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(54) Title: COMPOSITIONS CONTAINING DIFLUOROMETHANE, TETRAFLUOROPROPENE, AND CARBON DIOXIDE AND USES THEREOF

(57) Abstract: In accordance with the present invention refrigerant compositions are disclosed. The compositions comprise a refrigerant mixture consisting essentially of HFC-32, HFO-1234yf, and CO₂. The compositions are useful as refrigerants in processes to produce cooling and heating, in methods for replacing refrigerant R-410A, and in refrigeration, air conditioning or heat pump systems. These inventive compositions match cooling capacity for R-410A within ±10% with GWP less than 400 or less than 300.

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TITLE

COMPOSITIONS CONTAINING DIFLUOROMETHANE,
TETRAFLUOROPROPENE, AND CARBON DIOXIDE AND USES THEREOF

BACKGROUND5 **1. Field of the Disclosure.**

The present disclosure relates to compositions for use in refrigeration, air conditioning or heat pump systems. The compositions of the present invention are useful in methods for producing cooling and heating, and methods for replacing refrigerants and refrigeration, air conditioning and heat pump apparatus.

10 **2. Description of Related Art.**

The refrigeration industry has been working for the past few decades to find replacement refrigerants for the ozone-depleting chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) being phased out as a result of the

15 Montreal Protocol. The solution for most refrigerant producers has been the commercialization of hydrofluorocarbon (HFC) refrigerants. These HFC refrigerants, including HFC-134a, R-32 and R-410A, among others, being widely used at this time, have zero ozone depletion potential and thus are not affected by the current regulatory phase out as a result of the original Montreal Protocol.

20 With implementation to the Kigali amendment to the Montreal Protocol, even lower GWP replacement refrigerants are being sought.

BRIEF SUMMARY

Certain compositions comprising difluoromethane, tetrafluoropropene and carbon dioxide have been found to possess suitable properties to allow their use as replacements for currently available commercial refrigerants, in particular R-410A, with relatively high GWP. Therefore, the present inventors have discovered refrigerant gases that are non-ozone depleting, and have significantly

less direct global warming potential and match the performance of R-410A, and are thus, environmentally sustainable alternatives.

In accordance with the present invention compositions comprising refrigerant mixtures are disclosed. The refrigerant mixtures consist essentially of

5 difluoromethane, tetrafluoropropene and carbon dioxide.

The refrigerant mixtures are useful as components in compositions also containing non-refrigerant components (e.g., lubricants), in processes to produce cooling or heating, in methods for replacing refrigerant R-410A, and, in particular, in air conditioning and heat pump systems.

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DETAILED DESCRIPTION

Before addressing details of embodiments described below, some terms are defined or clarified.

Definitions

As used herein, the term heat transfer fluid (also referred to as heat transfer medium) means a composition used to carry heat from a heat source to a heat sink.

A heat source is defined as any space, location, object or body from which it is desirable to add, transfer, move or remove heat. Examples of heat sources are spaces (open or enclosed) requiring refrigeration or cooling, such as 20 refrigerator or freezer cases in a supermarket, transport refrigerated containers, building spaces requiring air conditioning, industrial water chillers or the passenger compartment of an automobile requiring air conditioning. In some embodiments, the heat transfer composition may remain in a constant state throughout the transfer process (i.e., not evaporate or condense). In other 25 embodiments, evaporative cooling processes may utilize heat transfer compositions as well.

A heat sink is defined as any space, location, object or body capable of absorbing heat. A vapor compression refrigeration system is one example of such a heat sink.

A refrigerant is defined as a heat transfer fluid that undergoes a phase

5 change from liquid to gas and back again during a cycle used to transfer of heat.

A heat transfer system is the system (or apparatus) used to produce a heating or cooling effect in a particular space. A heat transfer system may be a mobile system or a stationary system.

Examples of heat transfer systems are any type of refrigeration systems and

10 air conditioning systems including, but are not limited to, stationary heat transfer systems, air conditioners, freezers, refrigerators, heat pumps, water chillers, flooded evaporator chillers, direct expansion chillers, walk-in coolers, mobile refrigerators, mobile heat transfer systems, mobile air conditioning units, dehumidifiers, and combinations thereof.

15 Refrigeration capacity (also referred to as cooling capacity) is a term which defines the change in enthalpy of a refrigerant in an evaporator per pound of refrigerant circulated, or the heat removed by the refrigerant in the evaporator per unit volume of refrigerant vapor exiting the evaporator (volumetric capacity). The refrigeration capacity is a measure of the ability of a refrigerant or heat

20 transfer composition to produce cooling. Therefore, the higher the capacity, the greater the cooling that is produced. Cooling rate refers to the heat removed by the refrigerant in the evaporator per unit time.

Coefficient of performance (COP) is the amount of heat removed divided by the required energy input to operate the cycle. The higher the COP, the higher

25 is the energy efficiency. COP is directly related to the energy efficiency ratio (EER) that is the efficiency rating for refrigeration or air conditioning equipment at a specific set of internal and external temperatures.

The term “subcooling” refers to the reduction of the temperature of a liquid below that liquid's saturation point for a given pressure. The saturation point is

the temperature at which the vapor is completely condensed to a liquid, but subcooling continues to cool the liquid to a lower temperature liquid at the given pressure. By cooling a liquid below the saturation temperature (or bubble point temperature), the net refrigeration capacity can be increased. Subcooling

5 thereby improves refrigeration capacity and energy efficiency of a system. Subcool amount is the amount of cooling below the saturation temperature (in degrees).

Superheat is a term that defines how far above its saturation vapor temperature (the temperature at which, if the composition is cooled, the first drop 10 of liquid is formed, also referred to as the “dew point”) a vapor composition is heated.

Temperature glide (sometimes referred to simply as “glide”) is the absolute value of the difference between the starting and ending temperatures of a phase-change process by a refrigerant within a component of a refrigerant

15 system, exclusive of any subcooling or superheating. This term may be used to describe condensation or evaporation of a near azeotrope or non-azeotropic composition. When referring to the temperature glide of a refrigeration, air conditioning or heat pump system, it is common to provide the average temperature glide being the average of the temperature glide in the evaporator 20 and the temperature glide in the condenser.

The net refrigeration effect is the quantity of heat that each kilogram of refrigerant absorbs in the evaporator to produce useful cooling.

The mass flow rate is the quantity of refrigerant in kilograms circulating through the refrigeration, heat pump or air conditioning system over a given 25 period of time.

As used herein, the term “lubricant” means any material added to a composition or a compressor (and in contact with any heat transfer composition in use within any heat transfer system) that provides lubrication to the compressor to aid in preventing parts from seizing.

As used herein, compatibilizers are compounds which improve solubility of the hydrofluorocarbon of the disclosed compositions in heat transfer system lubricants. In some embodiments, the compatibilizers improve oil return to the compressor. In some embodiments, the composition is used with a system

5 lubricant to reduce oil-rich phase viscosity.

As used herein, oil-return refers to the ability of a heat transfer composition to carry lubricant through a heat transfer system and return it to the compressor.

That is, in use, it is not uncommon for some portion of the compressor lubricant

to be carried away by the heat transfer composition from the compressor into the

10 other portions of the system. In such systems, if the lubricant is not efficiently returned to the compressor, the compressor will eventually fail due to lack of lubrication.

As used herein, "ultra-violet" dye is defined as a UV fluorescent or phosphorescent composition that absorbs light in the ultra-violet or "near" ultra-

15 violet region of the electromagnetic spectrum. The fluorescence produced by the UV fluorescent dye under illumination by a UV light that emits at least some radiation with a wavelength in the range of from 10 nanometers to about 775 nanometers may be detected.

Flammability is a term used to mean the ability of a composition to ignite and/or propagate a flame. For refrigerants and other heat transfer compositions,

the lower flammability limit ("LFL") is the minimum concentration of the heat

transfer composition in air that is capable of propagating a flame through a

homogeneous mixture of the composition and air under test conditions specified in ASTM (American Society of Testing and Materials) E681. The upper

25 flammability limit ("UFL") is the maximum concentration of the heat transfer composition in air that is capable of propagating a flame through a

homogeneous mixture of the composition and air under the same test

conditions. Determination of whether a refrigerant compound or mixture is flammable or non-flammable is also done by testing under the conditions of

30 ASTM-681.

During a refrigerant leak, lower boiling components of a mixture may leak preferentially. Thus, the composition in the system, as well as, the vapor leaking can vary over the time period of the leak. Thus, a non-flammable mixture may become flammable under leakage scenarios. And in order to be classified as

5 non-flammable by ASHRAE (American Society of Heating, Refrigeration and Air-conditioning Engineers), a refrigerant or heat transfer composition must be non-flammable as formulated, but also under leakage conditions.

Global warming potential (GWP) is an index for estimating relative global warming contribution due to atmospheric emission of a kilogram of a particular

10 greenhouse gas compared to emission of a kilogram of carbon dioxide. GWP can be calculated for different time horizons showing the effect of atmospheric lifetime for a given gas. The GWP for the 100 year time horizon is commonly the value referenced. For mixtures, a weighted average can be calculated based on the individual GWPs for each component.

