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COMPOSITIONS

The invention relates to compositions according to claims 1, 5, 9 and 11, preferably to heat transfer compositions, and in particular to ultra-low temperature heat transfer compositions which may be suitable as replacements for existing refrigerants such as R-508A, R-508B, R23 or R13B1.

The listing or discussion of a prior-published document or any background in the specification should not necessarily be taken as an acknowledgement that a document or background is part of the state of the art or is common general knowledge.

Mechanical refrigeration systems and related heat transfer devices such as heat pumps and air-conditioning systems are well known. In such systems, a refrigerant liquid evaporates at low pressure taking heat from the surrounding zone. The resulting vapour is then compressed and passed to a condenser where it condenses and gives off heat to a second zone, the condensate being returned through an expansion valve to the evaporator, so completing the cycle. Mechanical energy required for compressing the vapour and pumping the liquid is provided by, for example, an electric motor or an internal combustion engine.

Certain refrigerant applications, notably biomedical refrigeration, use low-boiling refrigerant gases to achieve cooling of materials, typically to temperatures of about -85 °C or below. These fluids are sometimes referred to as ultra-low temperature (ULT) or cryogenic refrigerants.

The most commonly used non-flammable ULT refrigerants currently are R-508A and R-508B. The term R-508 is used herein to refer to R-508A and R-508B, which are both mixtures of trifluoromethane (R-23) with hexafluoroethane (R-116) and are rated A1 by the ASHRAE Standard 34 classification.

Typical low-temperature applications of R-508 fluids are normally cascade systems: a first vapour compression refrigeration cycle cools air inside a refrigerated compartment to between about -80 and -95°C by evaporation of liquid R-508. The gaseous refrigerant is then compressed and condensed in a heat exchanger, where it vaporises a second refrigerant (for example R-404A). A typical condensing temperature for R-508 in this

exchanger is in the range -50 to -30°C. The second refrigerant vapour is compressed by a second compressor and is then condensed against ambient air.

5 The greenhouse (or global) warming potential (GWP) of low boiling non-flammable refrigerant gases such as R-508 or R-23 is high (e.g. about 13000), and it is desired to find fluids able to be used in this application with lower GWP, so as to reduce environmental impact of refrigerant leakage.

10 In looking for alternative low temperature refrigerants several other factors must also be considered. Firstly, if the fluid is to be used as a retrofit or conversion fluid in existing equipment, or as a “drop-in” to new equipment using an essentially unchanged R-508 system design, then non-flammability is highly desired, as the existing design will have been based on the use of non-flammable fluid.

15 If an alternative fluid is to be employed in a wholly new system design then a degree of flammability may be tolerable; but the use of highly flammable fluids may impose cost and performance penalties to mitigate hazards. Acceptable charge size (refrigerant mass) in a system is also governed by the flammability classification of the fluid, with class 3 fluids, such as ethane, being the most strictly limited. In this case a weaker flammability
20 characteristic is highly desirable since it may allow larger system charges.

Thirdly, the typical application of such fluids is in commercial or laboratory based equipment and so the systems will be located in buildings. It is therefore desirable to have acceptably low toxicity as a characteristic of the fluid.

25 Furthermore, the volumetric capacity (a measure of the cooling power achievable by a given size of compressor) and energy efficiency are important. This is especially so in cascade operation as inefficiency in the low temperature stage also increases power consumption of the compressor in the top stage of the cascade.

30 R-170 (ethane) has very low GWP, acceptable refrigeration performance and toxicity but its high flammability limits its application: for example safety regulations can restrict the maximum charge quantity of refrigerant in appliances.

Binary mixtures of R-170 with R-116 have been described by Zhang et al. (J Chem Eng Data **2005** 50 2074-2076 and Fluid Phase Equilibria **2006** 240 73-78). They identified an azeotropic binary composition of these two components.

