal management device as a recovered thermal fluid at a site;
 - recycling the recovered thermal fluid at the site, wherein the recycling comprises testing the recovered thermal fluid for composition and level of impurities, purifying the recovered thermal fluid to reduce the level of impurities as needed and adjusting the composition of the recovered thermal fluid as needed to provide a recycled thermal fluid meeting predetermined purity and composition criteria for a predetermined thermal fluid type, and validating that the recycled thermal fluid has greater than 98 wt% organic purity; and
 - reusing the thermal fluid at the site, wherein the reusing comprises charging the recycled thermal fluid to a thermal management device.
2. The process of claim 1, wherein the recycling further comprises combining the recovered thermal fluid with additional recovered thermal fluid of the same predetermined thermal fluid type.
3. The process of any of claims 1-2, wherein the purifying comprises filtering the recovered thermal fluid.
4. The process of any of claims 1-3, wherein the purifying reduces a moisture content of the recovered thermal fluid.
5. The process of any of claims 1-4, wherein the purifying reduces a high boiling residue content of the recovered thermal fluid.
6. The process of any of claims 1-5, wherein the purifying reduces a non-absorbable gases level in the recovered thermal fluid.
7. The process of any of claims 1-6, wherein the purifying reduces a non-absorbable gases content below 1.5 vol%, a high boiling residue content below

500 parts-per-million by weight, and a moisture content below 50 parts-per-million by weight.

8. The process of any of claims 1-7, wherein the recycling further comprises adding at least one inhibitor to the recovered thermal fluid to stabilize the recovered thermal fluid.
9. The process of any of claims 1-8, wherein the recycling further comprises adding at least one dye to the recovered thermal fluid.
10. The process of any of claims 1-9, wherein the at least one thermal management device comprises a plurality of air-conditioning systems of a plurality of automobiles.
11. The process of any of claims 1-10, wherein a location of the site is selected from the group consisting of an automobile service shop and an automobile dealership.
12. The process of any of claims 1-11, wherein the at least one refrigerant compound is selected from the group consisting of R-12, R-123, R-134a, R-134, R-152a, R-227ea, R-1130(E), R-1234yf, R-1132(E), R-1132(Z), R-32, R-1233zd(E), R-1233zd(Z), R-1233xf, R-1224yd(Z), R-1224yd(E), R-1234ze(E), R-1234ze(Z), R-1252zc, R-1243yc, R-1336mzz(E), and R-1336mzz(Z).
13. The process of any of claims 1-12, wherein the predetermined thermal fluid type is selected from the group consisting of R-134a and R-1234yf.
14. The process of any of claims 1-13, wherein the recycled thermal fluid comprises R-134a and one or more additional compounds selected from the group consisting of HFC-134, HCFC-124, HCFO-1122, HFC-143a, HCFC-31, HFC-32, HFC-125, CFC-114, CFC-114a and HFO-1234yf.
15. The process of any of claims 1-14, wherein the recycled thermal fluid comprises R-1234yf and one or more additional compounds selected from the group consisting of R-1225zc, R-1225ye(Z), R-1225yf(E), R-245cb, R-245eb, R-1243zf, F-40, R-244bb, R-254eb, R-32, R-134a, R-134, R-152a, R-2223,

R-1234ze(E), R-1233zd(E), R-1233zd(Z), R-1233xf, R-124, R-1132(E), R-1131a, R-142b and R-1131(E).

16. The process of any of claims 1-15, wherein the recycled thermal fluid comprises R-134a and R-1234yf and (i) one or more additional compounds selected from the group consisting of HFC-134, HCFC-124, HCFO-1122, HFC-143a, HCFC-31, HFC-32, HFC-125, CFC-114, CFC-114a and HFO-1234yf, and (ii) one or more additional compounds selected from the group consisting of R-1225cz, R-1225ye(Z), R-1225yf(E), R-245cb, R-245eb, R-1243zf, F-40, R-244bb, R-254eb, R-134a, R-152a, R-2223, R-1234ze(E), R-1233zd(E), R-1233zd(Z), R-1233xf, R-124, R-1131a, R-142b R-1131(E).
17. The process of any of claims 1-16, wherein the recycled thermal fluid comprises (i) R-1234ze(E) and one or more additional compounds selected from the group consisting of R-134a, R-1225zc, R-1234yf, R-245cb, R-236fa, R-1234ze(Z), R-1225ye(E), R-1225ye(Z), R-245fa, R-124, R-114, R-152a, R-1243zf, R-2223, R-1234zc, R-1233zd(E), R-1233zd(Z), R-1233xf, and R-263fb; or (ii) R-1132(E) and one or more additional compounds selected from the group consisting of R-32, R-1234ze(E) and R-1234yf.
18. The process of any of claims 1-17, wherein the recycled thermal fluid comprises R-227ea and one or more additional compounds selected from the group consisting of R-236fa, R-124, R-217ba, R-1225zc and R-1225ye(Z).
19. The process of any of claims 1-18, wherein the predetermined thermal fluid type is selected from the group consisting of R-410A, R-512A, R-513A, R-513B, R-514A, R-515A, R-515B, and R-516A.
20. The process of any of claims 1-19, wherein the at least one refrigerant compound is selected from the group consisting of R-1234yf, R-1234ze(E), R-1234ze(Z), R-1233zd(E), R-1233zd(Z), R-1233xf, R-1224yd(Z), R-1224yd(E), R-1336mzz(E), and R-1336mzz(Z).
21. The process of any of claims 1-20, wherein the process is performed by a recover, recycle, recharge (RRR) machine.
22. The process of any of claims 1-21, wherein the at least one refrigerant compound is a hydrofluoroolefin.

23. The process of any of claims 1-22, wherein the recycling further comprises adding at least one inhibitor to the recovered thermal fluid to stabilize the recovered thermal fluid.
24. The process of claim 23, wherein the at least one inhibitor is selected from the group consisting of hydrocarbons including at least cyclic monoterpene; lipophilic organic compounds; and phenols, aromatic organic compounds having at least one chemical moiety -C₆H₄(OH), including benzene-1,4-diol, preferably at least one member selected from the group consisting of D-limonene, pinene, α -pinene, β -pinene, α -terpinene, α -tocopherol, butylated hydroxytoluene, 4-methoxyphenol, benzene-1,4-diol, and mixtures thereof.
25. The process of any of claims 1-24, wherein the recovered thermal fluid and/or the recycled thermal fluid optionally comprises at least one inhibitor selected from the group consisting of hydrocarbons including at least cyclic monoterpene; lipophilic organic compounds; and phenols, aromatic organic compounds having at least one chemical moiety -C₆H₄(OH), preferably at least one member selected from the group consisting of D-limonene, pinene, α -pinene, β -pinene, α -terpinene, α -tocopherol, butylated hydroxytoluene, 4-methoxyphenol, benzene-1,4-diol, and mixtures thereof.
26. The process of claim 25, wherein the at least one refrigerant compound is a hydrofluoroolefin, preferably R-1234yf.
27. The process of any of claims 1-24, wherein the recovered thermal fluid and/or the recycled thermal fluid optionally comprises at least one acid scavenger.
28. A reused thermal fluid formed by the process of any of claims 1-27.