15 Ozone depletion potential (ODP) is a number that refers to the amount of ozone depletion caused by a substance. The ODP is the ratio of the impact on ozone of a chemical compared to the impact of a similar mass of CFC-11

(fluorotrichloromethane). Thus, the ODP of CFC-11 is defined to be 1.0. Other CFCs and HCFCs have ODPs that range from 0.01 to 1.0. HFCs and HFOs

20 have zero ODP because they do not contain chlorine or other ozone depleting halogens.

As used herein, the terms "comprises," "comprising," "includes," "including," "has," "having" or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a composition, process, method, article, or

25 apparatus that comprises a list of elements is not necessarily limited to only those elements but may include other elements not expressly listed or inherent to such composition, process, method, article, or apparatus.

The transitional phrase "consisting of" excludes any element, step, or ingredient not specified. If in the claim such would close the claim to the

inclusion of materials other than those recited except for impurities ordinarily associated therewith. When the phrase "consists of" appears in a clause of the body of a claim, rather than immediately following the preamble, it limits only the element set forth in that clause; other elements are not excluded from the claim

5 as a whole.

The transitional phrase "consisting essentially of" is used to define a composition, method or apparatus that includes materials, steps, features, components, or elements, in addition to those literally disclosed provided that these additional included materials, steps, features, components, or elements do not materially affect the basic and novel characteristic(s) of the claimed invention. The term 'consisting essentially of' occupies a middle ground between "comprising" and 'consisting of'. Typically, components of the refrigerant mixtures and the refrigerant mixtures themselves can contain minor amounts (e.g., less than about 0.5 weight percent total) of impurities and/or byproducts (e.g., from the manufacture of the refrigerant components or reclamation of the refrigerant components from other systems) which do not materially affect the novel and basic characteristics of the refrigerant mixture.

10

15

Where applicants have defined an invention or a portion thereof with an open-ended term such as "comprising," it should be readily understood that (unless otherwise stated) the description should be interpreted to also describe such an invention using the terms "consisting essentially of" or "consisting of."

20

Also, use of "a" or "an" are employed to describe elements and components described herein. This is done merely for convenience and to give a general sense of the scope of the invention. This description should be read to include one or at least one and the singular also includes the plural unless it is obvious that it is meant otherwise.

25

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although methods and materials similar or

equivalent to those described herein can be used in the practice or testing of embodiments of the disclosed compositions, suitable methods and materials are described below. All publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their entirety,

5 unless a particular passage is cited. In case of conflict, the present specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

2,3,3,3-tetrafluoropropene may also be referred to as HFO-1234yf, HFC-1234yf, or R-1234yf. HFO-1234yf may be made by methods known in the art, 10 such as by dehydrofluorination 1,1,1,2,3-pentafluoropropane (HFC-245eb) or 1,1,1,2,2-pentafluoropropane (HFC-245cb).

Difluoromethane (HFC-32 or R-32) is commercially available or may be made by methods known in the art, such as by dechlorofluorination of methylene chloride.

15 Carbon dioxide (CO₂) is commercially available from many gas supply houses or may be produced by any of numerous well known methods.

Compositions

The refrigerants industry has struggled to develop new refrigerant products that provide acceptable performance and environmental sustainability. New

20 global warming regulations may place a cap on global warming potential (GWP) for new refrigerant compositions. Thus, the industry must find, low GWP, low-toxicity, low ozone depletion potential (ODP) compositions that also provide good performance for cooling and heating. R-410A (a blend of 50 weight percent HFC-32 and 50 weight percent HFC-125) has been used in air conditioning and heat pumps for many years as an alternative for R-22, but it too has high GWP and must be replaced. The compositions as described herein provide such a replacement with lower GWP than previously proposed replacement refrigerants.

In one embodiment, refrigerant mixtures have GWP of 400 or less, based on AR4 data. In another embodiment, refrigerant mixtures have GWP of 300 or less, based on AR4 data.

The present inventors have identified compositions that provide performance properties to serve as replacements for R-410A in refrigeration, air conditioning and heat pump apparatus. These compositions comprise refrigerant mixtures consisting essentially of difluoromethane, 2,3,3,3-tetrafluoropropene, and carbon dioxide. In one embodiment, the compositions comprising refrigerant mixtures consist of difluoromethane, 2,3,3,3-tetrafluoropropene, and carbon dioxide.

Identifying replacement refrigerants with the right balance of properties needed by certain applications is not a trivial undertaking. The industry has struggled to find high capacity refrigerants with reasonable temperature glide. In particular, a refrigerant for replacing R-410A that can match the cooling capacity of R-410A with an acceptable temperature glide and with GWP of 400 or less, or even 300 or less has been desired.

Disclosed herein are compositions comprising refrigerant mixtures for replacing R-410A said refrigerant mixtures consisting essentially of from about 42 to about 59 weight percent difluoromethane (HFC-32), about 33 to about 53 weight percent 2,3,3,3-tetrafluoropropene (HFO-1234yf), and about 1 to about 9 weight percent carbon dioxide (CO₂).

In another embodiment, said refrigerant mixture consists essentially of from about 42 to about 59 weight percent HFC-32, about 35 to about 51 weight percent 2,3,3,3-tetrafluoropropene, and about 2 to about 9 weight percent CO₂.

In another embodiment, said refrigerant mixture consisting essentially of about 42 to 59 weight percent HFC-32, about 37 to 48 weight percent 2,3,3,3-tetrafluoropropene, and about 3 to 9 weight percent CO₂.

In another embodiment, said refrigerant mixture consisting essentially of about 42 to 47 weight percent HFC-32, about 40 to 49 weight percent 2,3,3,3-tetrafluoropropene, and about 3 to 9 weight percent CO₂.

In another embodiment, said refrigerant mixture consisting essentially of about 44 to 47 weight percent HFC-32, about 40 to 49 weight percent 2,3,3,3-tetrafluoropropene, and about 5 to 9 weight percent CO₂.

5 In another embodiment, said refrigerant mixture consisting essentially of about 42 to 45 weight percent difluoromethane, about 46 to 49 weight percent 2,3,3,3-tetrafluoropropene, and about 6 to 9 weight percent CO₂.

In another embodiment, said refrigerant mixture consisting essentially of about 42 to 44 weight percent HFC-32, about 48 to 51 weight percent 2,3,3,3-tetrafluoropropene, and about 7 to 9 weight percent CO₂.

10 In another embodiment, said refrigerant mixture consisting essentially of about 43 to 44 weight percent HFC-32, about 48 to 50 weight percent 2,3,3,3-tetrafluoropropene, and about 7 to 8 weight percent CO₂.

15 In another embodiment, said refrigerant mixture consisting essentially of about 44 weight percent HFC-32, about 49 weight percent 2,3,3,3-tetrafluoropropene, and about 7 weight percent CO₂.

In another embodiment, said refrigerant mixture consisting essentially of from about 47 to about 59 weight percent difluoromethane, about 37 to about 49 weight percent 2,3,3,3-tetrafluoropropene, and about 3 to about 8 weight percent carbon dioxide.

20 In another embodiment, said refrigerant mixture consisting essentially of from about 52 to about 59 weight percent difluoromethane, about 37 to about 42 weight percent 2,3,3,3-tetrafluoropropene, and about 3 to about 6 weight percent carbon dioxide.

25 In another embodiment, said refrigerant mixture consisting essentially of from about 57 to about 59 weight percent difluoromethane, about 37 to about 39 weight percent 2,3,3,3-tetrafluoropropene, and about 3 to about 5 weight percent carbon dioxide.

In another embodiment, said refrigerant mixture consisting essentially of about 58 weight percent difluoromethane, about 38 weight percent 2,3,3,3-tetrafluoropropene, and about 4 weight percent carbon dioxide.

In any of the above embodiment, the total of the refrigerant mixture, must of course add to 100%.

In one embodiment, the refrigerant mixtures provide replacements for R-410A with cooling capacity within 10% of the cooling capacity for R-410A. In another embodiment, the refrigerant mixtures provide replacements for R-410A with cooling capacity within 5% of the cooling capacity for R-410A. In another embodiment, the refrigerant mixtures provide replacements for R-410A with cooling capacity within 2% of the cooling capacity for R-410A. In another embodiment, the refrigerant mixtures provide replacements for R-410A with cooling capacity that matches or improves upon the cooling capacity for R-410A.

In one embodiment, the refrigerant mixtures provide replacements for R-410A with average temperature glide in the heat exchangers of less than 8.0°C. In another embodiment, the refrigerant mixtures provide replacements for R-410A with average temperature glide in the heat exchangers of less than 7.5°C.

Of particular interest, as replacements for R-410A, are compositions as listed in Table A.