5 R-744 (carbon dioxide) is non-flammable but cannot be used alone in the bottom stage of ULT cascade systems because the operating temperatures are below the triple point of R-744. This means that solid carbon dioxide (dry-ice) could form in low pressure sections of the system, leading to blockages, poor control and inefficient operation.

10 Binary mixtures of R-744 with R-116 have been described by Valtz et al (Fluid Phase Equilibria 258 (2007) 179–185). They identified an azeotropic binary composition of these two components.

R-1132a (1,1-difluoroethene, also known as vinylidene fluoride) also has low GWP and acceptable toxicity. The flammability of R-1132a is reduced compared to ethane but it is still in flammability class 2. US6054064 describes the use of R-1132a in certain refrigerant compositions including mixtures with R-23, R-32, R-125, R-134a and R-143a. The thermodynamic energy efficiency of pure R-1132a is close to that of R-508 but its refrigeration capacity is reduced.

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US 2008/053908 (A1) describes a method for separating a sample using high pressure flash chromatography and mentions, *inter alia*, carbon dioxide, 1,1-difluoroethylene, ethane and hexafluoroethane as members of a long list of compounds which are suitable for use as a mobile phase to elute the sample containing a compound of interest.

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Thus there is a need to provide alternative refrigerants having improved properties such as low GWP, yet possessing acceptable refrigeration performance, flammability characteristics and toxicology. There is also a need to provide alternative refrigerants that may be used in existing devices such as refrigeration devices with little or no modification.

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The subject invention addresses the above and other deficiencies by the provision of the following compositions:

(a) a composition comprising from 10 to 99% by weight 1,1-difluoroethene (R-1132a),
35 a second component which is from 1 to 90% by weight hexafluoroethane (R-116), and optionally ethane (R-170); and optionally carbon dioxide (CO₂);

- (b) a composition comprising from 20 to 99% by weight R-1132a, a second component which is from 1 to 80 % by weight R-170, and optionally R-116 and optionally CO₂
- 5 (c) a composition comprising from 2 to 98 % by weight R-1132a, from 2 to 98 % by weight R-116 and from 2 to 60 % by weight CO₂;
- (d) a composition comprising R-1132a, R-170 and up to 70% by weight CO₂; and
- 10 (e) a composition comprising R-1132a, R-116 and R-170 and optionally CO₂.

Such compositions, which may be considered to be heat transfer or refrigerant compositions, are referred to hereinafter as compositions of the invention.

- 15 Described herein is a composition comprising 1,1-difluoroethene (R-1132a), a second component selected from the group consisting of hexafluoroethane (R-116), ethane (R-170) and mixtures thereof and, optionally, carbon dioxide (CO₂, R-744).

Certain compositions of the invention comprise from about 10 to about 99 % by weight of
 20 R-1132a and from about 1 to about 90 % by weight of R-116. A preferred such composition comprises from about 14 to about 99 % by weight of R-1132a and from about 1 to about 86 % by weight of R-116.

Another preferred composition of the invention comprises from about 35 to about 99 % by
 25 weight of R-1132a and from about 1 to about 65 % by weight of R-116. Further preferred compositions of the invention comprise from about 36 to about 98 % by weight of R-1132a and from about 2 to about 64 % by weight of R-116, for example from about 36 to about 96 % by weight of R-1132a and from about 4 to about 64 % by weight of R-116.

30 A binary minimum-boiling azeotrope has been identified between R-1132a and R-116 by vapour-liquid equilibrium studies (see the Examples), whose composition at atmospheric pressure is about 50% w/w R-1132a (49.8%), having an atmospheric boiling point of about -85.7°C. The azeotropic composition increases to about 53% w/w R-1132a at 30 bara. Thus, in a preferred embodiment, the invention provides an azeotropic or near-azeotropic
 35 composition comprising R-1132a and R-116. A further preferred composition of the

invention comprises from about 45 to about 60 % by weight of R-1132a and from about 40 to about 55 % by weight of R-116.

5 By azeotropic composition, we include the meaning of a binary composition which at vapour-liquid equilibrium has the same composition in both phases, and whose boiling point is lower than that of either of the pure components. By near-azeotropic composition (e.g. a near-azeotropic composition of R-1132a and R-116), we include the meaning of binary liquid compositions whose vapour pressure is above that of the pure component with the lower boiling point (e.g. R-1132a compared to R-116) when measured at
10 equivalent temperature, but whose equilibrium vapour composition may differ from the liquid composition.

Also described herein are compositions comprising R-1132a, R-116 and CO₂, for example compositions comprising R-1132a, R-116 and up to about 70 % by weight CO₂.

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In another aspect of the present invention, there are provided compositions comprising from about 2 to about 98 % by weight of R-1132a, from about 2 to about 98 % by weight of R-116 and from about 2 to about 60 % by weight CO₂.

20 Preferred compositions of the invention comprise from about 4 to about 96 % by weight of R-1132a, from about 4 to about 96 % by weight of R-116 and from about 4 to about 50 % by weight CO₂. Such compositions may contain from about 6 to about 40 % by weight CO₂, for example from about 8 to about 30 % by weight CO₂.

25 In a preferred embodiment, the amount of CO₂ in the compositions of the invention is less than about 20% by weight, preferably less than about 15 % by weight, for example less than about 13 % by weight. It is believed that by limiting the CO₂ content to such levels, undesirable dry ice (solid CO₂) formation can be reduced or avoided during use of the compositions of the invention as refrigerants.

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Further advantageous compositions of the invention contain from about 5 to about 60 % by weight of R-1132a, from about 30 to about 70 % by weight of R-116 and from about 2 to about 20 % by weight CO₂. Such compositions typically contain from about 10 to about 50 % by weight of R-1132a, from about 40 to about 70 % by weight of R-116 and from
35 about 5 to about 15 % by weight CO₂; or from about 40 to about 60 % by weight of R-1132a, from about 35 to about 55 % by weight of R-116 and from about 5 to about 20 %

by weight CO₂. In one embodiment, the compositions of the invention contain up to about 35 % by weight of R-1132a, at least about 55 % by weight of R-116 and up to about 13 % by weight CO₂.

5 Certain compositions of the invention comprise from about 20 to about 99 % by weight of R-1132a and from about 1 to about 80 % by weight of R-170. A preferred such composition comprises from about 50 to about 99 % by weight of R-1132a and from about 1 to about 50 % by weight of R-170.

10 Another preferred composition of the invention comprises from about 75 to about 99 % by weight of R-1132a and from about 1 to about 25 % by weight of R-170.

A binary minimum-boiling azeotrope has been identified between R-1132a and R-170 by vapour-liquid equilibrium studies (see the Examples), whose composition varies with
 15 temperature, from about 54 % by weight R-170 at 0 °C to about 41 % by weight R-170 at -80 °C. In a preferred embodiment, the invention provides an azeotropic or near-azeotropic composition comprising R-1132a and R-170. A further preferred composition of the invention comprises from about 40 to about 60 % by weight of R-1132a and from about 40 to about 60 % by weight of R-170.

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Described herein are compositions comprising R-1132a, R-170 and CO₂. In one aspect, the compositions of the present invention comprise R-1132a, R-170 and up to about 70 % by weight CO₂.

25 Advantageous compositions of the invention comprise from about 2 to about 98 % by weight of R-1132a, from about 2 to about 98 % by weight of R-170 and from about 2 to about 60 % by weight CO₂.

Preferred compositions of the invention comprise from about 4 to about 96 % by weight of
 30 R-1132a, from about 4 to about 96 % by weight of R-170 and from about 4 to about 50 % by weight CO₂. Such compositions may contain from about 6 to about 40 % by weight CO₂, for example from about 8 to about 30 % by weight CO₂. In one aspect, as previously described, the amount of CO₂ in such compositions comprising R-1132a, R-170 and CO₂ is less than about 20% by weight, preferably less than about 15 % by weight, for example
 35 less than about 13 % by weight.