20

Table A

R32/R1234yf/CO ₂ (wt%)	
59/39/2	44/53/3
59/38/3	44/52/4
59/37/4	44/51/5
59/36/5	44/50/6
59/35/6	44/49/7
59/34/7	44/48/8
59/33/8	43/53/4
58/41/1	43/52/5
58/40/2	43/51/6
58/39/3	43/50/7

R32/R1234yf/CO ₂ (wt%)	
58/38/4	43/49/8
58/37/5	42/53/5
58/36/6	42/52/6
58/35/7	42/51/7
58/34/8	42/50/8
57/39/4	50/45/5
56/40/4	49/46/5
55/40/5	48/47/5
54/42/4	47/48/5
53/41/6	46/49/5
52/42/6	45/48/7
51/43/6	

In some embodiments, in addition to the difluoromethane, 2,3,3,3-tetrafluoropropene, and carbon dioxide, the disclosed compositions may comprise optional non-refrigerant components. Thus, disclosed herein are

5 compositions comprising a refrigerant mixture consisting essentially of difluoromethane, 2,3,3,3-tetrafluoropropene, and carbon dioxide, further comprising one or more optional non-refrigerant components selected from the group consisting of lubricants, dyes (including UV dyes), solubilizing agents, compatibilizers, stabilizers, tracers, anti-wear agents, extreme pressure agents,

10 corrosion and oxidation inhibitors, metal surface energy reducers, metal surface deactivators, free radical scavengers, foam control agents, viscosity index improvers, pour point depressants, detergents, viscosity adjusters, and mixtures thereof. In some embodiments, the optional non-refrigerant components may be referred to as additives. Indeed, many of these optional non-refrigerant

15 components fit into one or more of these categories and may have qualities that lend themselves to achieve one or more performance characteristic.

In some embodiments, one or more non-refrigerant components are present in small amounts relative to the overall composition. In some embodiments, the amount of additive(s) concentration in the disclosed compositions is from less

than about 0.1 weight percent to as much as about 5 weight percent of the total composition. In some embodiments of the present invention, the additives are present in the disclosed compositions in an amount between about 0.1 weight percent to about 5 weight percent of the total composition or in an amount

5 between about 0.1 weight percent to about 3.5 weight percent. The additive component(s) selected for the disclosed composition is selected on the basis of the utility and/or individual equipment components or the system requirements.

In one embodiment, the lubricant is selected from the group consisting of mineral oil, alkylbenzene, polyol esters, polyalkylene glycols, polyvinyl ethers, 10 polycarbonates, perfluoropolyethers, silicones, silicate esters, phosphate esters, paraffins, naphthenes, polyalpha-olefins, and combinations thereof.

The lubricants as disclosed herein may be commercially available lubricants. For instance, the lubricant may be paraffinic mineral oil, sold by BVA Oils as BVM 100 N, naphthenic mineral oils sold by Crompton Co. under the trademarks

15 Suniso® 1GS, Suniso® 3GS and Suniso® 5GS, naphthenic mineral oil sold by Pennzoil under the trademark Sontex® 372LT, naphthenic mineral oil sold by Calumet Lubricants under the trademark Calumet® RO-30, linear alkylbenzenes sold by Shrieve Chemicals under the trademarks Zerol® 75, Zerol® 150 and Zerol® 500 and branched alkylbenzene sold by Nippon Oil as HAB 22, polyol 20 esters (POEs) sold under the trademark Castrol® 100 by Castrol, United Kingdom, polyalkylene glycols (PAGs) such as RL-488A from Dow (Dow Chemical, Midland, Michigan), and mixtures thereof, meaning mixtures of any of the lubricants disclosed in this paragraph.

In the compositions of the present invention including a lubricant, the lubricant is present in an amount of less than 40.0 weight percent to the total composition. In other embodiments, the amount of lubricant is less than 20 weight percent of the total composition. In other embodiments, the amount of lubricant is less than 10 weight percent of the total composition. In other embodiments, the about of lubricant is between about 0.1 and 5.0 weight

30 percent of the total composition.

Notwithstanding the above weight ratios for compositions disclosed herein, it is understood that in some heat transfer systems, while the composition is being used, it may acquire additional lubricant from one or more equipment components of such heat transfer system. For example, in some refrigeration, 5 air conditioning and heat pump systems, lubricants may be charged in the compressor and/or the compressor lubricant sump. Such lubricant would be in addition to any lubricant additive present in the refrigerant in such a system. In use, the refrigerant composition when in the compressor may pick up an amount of the equipment lubricant to change the refrigerant-lubricant composition from 10 the starting ratio.

The non-refrigerant component used with the compositions of the present invention may include at least one dye. The dye may be at least one ultra-violet (UV) dye. The UV dye may be a fluorescent dye. The fluorescent dye may be selected from the group consisting of naphthalimides, perylenes, coumarins, 15 anthracenes, phenanthracenes, xanthenes, thioxanthenes, naphthoxanthenes, fluoresceins, and derivatives of said dye, and combinations thereof, meaning mixtures of any of the foregoing dyes or their derivatives disclosed in this paragraph.

In some embodiments, the disclosed compositions contain from about 0.001 20 weight percent to about 1.0 weight percent UV dye. In other embodiments, the UV dye is present in an amount of from about 0.005 weight percent to about 0.5 weight percent; and in other embodiments, the UV dye is present in an amount of from 0.01 weight percent to about 0.25 weight percent of the total composition.

25 UV dye is a useful component for detecting leaks of the composition by permitting one to observe the fluorescence of the dye at or in the vicinity of a leak point in an apparatus (e.g., refrigeration unit, air-conditioner or heat pump). The UV emission, e.g., fluorescence from the dye may be observed under an ultra-violet light. Therefore, if a composition containing such a UV dye is leaking

from a given point in an apparatus, the fluorescence can be detected at the leak point, or in the vicinity of the leak point.

Another non-refrigerant component which may be used with the compositions of the present invention may include at least one solubilizing agent 5 selected to improve the solubility of one or more dye in the disclosed compositions. In some embodiments, the weight ratio of dye to solubilizing agent ranges from about 99:1 to about 1:1. The solubilizing agents include at least one compound selected from the group consisting of hydrocarbons, hydrocarbon ethers, polyoxyalkylene glycol ethers (such as dipropylene glycol 10 dimethyl ether), amides, nitriles, ketones, chlorocarbons (such as methylene chloride, trichloroethylene, chloroform, or mixtures thereof), esters, lactones, aromatic ethers, fluoroethers and 1,1,1-trifluoroalkanes and mixtures thereof, meaning mixtures of any of the solubilizing agents disclosed in this paragraph.

In some embodiments, the non-refrigerant component comprises at least one 15 compatibilizer to improve the compatibility of one or more lubricants with the disclosed compositions. The compatibilizer may be selected from the group consisting of hydrocarbons, hydrocarbon ethers, polyoxyalkylene glycol ethers (such as dipropylene glycol dimethyl ether), amides, nitriles, ketones, chlorocarbons (such as methylene chloride, trichloroethylene, chloroform, or 20 mixtures thereof), esters, lactones, aromatic ethers, fluoroethers, 1,1,1-trifluoroalkanes, and mixtures thereof, meaning mixtures of any of the compatibilizers disclosed in this paragraph.

The solubilizing agent and/or compatibilizer may be selected from the group 25 consisting of hydrocarbon ethers consisting of the ethers containing only carbon, hydrogen and oxygen, such as dimethyl ether (DME) and mixtures thereof, meaning mixtures of any of the hydrocarbon ethers disclosed in this paragraph.

The compatibilizer may be linear or cyclic aliphatic or aromatic hydrocarbon compatibilizer containing from 3 to 15 carbon atoms. The compatibilizer may be at least one hydrocarbon, which may be selected from the group consisting of at

least propanes, including propylene and propane, butanes, including n-butane and isobutene, pentanes, including n-pentane, isopentane, neopentane and cyclopentane, hexanes, octanes, nonane, and decanes, among others.

Commercially available hydrocarbon compatibilizers include but are not limited

5 to those from Exxon Chemical (USA) sold under the trademarks Isopar® H, a mixture of undecane (C₁₁) and dodecane (C₁₂) (a high purity C₁₁ to C₁₂ iso-paraffinic), Aromatic 150 (a C₉ to C₁₁ aromatic), Aromatic 200 (a C₉ to C₁₅ aromatic) and Naptha 140 (a mixture of C₅ to C₁₁ paraffins, naphthenes and aromatic hydrocarbons) and mixtures thereof, meaning mixtures of any of the

10 hydrocarbons disclosed in this paragraph.

The compatibilizer may alternatively be at least one polymeric compatibilizer. The polymeric compatibilizer may be a random copolymer of fluorinated and non-fluorinated acrylates, wherein the polymer comprises repeating units of at least one monomer represented by the formulae CH₂=C(R¹)CO₂R²,

15 CH₂=C(R³)C₆H₄R⁴, and CH₂=C(R⁵)C₆H₄XR⁶, wherein X is oxygen or sulfur; R¹, R³, and R⁵ are independently selected from the group consisting of H and C₁-C₄ alkyl radicals; and R², R⁴, and R⁶ are independently selected from the group consisting of carbon-chain-based radicals containing C, and F, and may further contain H, Cl, ether oxygen, or sulfur in the form of thioether, sulfoxide, or

20 sulfone groups and mixtures thereof. Examples of such polymeric compatibilizers include those commercially available from E. I. du Pont de Nemours and Company, (Wilmington, DE, 19898, USA) under the trademark Zonyl® PHS. Zonyl® PHS is a random copolymer made by polymerizing 40 weight percent CH₂=C(CH₃)CO₂CH₂CH₂(CF₂CF₂)_mF (also referred to as Zonyl®
25 fluoromethacrylate or ZFM) wherein m is from 1 to 12, primarily 2 to 8, and 60 weight percent lauryl methacrylate (CH₂=C(CH₃)CO₂(CH₂)₁₁CH₃, also referred to as LMA).