In another aspect of the present invention, there is provided a composition comprising R-1132a, R-116 and R-170.

Advantageous compositions of the invention comprise from about 4 to about 70 % by weight of R-1132a, from about 4 to about 96 % by weight of R-116 and from about 4 to about 92 % by weight R-170.

Preferred compositions of the invention comprise from about 4 to about 70 % by weight of R-1132a, from about 4 to about 88 % by weight of R-116 and from about 8 to about 92 % by weight R-170.

Yet further compositions of the invention consist of quaternary mixtures of ethane, carbon dioxide, R-1132a and R-116. Preferred embodiments of these quaternary compositions are those in which the bulk composition can be assessed as non-flammable by the ASHRAE-34 methodology. Advantageously, the combined amount of ethane and carbon dioxide makes up less than 50 % by weight of the composition. Preferably, such compositions contain at least as much CO₂ as ethane (by weight), preferably twice as much CO₂ as ethane (by weight).

Advantageous compositions comprise from about 2 to about 20 % by weight ethane, from about 2 to about 45 % by weight CO₂, from about 15 to about 85 % by weight R-1132a and from about 5 to about 80 % by weight R-116. Preferred compositions comprise from about 4 to about 12 % by weight ethane, from about 4 to about 40 % by weight CO₂, from about 20 to about 80 % by weight R-1132a and from about 8 to about 76 % by weight R-116.

Any of the above described compositions may additionally contain pentafluoroethane (R-125).

Any of the above described compositions may further contain a hydrocarbon, wherein the hydrocarbon is in addition to any ethane present in the composition. Advantageously, the hydrocarbon is one or more compound(s) selected from the group consisting of propane, propene, isobutane, n-butane, n-pentane, isopentane and mixtures thereof. In a preferred embodiment, the hydrocarbon comprises n-pentane.

Without being bound by theory, it is believed that, when present, the inclusion of ethane and/or an additional hydrocarbon compound may enhance oil miscibility, solubility and/or return characteristics. Preferably, the compositions of the invention preferably contain from about 1 to about 50% by weight of the hydrocarbon component, for example from
5 about 1 to about 20%.

All of the chemicals herein described are commercially available. For example, the fluorochemicals may be obtained from Apollo Scientific (UK) and carbon dioxide may be obtained from liquefied gas suppliers such as Linde AG.

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As used herein, all % amounts mentioned in compositions herein, including in the claims, are by weight based on the total weight of the compositions, unless otherwise stated.

15

By the term "about", as used in connection with numerical values of amounts of components in % by weight, we include the meaning of ± 0.5 % by weight, for example ± 0.2 % by weight or ± 0.1 % by weight.

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For the avoidance of doubt, it is to be understood that the stated upper and lower values for ranges of amounts of components in the compositions of the invention described herein may be interchanged in any way, provided that the resulting ranges fall within the broadest scope of the invention.

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In an embodiment, the compositions of the invention are substantially free of any component that has heat transfer properties (other than the components specified).

For instance, the compositions of the invention may be substantially free of any other hydrofluorocarbon compound (other than R-1132a, R-116 and optionally R-125).

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Any of the compositions of the invention described herein, including those with specifically defined amounts of R-1132a, the second component and, optionally, CO₂, may consist essentially of (or consist of) the amounts of R-1132a, the second component and, optionally, CO₂ defined in those compositions.

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By the term "consist essentially of", we include the meaning that the compositions of the invention contain substantially no other components, particularly no further hydrofluorocarbon compounds known to be used in heat transfer compositions (e.g.

hydrofluoroalkanes or hydrofluoroalkenes). We include the term “consist of” within the meaning of “consist essentially of”.

By “substantially no” and “substantially free of”, we include the meaning that the compositions of the invention contain 0.5% by weight or less of the stated component, preferably 0.1% or less, based on the total weight of the composition.