In some embodiments, the compatibilizer component contains from about 0.01 to 30 weight percent (based on total amount of compatibilizer) of an additive

30 which reduces the surface energy of metallic copper, aluminum, steel, or other

metals and metal alloys thereof found in heat exchangers in a way that reduces the adhesion of lubricants to the metal. Examples of metal surface energy reducing additives include those commercially available from DuPont under the trademarks Zonyl® FSA, Zonyl® FSP, and Zonyl® FSJ.

5 Another optional non-refrigerant component which may be used with the compositions of the present invention may be a metal surface deactivator. The metal surface deactivator is selected from the group consisting of areoxalyl bis (benzylidene) hydrazide (CAS reg no. 6629-10-3), N,N'-bis(3,5-di-tert-butyl-4-hydroxyhydrocinnamoylhydrazine (CAS reg no. 32687-78-8), 2,2,' - oxamidobis-10 ethyl-(3,5-di-tert-butyl-4-hydroxyhydrocinnamate (CAS reg no. 70331-94-1), N,N'-(disalicyclidene)-1,2-diaminopropane (CAS reg no. 94-91-7) and ethylenediaminetetra-acetic acid (CAS reg no. 60-00-4) and its salts, and mixtures thereof, meaning mixtures of any of the metal surface deactivators disclosed in this paragraph.

15 The optional non-refrigerant component used with the compositions of the present invention may alternatively be a stabilizer selected from the group consisting of hindered phenols, thiophosphates, butylated triphenylphosphorothionates, organo phosphates, or phosphites, aryl alkyl ethers, terpenes, terpenoids, epoxides, fluorinated epoxides, oxetanes, ascorbic acid, thiols, lactones, thioethers, amines, nitromethane, alkylsilanes, benzophenone derivatives, aryl sulfides, divinyl terephthalic acid, diphenyl terephthalic acid, ionic liquids, and mixtures thereof, meaning mixtures of any of the stabilizers disclosed in this paragraph.

20 The stabilizer may be selected from the group consisting of tocopherol; hydroquinone; t-butyl hydroquinone; monothiophosphates; and dithiophosphates, commercially available from Ciba Specialty Chemicals, Basel, Switzerland, hereinafter "Ciba", under the trademark Irgalube® 63; dialkylthiophosphate esters, commercially available from Ciba under the trademarks Irgalube® 353 and Irgalube® 350, respectively; butylated 25 triphenylphosphorothionates, commercially available from Ciba under the

trademark Irgalube® 232; amine phosphates, commercially available from Ciba under the trademark Irgalube® 349 (Ciba); hindered phosphites, commercially available from Ciba as Irgafos® 168 and Tris-(di-tert-butylphenyl)phosphite, commercially available from Ciba under the trademark Irgafos® OPH; (Di-n-octyl phosphite); and iso-decyl diphenyl phosphite, commercially available from Ciba under the trademark Irgafos® DDPP; trialkyl phosphates, such as trimethyl phosphate, triethylphosphate, tributyl phosphate, trioctyl phosphate, and tri(2-ethylhexyl)phosphate; triaryl phosphates including triphenyl phosphate, tricresyl phosphate, and trixylenyl phosphate; and mixed alkyl-aryl phosphates including 5 isopropylphenyl phosphate (IPPP), and bis(t-butylphenyl)phenyl phosphate (TBPP); butylated triphenyl phosphates, such as those commercially available under the trademark Syn-O-Ad® including Syn-O-Ad® 8784; tert-butylated triphenyl phosphates such as those commercially available under the trademark Durad®620; isopropylated triphenyl phosphates such as those commercially 10 available under the trademarks Durad® 220 and Durad®110; anisole; 1,4-dimethoxybenzene; 1,4-diethoxybenzene; 1,3,5-trimethoxybenzene; myrcene, alloocimene, limonene (in particular, d-limonene); retinal; pinene; menthol; geraniol; farnesol; phytol; Vitamin A; terpinene; delta-3-carene; terpinolene; phellandrene; fenchene; dipentene; carotenoids, such as lycopene, beta 15 carotene, and xanthophylls, such as zeaxanthin; retinoids, such as hepxanthin and isotretinoin; bornane; 1,2-propylene oxide; 1,2-butylene oxide; n-butyl glycidyl ether; trifluoromethyloxirane; 1,1-bis(trifluoromethyl)oxirane; 3-ethyl-3-hydroxymethyl-oxetane, such as OXT-101 (Toagosei Co., Ltd); 3-ethyl-3-((phenoxy)methyl)-oxetane, such as OXT-211 (Toagosei Co., Ltd); 3-ethyl-3-((2-20 ethyl-hexyloxy)methyl)-oxetane, such as OXT-212 (Toagosei Co., Ltd); ascorbic acid; methanethiol (methyl mercaptan); ethanethiol (ethyl mercaptan); Coenzyme A; dimercaptosuccinic acid (DMSA); grapefruit mercaptan ((R)-2-(4-methylcyclohex-3-enyl)propane-2-thiol)); cysteine ((R)-2-amino-3-sulfanyl-propanoic acid); lipoamide (1,2-dithiolane-3-pentanamide); 5,7-bis(1,1-dimethylethyl)-3-[2,3(or 3,4)-dimethylphenyl]-2(3H)-benzofuranone, 25 commercially available from Ciba under the trademark Irganox® HP-136; benzyl 30

phenyl sulfide; diphenyl sulfide; diisopropylamine; dioctadecyl 3,3'-thiodipropionate, commercially available from Ciba under the trademark Irganox® PS 802 (Ciba); didodecyl 3,3'-thiopropionate, commercially available from Ciba under the trademark Irganox® PS 800; di-(2,2,6,6-tetramethyl-4-piperidyl)sebacate, commercially available from Ciba under the trademark Tinuvin® 770; poly-(N-hydroxyethyl-2,2,6,6-tetramethyl-4-hydroxy-piperidyl succinate, commercially available from Ciba under the trademark Tinuvin® 622LD (Ciba); methyl bis tallow amine; bis tallow amine; phenol-alpha-naphthylamine; bis(dimethylamino)methylsilane (DMAMS);

10 tris(trimethylsilyl)silane (TTMSS); vinyltriethoxysilane; vinyltrimethoxysilane; 2,5-difluorobenzophenone; 2',5'-dihydroxyacetophenone; 2-aminobenzophenone; 2-chlorobenzophenone; benzyl phenyl sulfide; diphenyl sulfide; dibenzyl sulfide; ionic liquids; and mixtures and combinations thereof.

The optional non-refrigerant component used with the compositions of the present invention may alternatively be an ionic liquid stabilizer. The ionic liquid stabilizer may be selected from the group consisting of organic salts that are liquid at room temperature (approximately 25 °C), those salts containing cations selected from the group consisting of pyridinium, pyridazinium, pyrimidinium, pyrazinium, imidazolium, pyrazolium, thiazolium, oxazolium and triazolium and mixtures thereof; and anions selected from the group consisting of [BF₄]-, [PF₆]-, [SbF₆]-, [CF₃SO₃]-, [HCF₂CF₂SO₃]-, [CF₃HFCCF₂SO₃]-, [HCCIFCF₂SO₃]-, [(CF₃SO₂)₂N]-, [(CF₃CF₂SO₂)₂N]-, [(CF₃SO₂)₃C]-, [CF₃CO₂]-, and F- and mixtures thereof. In some embodiments, ionic liquid stabilizers are selected from the group consisting of emim BF₄ (1-ethyl-3-methylimidazolium tetrafluoroborate); bmim BF₄ (1-butyl-3-methylimidazolium tetraborate); emim PF₆ (1-ethyl-3-methylimidazolium hexafluorophosphate); and bmim PF₆ (1-butyl-3-methylimidazolium hexafluorophosphate), all of which are available from Fluka (Sigma-Aldrich).

In some embodiments, the stabilizer may be a hindered phenol, which is any substituted phenol compound, including phenols comprising one or more

substituted or cyclic, straight chain, or branched aliphatic substituent group, such as, alkylated monophenols including 2,6-di-tert-butyl-4-methylphenol; 2,6-di-tert-butyl-4-ethylphenol; 2,4-dimethyl-6-tertbutylphenol; tocopherol; and the like, hydroquinone and alkylated hydroquinones including t-butyl hydroquinone, other

5 derivatives of hydroquinone; and the like, hydroxylated thiodiphenyl ethers, including 4,4'-thio-bis(2-methyl-6-tert-butylphenol); 4,4'-thiobis(3-methyl-6-tertbutylphenol); 2,2'-thiobis(4methyl-6-tert-butylphenol); and the like, alkylidene-bisphenols including,: 4,4'-methylenebis(2,6-di-tert-butylphenol); 4,4'-bis(2,6-di-tert-butylphenol); derivatives of 2,2'- or 4,4-biphenoldiols; 2,2'-methylenebis(4-

10 ethyl-6-tertbutylphenol); 2,2'-methylenebis(4-methyl-6-tertbutylphenol); 4,4-butylidenebis(3-methyl-6-tert-butylphenol); 4,4-isopropylidenebis(2,6-di-tert-butylphenol); 2,2'-methylenebis(4-methyl-6-nonylphenol); 2,2'-isobutylidenebis(4,6-dimethylphenol); 2,2'-methylenebis(4-methyl-6-cyclohexylphenol, 2,2- or 4,4- biphenyldiols including 2,2'-methylenebis(4-ethyl-6-tert-butylphenol); butylated hydroxytoluene (BHT, or 2,6-di-tert-butyl-4-

15 methylphenol), bisphenols comprising heteroatoms including 2,6-di-tert-alpha-dimethylamino-p-cresol, 4,4-thiobis(6-tert-butyl-m-cresol); and the like; acylaminophenols; 2,6-di-tert-butyl-4(N,N'-dimethylaminomethylphenol); sulfides including; bis(3-methyl-4-hydroxy-5-tert-butylbenzyl)sulfide; bis(3,5-di-tert-butyl-4-hydroxybenzyl)sulfide and mixtures thereof, meaning mixtures of any of the phenols disclosed in this paragraph.

In some embodiments, a stabilizer may be a single stabilizing compound as described in detail above. In other embodiments, a stabilizer may be a mixture of two or more of the stabilizing compounds, either from the same class of

25 compounds or from differing classes of compounds, said classes being described in detail above.

The optional non-refrigerant component which is used with compositions of the present invention may alternatively be a tracer. The tracer may be a single compound or two or more tracer compounds from the same class of compounds or from different classes of compounds. In some embodiments, the tracer is

present in the compositions at a total concentration of about 1 part per million by weight (ppm) to about 5000 ppm, based on the weight of the total composition. In other embodiments, the tracer is present at a total concentration of about 10 ppm to about 1000 ppm. In other embodiments, the tracer is present at a total concentration of about 20 ppm to about 500 ppm. In other embodiments, the tracer is present at a total concentration of about 25 ppm to about 500 ppm. In other embodiments, the tracer is present at a total concentration of about 50 ppm to about 500 ppm. Alternatively, the tracer is present at a total concentration of about 100 ppm to about 300 ppm.

10 The tracer may be selected from the group consisting of hydrofluorocarbons (HFCs), deuterated hydrofluorocarbons, chlorofluorocarbons (CFCs), hydrofluorochlorocarbons (HCFCs), chlorocarbons, perfluorocarbons, fluoroethers, brominated compounds, iodated compounds, alcohols, aldehydes and ketones, nitrous oxide and combinations thereof. Alternatively, the tracer

15 may be selected from the group consisting of trifluoromethane (HFC-23), dichlorodifluoromethane (CFC-12), chlorodifluoromethane HCFC-22), methyl chloride (R-40), chlorofluoromethane (HCFC-31), fluoroethane (HFC-161), 1,1,-difluoroethane (HFC-152a), 1,1,1-trifluoroethane (HFC-143a), chloropentafluoroethane (CFC-115), 1,2-dichloro-1,1,2,2-tetrafluoroethane

20 (CFC-114), 1,1-dichloro-1,2,2,2-tetrafluoroethane (CFC-114a), 2-chloro-1,1,1,2-tetrafluoroethane (HCFC-124), pentafluoroethane (HFC-125), 1,1,2,2-tetrafluoroethane (HFC-134), 1,1,1,2-tetrafluoroethane (HFC-134a), 1,1,1,3,3,3-hexafluoropropane (HFC-236fa), 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea), 1,1,1,2,2,3,3-heptafluoropropane (HFC-227ea), 1,1,1,3,3,3-pentafluoropropane(HFC-245fa), 1,1,1,2,2-pentafluoropropane (HFC-245cb), 1,1,1,2,3-pentafluoropropane (HFC-245eb), 1,1,2,2-tetrafluoropropane (HFC-254cb), 1,1,1,2-tetrafluoropropane (HFC-254eb), 1,1,1-trifluoropropane (HFC-263fb), 1,1-difluoro-2-chloroethylene (HCFC-1122), 2-chloro-1,1,2-trifluoroethylene (CFC-1113), 1,1,1,3,3-pentafluorobutane (HFC-365mfc),

25 1,1,1,2,3,4,4,5,5,5-decafluoropentane (HFC-43-10mee), 1,1,1,2,2,3,4,5,5,6,6,7,7,7-tetradecafluoroheptane, hexafluorobutadiene, 3,3,3-

trifluoropropyne, iodotrifluoromethane, deuterated hydrocarbons, deuterated hydrofluorocarbons, perfluorocarbons, fluoroethers, brominated compounds, iodated compounds, alcohols, aldehydes, ketones, nitrous oxide (N₂O) and mixtures thereof. In some embodiments, the tracer is a blend containing two or 5 more hydrofluorocarbons, or one hydrofluorocarbon in combination with one or more perfluorocarbons. In other embodiments, the tracer is a blend of at least one CFC and at least one HCFC, HFC, or PFC.

The tracer may be added to the compositions of the present invention in predetermined quantities to allow detection of any dilution, contamination or 10 other alteration of the composition. Additionally, the tracers may allow detection of product that infringes existing patent rights, by identification of the patent owner's product versus competitive infringing product. Further, in one embodiment, the tracer compounds may allow detection of a manufacturing process by which a product is produced, thus, allowing detection of infringement 15 of a patent to specific manufacturing process chemistry.

The additive which may be used with the compositions of the present invention may alternatively be a perfluoropolyether as described in detail in US2007-0284555, incorporated herein by reference.

It will be recognized that certain of the additives referenced above as suitable 20 for the non-refrigerant component have been identified as potential refrigerants. However, in accordance with this invention, when these additives are used, they are not present at an amount that would affect the novel and basic characteristics of the refrigerant mixtures of this invention. Preferably, the refrigerant mixtures and the compositions of this invention containing them, 25 contain no more than about 0.5 weight percent of the refrigerants other than HFC-32, HFO-1234yf, and CO₂.

In one embodiment, the compositions disclosed herein may be prepared by any convenient method to combine the desired amounts of the individual components. A preferred method is to weigh the desired component amounts

and thereafter combine the components in an appropriate vessel. Agitation may be used, if desired.

Compositions of the present invention have zero ozone depletion potential and low global warming potential (GWP). Additionally, the compositions of the 5 present invention will have global warming potentials that are less than many hydrofluorocarbon refrigerants currently in use and even less than many proposed replacement products.

Apparatus and Methods of Use

The compositions disclosed herein are useful as heat transfer compositions 10 or refrigerants. In particular, the compositions comprising a refrigerant mixture consisting essentially of HFC-32, HFO-1234yf, and CO₂ are useful as refrigerants. Also, the compositions comprising a refrigerant mixture consisting essentially of HFC-32, HFO-1234yf, and CO₂ are useful as replacements for R-410A in refrigeration, air conditioning or heat pump systems. In particular, the 15 compositions comprising a refrigerant mixture consisting essentially of HFC-32, HFO-1234yf, and CO₂ are useful as replacements for R-410A in air conditioning and heat pump systems and apparatus. Alternatively, the compositions comprising a refrigerant mixture consisting of HFC-32, HFO-1234yf, and CO₂ are useful as replacements for R-410A in air conditioning and heat pump 20 systems and apparatus. Additionally, the compositions comprising a refrigerant mixture consisting essentially of HFC-32, HFO-1234yf, and CO₂ are useful as replacements for R-410A in refrigeration systems and apparatus. Further, the compositions comprising a refrigerant mixture consisting of HFC-32, HFO-1234yf, and CO₂ are useful as replacements for R-410A in refrigeration systems 25 and apparatus. And the use of the present inventive compositions in refrigeration systems and apparatus applies to use in low temperature refrigeration and medium temperature refrigeration.

Thus, disclosed herein is a process for producing cooling comprising evaporating a composition comprising a refrigerant mixture consisting essentially 30 of HFC-32, HFO-1234yf, and CO₂ in the vicinity of a body to be cooled and

thereafter condensing said composition. Alternatively, the process for producing cooling comprises evaporating a composition comprising a refrigerant mixture consisting of HFC-32, HFO-1234yf, and CO₂ in the vicinity of a body to be cooled and thereafter condensing said composition. The use of this method can

5 be, in one embodiment, in refrigeration, air conditioning and heat pumps. In another embodiment, the use of the method for cooling can be in refrigeration. In another embodiment, the use of the method for cooling can be in low temperature refrigeration. In another embodiment, the use of the method for cooling can be in medium temperature refrigeration. In another embodiment, the

10 use of the method for cooling can be in air conditioning. In another embodiment, the use of the method for cooling can be in heat pumps.