The compositions of the invention have zero ozone depletion potential

Typically, the compositions of the invention have a GWP of less than about 12000, such as less than about 11000.

In one embodiment, the compositions of the invention comprising R-1132a and R-116 have a GWP of less than about 11000, preferably less than about 10500 or about 10000 or about 9000 or about 8000.

In one aspect, the compositions of the invention comprising R-1132a, R-116 and CO₂ have a GWP of less than about 11000, for instance less than about 10000, e.g. from about 100 to about 10000, or from about 100 to about 7000

Typically, the compositions of the invention comprising R-1132a and R-170 have a GWP of about 4 or less.

Typically, the compositions of the invention comprising R-1132a, R-170 and CO₂ have a GWP of about 4 or less.

In one embodiment, the compositions of the invention comprising R-1132a, R-170, R-116 and CO₂ have a GWP of less than about 10000, for instance less than about 9000, e.g. from about 1000 to about 8000, or from about 2000 to about 7000.

Typically, the compositions of the subject invention are of reduced flammability hazards when compared to R-1132a.

Flammability may be determined in accordance with ASHRAE Standard 34 incorporating the ASTM Standard E-681 with test methodology as per Addendum 34p dated 2004, the entire content of which is incorporated herein by reference.

In one aspect, the compositions have one or more of (a) a higher lower flammable limit; (b) a higher ignition energy (sometimes referred to as auto ignition energy or pyrolysis); or (c) a lower flame velocity compared to R-1132a alone. Preferably, the compositions of the invention are less flammable compared to R-1132a in one or more of the following respects: lower flammable limit at 23°C; lower flammable limit at 60°C; breadth of flammable range at 23°C or 60°C; auto-ignition temperature (thermal decomposition temperature); minimum ignition energy in dry air or flame speed. The flammable limits being determined according to the methods specified in ASHRAE-34 and the auto-ignition temperature being determined in a 500ml glass flask by the method of ASTM E659-78.

In a preferred embodiment, the compositions of the invention are non-flammable. For example, the compositions of the invention are non-flammable at a test temperature of 60°C using the ASHRAE-34 methodology. Advantageously, the mixtures of vapour that exist in equilibrium with the compositions of the invention at any temperature between about -20°C and 60°C are also non-flammable.

Certain non-flammable compositions of the invention are described in the Examples. A preferred non-flammable composition of the invention comprises (optionally consists essentially of or consists of) up to about 30 % by weight R-1132a and at least about 70 % by weight R116.

In some applications it may not be necessary for the formulation to be classed as non-flammable by the ASHRAE-34 methodology; it is possible to develop fluids whose flammability limits will be sufficiently reduced in air to render them safe for use in the application, for example if it is physically not possible to make a flammable mixture by leaking the refrigeration equipment charge into the surrounds. Certain such reduced flammability compositions of the invention are described in the Examples.

In one embodiment, the compositions of the invention have a flammability classifiable as 1 or 2L according to the ASHRAE standard 34 classification method

The compositions of the invention, particularly those comprising R-1132a, R-116 and CO₂, advantageously have a temperature glide in an evaporator or a condenser of less than 10 K. Preferably such compositions have a temperature glide of less than about 5 K, and even more preferably less than about 1 K.

The critical temperature of a heat transfer composition should be higher than the maximum expected condenser temperature. This is because the cycle efficiency drops as critical temperature is approached. As this happens, the latent heat of the refrigerant is reduced
5 and so more of the heat rejection in the condenser takes place by cooling gaseous refrigerant; this requires more area per unit heat transferred. The critical temperature of R-508B is about 11 °C (data estimated by REFPROP).

In one aspect, the compositions of the invention have a critical temperature of greater than
10 about 0 °C, preferably greater than about 11 °C

It is believed that the compositions of the invention exhibit a completely unexpected combination of low-/non-flammability, low GWP, improved lubricant miscibility and improved refrigeration performance properties. Some of these refrigeration performance
15 properties are explained in more detail below.