In another embodiment, disclosed herein is a process for producing heating comprising evaporating a composition comprising a refrigerant mixture consisting essentially of HFC-32, HFO-1234yf, and CO₂ and thereafter

15 condensing said composition in the vicinity of a body to be heated. Alternatively, the process for producing heating comprises evaporating a composition comprising a refrigerant mixture consisting of HFC-32, HFO-1234yf, and CO₂ and thereafter condensing said composition in the vicinity of a body to be heated. The use of this method is, in one embodiment, in heat pumps.

20 Vapor-compression refrigeration, air conditioning and heat pump systems include an evaporator, a compressor, a condenser, and an expansion device. A refrigeration cycle re-uses refrigerant in multiple steps producing a cooling effect in one step and a heating effect in a different step. The cycle can be described simply as follows. Liquid refrigerant enters an evaporator through an expansion device, and the liquid refrigerant boils in the evaporator, by withdrawing heat from the environment, at a low temperature to form a gas and produce cooling. Often air or a heat transfer fluid flows over or around the evaporator to transfer the cooling effect caused by the evaporation of the refrigerant in the evaporator to a body to be cooled. The low-pressure gas enters a compressor where the

25 gas is compressed to raise its pressure and temperature. The higher-pressure

30

(compressed) gaseous refrigerant then enters the condenser in which the refrigerant condenses and discharges its heat to the environment. The refrigerant returns to the expansion device through which the liquid expands from the higher-pressure level in the condenser to the low-pressure level in the evaporator, thus repeating the cycle.

A body to be cooled or heated may be defined as any space, location, object or body for which it is desirable to provide cooling or heating. Examples include spaces (open or enclosed) requiring air conditioning, cooling, or heating, such as a room, an apartment, or building, such as an apartment building, university dormitory, townhouse, or other attached house or single family home, hospitals, office buildings, supermarkets, college or university classrooms or administration buildings and automobile or truck passenger compartments.

By "in the vicinity of" is meant that the evaporator of the system containing the refrigerant composition is located either within or adjacent to the body to be cooled, such that air moving over the evaporator would move into or around the body to be cooled. In the process for producing heating, "in the vicinity of" means that the condenser of the system containing the refrigerant composition is located either within or adjacent to the body to be heated, such that the air moving over the evaporator would move into or around the body to be heated.

A method is provided for replacing R-410A in air conditioning or heat pump systems comprising replacing said R-410A with a composition comprising a refrigerant mixture consisting essentially of HFC-32, HFO-1234yf, and CO₂ to said air conditioning or heat pump system in place of R-410A. Alternatively, the method for replacing R-410A in air conditioning or heat pump systems comprises replacing said R-410A with a composition comprising a refrigerant mixture consisting of HFC-32, HFO-1234yf, and CO₂ to said air conditioning or heat pump system in place of R-410A.

Often replacement refrigerants are most useful if capable of being used in the original refrigeration equipment designed for a different refrigerant.

Additionally, the compositions as disclosed herein may be useful as replacements for R-410A in equipment designed for R-410A with minimal to no system modifications. Further, the compositions may be useful for replacing R-410A in equipment specifically modified for or produced entirely for these new 5 compositions comprising HFC-32, HFO-1234yf, and CO₂.

In many applications, some embodiments of the disclosed compositions are useful as refrigerants and provide at least comparable cooling performance (meaning cooling capacity) as the refrigerant for which a replacement is being sought.

10 In one embodiment is provided a method for replacing R-410A comprising charging an air conditioning or heat pump system with a composition comprising a refrigerant mixture consisting of HFC-32, HFO-1234yf, and CO₂ as replacement for said R-410A.

15 In one embodiment of the method, the cooling capacity provided by the composition comprising a refrigerant mixture consisting essentially of HFC-32, HFO-1234yf, and CO₂ is within about $\pm 10\%$ of that produced by R-410A under the same operating conditions. In another embodiment of the method, the cooling capacity provided by the composition comprising a refrigerant mixture consisting essentially of HFC-32, HFO-1234yf, and CO₂ is within about $\pm 5\%$ of 20 that produced by R-410A under the same operating conditions. In another embodiment of the method, the cooling capacity provided by the composition comprising a refrigerant mixture consisting essentially of HFC-32, HFO-1234yf, and CO₂ is within about $\pm 2\%$ of that produced by R-410A under the same operating conditions.

25 Additionally, disclosed herein is an air conditioning or heat pump system comprising an evaporator, compressor, condenser and an expansion device characterized by containing a composition comprising HFC-32, HFO-1234yf, and CO₂.

In another embodiment, disclosed herein is a refrigeration system comprising an evaporator, compressor, condenser and an expansion device characterized by containing a composition comprising HFC-32, HFO-1234yf, and CO₂. The apparatus can be intended for low temperature refrigeration or for medium

5 temperature refrigeration.

It has been found that the compositions of the present invention will have some temperature glide in the heat exchangers. Thus, the systems will operate more efficiently if the heat exchangers are operated in counter-current mode or cross-current mode with counter-current tendency. Counter-current tendency

10 means that the closer the heat exchanger can get to counter-current mode the more efficient the heat transfer. Thus, air conditioning heat exchangers, in particular, evaporators, are designed to provide some aspect of counter-current tendency. Therefore, provided herein is an air conditioning or heat pump system wherein said system includes one or more heat exchangers (either evaporators, 15 condensers or both) that operate in counter-current mode or cross-current mode with counter-current tendency.

Additionally, the compositions of the present invention can be used in systems with heat exchangers operating in cross-current mode.

In another embodiment, provided herein is a refrigeration, air conditioning or

20 heat pump system wherein said system includes one or more heat exchangers (either evaporators, condensers or both) that operate in counter-current mode, cross-current mode, or cross-current mode with counter-current tendency.

In one embodiment, the refrigeration, air conditioning or heat pump system is a stationary refrigeration, air conditioning or heat pump system. In another

25 embodiment the refrigeration, air conditioning or heat pump system is a mobile refrigeration, air conditioning or heat pump system.

Additionally, in some embodiments, the disclosed compositions may function as primary refrigerants in secondary loop systems that provide cooling to remote locations by use of a secondary heat transfer fluid, which may comprise water,

an aqueous salt solution (e.g., calcium chloride), a glycol, carbon dioxide, or a fluorinated hydrocarbon fluid. In this case the secondary heat transfer fluid is the body to be cooled as it is adjacent to the evaporator and is cooled before moving to a second remote body to be cooled.

5 Examples of air conditioning or heat pump systems include but are not limited to residential air conditioners, residential heat pumps, chillers, including flooded evaporator chillers and direct expansion chillers, mobile air conditioning units, dehumidifiers, and combinations thereof.

As used herein, mobile refrigeration, air conditioning or heat pump systems 10 refers to any refrigeration, air conditioner or heat pump apparatus incorporated into a transportation unit for the road, rail, sea or air. Mobile air conditioning or heat pumps systems may be used in automobiles, trucks, railcars or other transportation systems. Mobile refrigeration may include transport refrigeration in trucks, airplanes, or rail cars. In addition, apparatus which are meant to 15 provide refrigeration for a system independent of any moving carrier, known as "intermodal" systems, are including in the present inventions. Such intermodal systems include "containers" (combined sea/land transport) as well as "swap bodies" (combined road and rail transport).

As used herein, stationary air conditioning or heat pump systems are 20 systems that are fixed in place during operation. A stationary air conditioning or heat pump system may be associated within or attached to buildings of any variety. These stationary applications may be stationary air conditioning and heat pumps, including but not limited to chillers, heat pumps, including residential and high temperature heat pumps, residential, commercial or 25 industrial air conditioning systems, and including window, ductless, ducted, packaged terminal, and those exterior but connected to the building such as rooftop systems.

Examples of refrigeration systems the disclosed compositions may be useful in are equipment including commercial, industrial or residential refrigerators and

freezers, ice machines, self-contained coolers and freezers, flooded evaporator chillers, direct expansion chillers, walk-in and reach-in coolers and freezers, and combination systems. In some embodiments, the disclosed compositions may be used in supermarket refrigeration systems. Additionally, stationary

5 applications may utilize a secondary loop system that uses a primary refrigerant to produce cooling in one location that is transferred to a remote location via a secondary heat transfer fluid.

In the refrigeration, air conditioning and heat pump system of the present invention, the heat exchangers will operate within certain temperature limitations.

10 For air conditioning, in one embodiment, the evaporator will operate at midpoint temperature of about 0°C to about 20°C. In another embodiment, the evaporator will operate at midpoint temperature of about 0°C to about 15°C. In yet another embodiment, the evaporator will operate at midpoint temperature of about 5°C to about 10°C.

15 For medium temperature refrigeration, in one embodiment, the evaporator will operate at midpoint temperature of about -25°C to about 0°C. In another embodiment, the evaporator will operate at midpoint temperature of about -18°C to about -1°C.

20 For low temperature refrigeration, in one embodiment, the evaporator will operate at midpoint temperature of about -45°C to about -10°C. In another embodiment, the evaporator will operate at midpoint temperature of about -40°C to about -18°C.

25 In one embodiment, the condenser will operate at an average temperature of about 15°C to about 60°C. In another embodiment, the condenser will operate at midpoint temperature of about 20°C to about 60°C. In another embodiment, the condenser will operate at midpoint temperature of about 20°C to about 50°C.