The compositions of the invention typically have a volumetric refrigeration capacity that is at least 85% of that of R-508. Preferably, the compositions of the invention have a volumetric refrigeration capacity that is at least 90% of that of R-508, for example from
20 about 95% to about 120% of that of R-508

The compositions of the invention typically are capable of reaching temperatures of -70 °C or lower, preferably -80 °C or lower, for example -85 °C or lower whilst maintain the evaporation pressure above atmospheric pressure.
25

In one embodiment, the cycle efficiency (Coefficient of Performance, COP) of the compositions of the invention is within about 5% or even better than the existing refrigerant fluid it is replacing. Conveniently, the compressor discharge temperature of the compositions of the invention is within about 15K of the existing refrigerant fluid it is
30 replacing, preferably about 10K or even about 5K.

The compositions of the invention are typically suitable for use in existing designs of equipment, for example, ULT refrigeration equipment and are compatible with all classes of lubricant currently used with established HFC refrigerants. They may be optionally
35 stabilised or compatibilised with mineral oils by the use of appropriate additives.

Preferably, when used in heat transfer equipment, the composition of the invention is combined with a lubricant.

Conveniently, the lubricant is selected from the group consisting of mineral oil, silicone oil, polyalkyl benzenes (PABs), polyol esters (POEs), polyalkylene glycols (PAGs), polyalkylene glycol esters (PAG esters), polyvinyl ethers (PVEs), poly (alpha-olefins) and combinations thereof. PAGs and POEs are currently preferred lubricants for the compositions of the invention.

Advantageously, the lubricant further comprises a stabiliser.

Preferably, the stabiliser is selected from the group consisting of diene-based compounds, phosphates, phenol compounds and epoxides, and mixtures thereof.

Conveniently, the composition of the invention may be combined with a flame retardant.

Advantageously, the flame retardant is selected from the group consisting of tri-(2-chloroethyl)-phosphate, (chloropropyl) phosphate, tri-(2,3-dibromopropyl)-phosphate, tri-(1,3-dichloropropyl)-phosphate, diammonium phosphate, various halogenated aromatic compounds, antimony oxide, aluminium trihydrate, polyvinyl chloride, a fluorinated iodocarbon, a fluorinated bromocarbon, trifluoro iodomethane, perfluoroalkyl amines, bromo-fluoroalkyl amines and mixtures thereof.

In one embodiment, the invention provides a heat transfer device comprising a composition of the invention.

Preferably, the heat transfer device is a refrigeration device.

Conveniently, the heat transfer device is an ultra-low temperature refrigeration system.

Advantageously, the heat transfer device contains a cascade system.

The invention also provides the use of a composition of the invention in a heat transfer device as herein described.

According to another aspect of the invention, there is provided a sprayable composition comprising a material to be sprayed and a propellant comprising a composition of the invention.

- 5 According to a further aspect of the invention, there is provided a method for cooling an article which comprises condensing a composition of the invention and thereafter evaporating said composition in the vicinity of the article to be cooled.

- 10 According to another aspect of the invention, there is provided a method for heating an article which comprises condensing a composition of the invention in the vicinity of the article to be heated and thereafter evaporating said composition.

- 15 According to a further aspect of the invention, there is provided a method for extracting a substance from biomass comprising contacting the biomass with a solvent comprising a composition of the invention, and separating the substance from the solvent.

- 20 According to another aspect of the invention, there is provided a method of cleaning an article comprising contacting the article with a solvent comprising a composition of the invention.

- 25 According to a further aspect of the invention, there is provided a method for extracting a material from an aqueous solution comprising contacting the aqueous solution with a solvent comprising a composition of the invention, and separating the material from the solvent.

- 30 According to another aspect of the invention, there is provided a method for extracting a material from a particulate solid matrix comprising contacting the particulate solid matrix with a solvent comprising a composition of the invention, and separating the material from the solvent.

- 35 According to a further aspect of the invention, there is provided a mechanical power generation device containing a composition of the invention.

- Preferably, the mechanical power generation device is adapted to use a Rankine Cycle or modification thereof to generate work from heat.

According to another aspect of the invention, there is provided a method of retrofitting a heat transfer device comprising the step of removing an existing heat transfer fluid, and introducing a composition of the invention. Preferably, the heat transfer device is a refrigeration device, more preferably still the device is an ultra-low temperature refrigeration system. Advantageously, the method further comprises the step of obtaining an allocation of greenhouse gas (e.g. carbon dioxide) emission credit.

In accordance with the retrofitting method described above, an existing heat transfer fluid can be fully removed from the heat transfer device before introducing a composition of the invention. An existing heat transfer fluid can also be partially removed from a heat transfer device, followed by introducing a composition of the invention.

The compositions of the invention may also be prepared simply by mixing the R-1132a, the second component (and optional components such as R-744, R-125, hydrocarbons, a lubricant, a stabiliser or an additional flame retardant) in the desired proportions. The compositions can then be added to a heat transfer device (or used in any other way as defined herein).

In a further aspect of the invention, there is provided a method for reducing the environmental impact arising from operation of a product comprising an existing compound or composition, the method comprising replacing at least partially the existing compound or composition with a composition of the invention. Preferably, this method comprises the step of obtaining an allocation of greenhouse gas emission credit.

By environmental impact we include the generation and emission of greenhouse warming gases through operation of the product.

As mentioned above, this environmental impact can be considered as including not only those emissions of compounds or compositions having a significant environmental impact from leakage or other losses, but also including the emission of carbon dioxide arising from the energy consumed by the device over its working life. Such environmental impact may be quantified by the measure known as Total Equivalent Warming Impact (TEWI). This measure has been used in quantification of the environmental impact of certain stationary refrigeration and air conditioning equipment, including for example supermarket refrigeration systems (see, for example, http://en.wikipedia.org/wiki/Total_equivalent_warming_impact).

The environmental impact may further be considered as including the emissions of greenhouse gases arising from the synthesis and manufacture of the compounds or compositions. In this case the manufacturing emissions are added to the energy consumption and direct loss effects to yield the measure known as Life-Cycle Carbon Production (LCCP, see for example <http://www.sae.org/events/aars/presentations/2007papasavva.pdf>). The use of LCCP is common in assessing environmental impact of automotive air conditioning systems.

Emission credit(s) are awarded for reducing pollutant emissions that contribute to global warming and may, for example, be banked, traded or sold. They are conventionally expressed in the equivalent amount of carbon dioxide. Thus if the emission of 1 kg of R-134a is avoided then an emission credit of $1 \times 1300 = 1300$ kg CO₂ equivalent may be awarded.

In another embodiment of the invention, there is provided a method for generating greenhouse gas emission credit(s) comprising (i) replacing an existing compound or composition with a composition of the invention, wherein the composition of the invention has a lower GWP than the existing compound or composition; and (ii) obtaining greenhouse gas emission credit for said replacing step.

In a preferred embodiment, the use of the composition of the invention results in the equipment having a lower Total Equivalent Warming Impact, and/or a lower Life-Cycle Carbon Production than that which would be attained by use of the existing compound or composition.

These methods may be carried out on any suitable product, for example in the fields of air-conditioning, refrigeration (e.g. low and medium temperature refrigeration), heat transfer, aerosols or sprayable propellants, gaseous dielectrics, flame suppression, solvents (e.g. carriers for flavorings and fragrances), cleaners, topical anesthetics, and expansion applications. Preferably, the field is ultra-low temperature refrigeration.

Examples of suitable products include heat transfer devices, sprayable compositions, solvents and mechanical power generation devices. In a preferred embodiment, the product is a heat transfer device, such as a refrigeration device or an ultra-low temperature refrigeration system.