EXAMPLES

The concepts disclosed herein will be further described in the following example, which do not limit the scope of the invention described in the claims.

EXAMPLE

5 Cooling Performance

Cooling performance at typical conditions for air conditioning and heat pump apparatus for compositions of the present invention is determined and displayed in Table 1 as compared to R-410A. The GWP values are from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report,

10 Working Group I, 2007 (AR4). Average temperature glide (Average Temp Glide: the average of the temperature glide in the evaporator and the temperature glide in the condenser), cooling capacity (Capacity), and compressor discharge temperatures (Compr Disch Temp) are calculated from physical property measurements for the compositions of the present invention at the following
15 specific conditions:

	Evaporator temperature	50°F (10°C)
	Condenser temperature	115°F (46.1°C)
	Amount of superheat	20°F (11.1 K)
	Amount of subcooling	15°F (8.3 K)
20	Compressor efficiency	70%

Table 1

Composition (wt%)	GWP (AR4)	Average Temp Glide, °C	Relative Capacity to R-410A (%)	Relative COP to R-410A (%)	Compr Disch Temp, °C
R-410A (100)	2088	0.1	100	100	81.5
Comparative compositions					
R32/R1234yf/CO₂, wt%					
40/51/9	272	8.3	98%	98%	74
21.5/75.5/3	148	8.4	72%	101%	65
21.5/72.5/6	148	10.5	79%	100%	68
21.5/69.5/9	148	12.3	86%	100%	71

Composition (wt%)	GWP (AR4)	Average Temp Glide, °C	Relative Capacity to R-410A (%)	Relative COP to R-410A (%)	Compr Disch Temp, °C
R32/R1234yf					
59/41	400	1.9	92%	103%	84
58/42	393	2.0	92%	103%	84
57/43	386	2.1	91%	103%	84
56/44	380	2.2	91%	103%	83
55/45	373	2.3	90%	103%	83
R32/ R1234yf/CO₂, wt%					
59/41/1	400	2.4	94%	102%	85
59/39/2	400	2.9	96%	102%	86
59/38/3	400	3.5	99%	102%	87
59/37/4	399.8	3.9	101%	102%	87
59/36/5	399.7	4.4	103%	101%	88
59/35/6	400	4.8	105%	101%	89
59/34/7	400	5.3	107%	101%	90
59/33/8	400	5.7	109%	100%	90
58/41/1	393	2.5	94%	102%	85
58/40/2	393	3.0	96%	102%	86
58/39/3	393	3.5	98%	102%	86
58/38/4	393	4.0	100%	102%	87
58/37/5	393	4.5	102%	101%	88
58/36/6	393	4.9	104%	101%	89
58/35/7	393	5.4	107%	101%	89
58/34/8	393	5.8	109%	100%	90
57/39/4	386	4.1	98%	102%	85
56/40/4	380	4.2	98%	102%	85
55/40/5	373	4.8	99%	101%	85
54/42/4	366	4.4	97%	102%	84
53/41/6	359	5.5	100%	101%	85
52/42/6	353	5.6	99%	101%	84
51/43/6	346	5.7	99%	101%	84
50/45/5	339	5.4	96%	101%	83
49/46/5	333	5.5	96%	101%	83
48/47/5	326	5.7	95%	101%	83
47/48/5	319	5.8	94%	101%	82
46/49/5	313	6.0	94%	101%	82
45/48/7	306	7.0	97%	101%	83
44/53/3	299	5.2	90%	102%	83
44/52/4	299	5.7	92%	102%	83
44/51/5	299	6.2	94%	101%	84

Composition (wt%)	GWP (AR4)	Average Temp Glide, °C	Relative Capacity to R-410A (%)	Relative COP to R-410A (%)	Compr Disch Temp, °C
44/50/6	299	6.7	97%	101%	85
44/49/7	299	7.2	99%	101%	86
44/48/8	299	7.7	101%	100%	87
43/53/4	286	6.4	91%	99%	81
43/52/5	286	6.9	93%	99%	81
43/51/6	286	7.3	95%	98%	82
43/50/7	286	7.8	97%	98%	82
43/49/8	292	5.8	90%	100%	80
42/53/5	292	6.3	92%	99%	81
42/52/6	292	6.7	94%	99%	82
42/51/7	292	7.2	96%	98%	82
42/50/8	292	7.6	97%	98%	83

All the compositions of the present invention provided in Table 1 provide volumetric capacity within $\pm 10\%$ of that for R-410A, while providing average temperature glide less than 8°C and having reasonable compressor discharge temperatures as compared to R-410A. Many of the compositions of Table 1

5 provide volumetric capacity within $\pm 5\%$ of that for R-410A. Additionally, some of the compositions of Table 1 provide volumetric capacity within $\pm 2\%$ of that for R-410A. And all of the compositions show excellent energy efficiency (as COP relative to R-410A) that is for many of the present compositions an improvement over R-410A.

Selected Embodiments

Embodiment A1: A composition comprising a refrigerant mixture for replacing R-410A consisting essentially of difluoromethane, 2,3,3,3-tetrafluoropropene, and carbon dioxide.

- 5 Embodiment A2: The composition of Embodiment A1, comprising a refrigerant mixture for replacing R-410A said refrigerant mixture consisting essentially of from about 42 to about 59 weight percent difluoromethane, about 33 to about 53 weight percent 2,3,3,3-tetrafluoropropene, and about 1 to about 9 weight percent carbon dioxide.
- 10 Embodiment A3: The composition of any of Embodiments A1 and A2, said refrigerant mixture consisting essentially of from about 42 to about 59 weight percent difluoromethane, about 35 to about 51 weight percent 2,3,3,3-tetrafluoropropene, and about 2 to about 9 weight percent carbon dioxide.

Embodiment A4: The composition of any of Embodiments A1-A3, said

- 15 refrigerant mixture consisting essentially of about 42 to 59 weight percent difluoromethane, about 37 to 48 weight percent 2,3,3,3-tetrafluoropropene, and about 3 to 9 weight percent carbon dioxide.

Embodiment A5: The composition of any of Embodiments A1-A4, said

- 20 refrigerant mixture consisting essentially of about 42 to 47 weight percent difluoromethane, about 40 to 49 weight percent 2,3,3,3-tetrafluoropropene, and about 3 to 9 weight percent carbon dioxide.

Embodiment A6: The composition of any of Embodiments A1-A5, said

- 25 refrigerant mixture consisting essentially of about 44 to 47 weight percent HFC-32, about 40 to 49 weight percent 2,3,3,3-tetrafluoropropene, and about 5 to 9 weight percent CO₂.

Embodiment A7: The composition of any of Embodiments A1-A6 said

refrigerant mixture consisting essentially of about 42 to 45 weight percent

difluoromethane, about 46 to 49 weight percent 2,3,3,3-tetrafluoropropene, and about 6 to 9 weight percent carbon dioxide.

Embodiment A8: The composition of any of Embodiments A1-A7, said refrigerant mixture consisting essentially of about 42 to 44 weight percent difluoromethane, about 48 to 51 weight percent 2,3,3,3-tetrafluoropropene, and about 7 to 9 weight percent carbon dioxide.

Embodiment A9: The composition of any of Embodiments A1-A8, said refrigerant mixture consisting essentially of about 44 weight percent difluoromethane, about 49 weight percent 2,3,3,3-tetrafluoropropene, and about 7 weight percent carbon dioxide.

Embodiment A10: The composition of any of Embodiments A1, said refrigerant mixture consisting essentially of from about 47 to about 59 weight percent difluoromethane, about 37 to about 49 weight percent 2,3,3,3-tetrafluoropropene, and about 3 to about 8 weight percent carbon dioxide.

15 Embodiment A11: The composition of any of Embodiments A1 and A10 said refrigerant mixture consisting essentially of from about 52 to about 59 weight percent difluoromethane, about 37 to about 42 weight percent 2,3,3,3-tetrafluoropropene, and about 3 to about 6 weight percent carbon dioxide.

20 Embodiment A12: The composition of any of Embodiments A1, A10 and A11, said refrigerant mixture consisting essentially of about 58 weight percent difluoromethane, about 38 weight percent 2,3,3,3-tetrafluoropropene, and about 4 weight percent carbon dioxide.

25 Embodiment A13: The composition of any of Embodiments A1 and A10-A12, said refrigerant mixture consisting essentially of about 58 weight percent difluoromethane, about 38 weight percent 2,3,3,3-tetrafluoropropene, and about 4 weight percent carbon dioxide.

Embodiment A14: The composition of any of Embodiments A1-A13, further comprising one or more components selected from the group consisting of

lubricants, dyes, solubilizing agents, compatibilizers, stabilizers, tracers, anti-wear agents, extreme pressure agents, corrosion and oxidation inhibitors, metal surface energy reducers, metal surface deactivators, free radical scavengers, foam control agents, viscosity index improvers, pour point depressants,

5 detergents, viscosity adjusters, and mixtures thereof.

Embodiment A15: The composition of any of Embodiments A1- A13, further comprising a lubricant selected from the group consisting of mineral oil, alkylbenzene, polyol esters, polyalkylene glycols, polyvinyl ethers, polycarbonates, perfluoropolyethers, synthetic paraffins, synthetic naphthenes, 10 polyalpha-olefins, and combinations thereof.

Embodiment A16: The composition of Embodiments A14, wherein said lubricant is selected from the group consisting of mineral oil, alkylbenzene, polyol esters, polyalkylene glycols, polyvinyl ethers, polycarbonates, perfluoropolyethers, synthetic paraffins, synthetic naphthenes, polyalpha-olefins, and combinations 15 thereof.

Embodiment B1: A process for producing cooling comprising condensing the composition of any of Embodiments A1-A12 and thereafter evaporating said composition in the vicinity of a body to be cooled.

Embodiment B2: A process for producing heating comprising evaporating

20 composition of any of Embodiments A1-A12 and thereafter condensing said composition in the vicinity of a body to be heated.

Embodiment C1: A method of replacing R-410A in air conditioning or heat pump systems comprising providing the composition of any of Embodiments A1-A12 to the system as replacement for said R-410A in said air conditioning or heat pump 25 system.

Embodiment C2: A method of replacing R-410A in refrigeration systems comprising providing the composition of any of Embodiments A1-A12 to the system as replacement for said R-410A in said air conditioning or heat pump system.

Embodiment C3: The method of Embodiment C1, wherein said system comprises an evaporator and wherein said evaporator operates with midpoint temperature between about 0°C to about 20°C.

Embodiment C4: The method of Embodiment C2, wherein said system

5 comprises an evaporator and wherein said evaporator operates with midpoint temperature between about -45°C and about -10°C.

Embodiment C5: The method of Embodiment C2, wherein said system comprises an evaporator and wherein said evaporator operates with midpoint temperature between about -25°C and about 0°C.

10 Embodiment D1: An air conditioning or heat pump system comprising an evaporator, a compressor, a condenser, and an expansion device, characterized by containing the composition of any of Embodiments A1-A12.

Embodiment D2: The air conditioning or heat pump system of Embodiment D1, wherein said system includes one or more heat exchangers that operate in

15 counter-current mode, cross-current mode, or cross-current mode with counter-current tendency.

Embodiment D3: A refrigeration system comprising an evaporator, a compressor, a condenser, and an expansion device, characterized by containing the composition of any of Embodiments A1-A12.

20 Embodiment D4: The refrigeration system of Embodiment D3, wherein said system includes one or more heat exchangers that operate in counter-current mode, cross-current mode, or cross-current mode with counter-current tendency.

Embodiment D5: The refrigeration system of Embodiment D3 or D4, wherein said system comprises a low temperature refrigeration system, and wherein said

25 evaporator operates at a midpoint temperature between about -45°C and about -10°C.

Embodiment D6: The refrigeration system of Embodiment D3 or D4, wherein said system comprises a medium temperature refrigeration system, and wherein

said evaporator operates at midpoint temperature between about -25°C and about 0°C.

Embodiment D7: The air conditioning or heat pump system of Embodiment D1 or D2, wherein said evaporator operates with midpoint temperature between 5 about 0°C to about 20°C.

Embodiment E1: The compositions of any of Embodiments A1-A12, the processes of Embodiments B1 or B2, the methods of Embodiments C1-C5, or the systems of any of Embodiments D1-D7, wherein the refrigerant mixture has a GWP of 400 or less.

10 Embodiment E2: The compositions of any of Embodiments A1-A12, the processes of Embodiments B1 or B2, the methods of Embodiments C1-C5, or the systems of any of Embodiments D1-D7, wherein the refrigerant mixture has a GWP of 300 or less.

CLAIMS

What is claimed is:

1. A composition comprising a refrigerant mixture for replacing R-410A said refrigerant mixture consisting essentially of from about 42 to about 59 weight percent difluoromethane, about 33 to about 53 weight percent 2,3,3,3-tetrafluoropropene, and about 1 to about 9 weight percent carbon dioxide.
2. The composition of claim 1, said refrigerant mixture consisting essentially of from about 42 to about 59 weight percent difluoromethane, about 35 to about 51 weight percent 2,3,3,3-tetrafluoropropene, and about 2 to about 9 weight percent carbon dioxide.
3. The composition of claim 1, said refrigerant mixture consisting essentially of about 42 to 59 weight percent difluoromethane, about 37 to 48 weight percent 2,3,3,3-tetrafluoropropene, and about 3 to 9 weight percent carbon dioxide.
4. The composition of claim 1, said refrigerant mixture consisting essentially of about 42 to 47 weight percent difluoromethane, about 40 to 49 weight percent 2,3,3,3-tetrafluoropropene, and about 3 to 9 weight percent carbon dioxide.
- 20 5. The composition of claim 1, said refrigerant mixture consisting essentially of about 42 to 45 weight percent difluoromethane, about 46 to 49 weight percent 2,3,3,3-tetrafluoropropene, and about 6 to 9 weight percent carbon dioxide.
- 25 6. The composition of claim 1, said refrigerant mixture consisting essentially of about 42 to 44 weight percent difluoromethane, about 48 to 51 weight percent 2,3,3,3-tetrafluoropropene, and about 7 to 9 weight percent carbon dioxide.
7. The composition of claim 1, said refrigerant mixture consisting essentially of about 43 to 44 weight percent difluoromethane, about 48 to 50 weight

percent 2,3,3,3-tetrafluoropropene, and about 7 to 8 weight percent carbon dioxide.

8. The composition of claim 1, said refrigerant mixture consisting essentially of about 44 weight percent difluoromethane, about 49 weight percent 2,3,3,3-tetrafluoropropene, and about 7 weight percent carbon dioxide.

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9. The composition of claim 1, said refrigerant mixture consisting essentially of from about 47 to about 59 weight percent difluoromethane, about 37 to about 49 weight percent 2,3,3,3-tetrafluoropropene, and about 3 to about 8 weight percent carbon dioxide.

10 10. The composition of claim 1, said refrigerant mixture consisting essentially of from about 52 to about 59 weight percent difluoromethane, about 37 to about 42 weight percent 2,3,3,3-tetrafluoropropene, and about 3 to about 6 weight percent carbon dioxide.

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11. The composition of claim 1, said refrigerant mixture consisting essentially of from about 57 to about 59 weight percent difluoromethane, about 37 to about 39 weight percent 2,3,3,3-tetrafluoropropene, and about 3 to about 5 weight percent carbon dioxide.

12. The composition of claim 1, said refrigerant mixture consisting essentially of about 58 weight percent difluoromethane, about 38 weight percent 2,3,3,3-tetrafluoropropene, and about 4 weight percent carbon dioxide.

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13. The composition of claim 1, further comprising one or more components selected from the group consisting of lubricants, dyes, solubilizing agents, compatibilizers, stabilizers, tracers, anti-wear agents, extreme pressure agents, corrosion and oxidation inhibitors, metal surface energy reducers, metal surface deactivators, free radical scavengers, foam control agents, viscosity index improvers, pour point depressants, detergents, viscosity adjusters, and mixtures thereof.

25

14. The composition of claim 13, wherein said lubricant is selected from the group consisting of mineral oil, alkylbenzene, polyol esters, polyalkylene

glycols, polyvinyl ethers, polycarbonates, perfluoropolyethers, synthetic paraffins, synthetic naphthenes, polyalpha-olefins, and combinations thereof.

15. A process for producing cooling comprising condensing the composition of
5 claim 1 and thereafter evaporating said composition in the vicinity of a body
to be cooled.
16. A process for producing heating comprising evaporating the composition of
claim 1 and thereafter condensing said composition in the vicinity of a body
to be heated.
- 10 17. A method of replacing R-410A in air conditioning or heat pump systems
comprising providing the composition of claim 1 as replacement for said R-
410A in said air conditioning or heat pump system.
18. An air conditioning or heat pump system comprising an evaporator, a
compressor, a condenser, and an expansion device, characterized by
15 containing the composition of claim 1.
20. The air conditioning or heat pump system of claim 18, wherein said system
includes one or more heat exchangers that operate in counter-current
mode, cross-current mode, or cross-current mode with counter-current
tendency.
- 20 21. A method of replacing R-410A in refrigeration systems comprising
providing the composition of claim 1 as replacement for said R-410A in said
refrigeration system.
22. A refrigeration system comprising an evaporator, a compressor, a
condenser, and an expansion device, characterized by containing the
25 composition of claim 1.
23. The refrigeration system of claim 22, wherein said system includes one or
more heat exchangers that operate in counter-current mode, cross-current
mode, or cross-current mode with counter-current tendency.

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/054085

A. CLASSIFICATION OF SUBJECT MATTER
INV. C09K/04 C10M171/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C09K C10M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2015/315446 A1 (YANA MOTTA SAMUEL F [US] ET AL) 5 November 2015 (2015-11-05) claims -----	1-23
A	US 2015/041704 A1 (SAITO MASANORI [JP] ET AL) 12 February 2015 (2015-02-12) paragraph [0134]; claims -----	1-23
A	WO 2017/151488 A1 (CHEMOURS CO FC LLC [US]) 8 September 2017 (2017-09-08) embodiment A6; claims -----	1-23



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 January 2019	24/01/2019
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Puetz, Christine

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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