The existing compound or composition has an environmental impact as measured by GWP and/or TEWI and/or LCCP that is higher than the composition of the invention which replaces it. The existing compound or composition may comprise a fluorocarbon
 5 compound, such as a perfluoro-, hydrofluoro-, chlorofluoro- or hydrochlorofluoro-carbon compound or it may comprise a fluorinated olefin.

Preferably, the existing compound or composition is a heat transfer compound or composition such as a refrigerant. Examples of refrigerants that may be replaced include
 10 ULT refrigerants such as R-508A, R-508B, R23 and R13B1.

Any amount of the existing compound or composition may be replaced so as to reduce the environmental impact. This may depend on the environmental impact of the existing compound or composition being replaced and the environmental impact of the
 15 replacement composition of the invention. Preferably, the existing compound or composition in the product is fully replaced by the composition of the invention.

The invention is illustrated by the following non-limiting examples.

20 **EXAMPLES**

Reference examples have been designated with “***”, where appropriate.

Binary Mixtures of R-1132a and R-116

25 A binary minimum-boiling azeotrope between R-1132a and R-116 was identified by study of the vapour-liquid equilibrium of binary mixtures over a temperature range of -70°C to 0 °C using a constant-volume apparatus. The data thus generated were regressed to a thermodynamic model capable of extrapolation from the measurement
 30 temperature/pressure range to atmospheric pressure conditions.

The experimental data were measured in a static constant-volume apparatus consisting of a vessel of precisely-known internal volume located in a temperature-controlled metal block. A magnetic stirring device was located inside the vessel. Refrigerated fluid was
 35 passed through the block to allow precise control of temperature inside the vessel. The cell was evacuated then known amounts of each component were then charged to the cell.

The temperature of the cell was then varied stepwise from about -70°C to 0°C. At each temperature the cell temperature and pressure were logged continuously and recorded when stable conditions were reached.

5 The resulting datasets were then regressed using Barker's method (as described in *The Properties of Gases and Liquids 3rd edition* (Reid, Sherwood & Prausnitz), which is incorporated herein by reference) to a thermodynamic model capable of representing non-ideal vapour liquid equilibria. The model used the Redlich Kwong equation of state to represent the gas phase properties and the Wilson equation to represent the non-ideality
10 of the liquid phase mixture, as described in Reid *et al.*

The phase behaviour of this system is illustrated in Figures 1 and 2. Figure 1 shows the vapour composition in the mixture (inferred using the regressed model) plotted against the equilibrium liquid composition. It is seen that the azeotropic point (where the vapour and
15 liquid compositions coincide) moves with pressure, increasing in R-1132a content.

A feature of the R-1132a/R-116 binary system identified is that the vapour pressure of any binary mixture containing more than about 14% w/w R-1132a is equal to or higher than the vapour pressure of R-1132a itself (the more volatile component of the system). This is
20 illustrated in Figure 2. This means that the refrigeration performance of binary mixtures of the fluids is unexpectedly enhanced compared to that which could be expected from considering the fluid as an ideal binary mixture. In particular we have found that compositions of more than about 35% w/w R-1132a will exhibit higher refrigeration capacity and improved volumetric compressor efficiency than pure R-1132a in typical low
25 temperature refrigeration cycle conditions.

Figure 3 shows calculated refrigeration cycle performance for binary compositions of the invention, with vapour liquid equilibrium modelled based on the measured phase equilibrium, together with a comparison made to the same compositions assuming
30 Raoult's Law (ideal) behaviour. The thermodynamic properties of R-116 used in this cycle modelling were taken from the NIST REFPROP software version 8. Properties of R-1132a were taken from available open literature data with the exception of saturated liquid vapour pressure, which was measured by us in the determination of the phase equilibrium data. The main source of data for R-1132a physical properties was the commercial PPDS
35 thermodynamic data package provided by TUV-NEL, augmented with data from the commercial DECHEMA database.

The cycle conditions for the modelling were as follows.

Table 1: Cycle conditions for R-1132a/R-116 binary system modelling

Cycle conditions for modelling		
Condensing temperature	°C	-40
Evaporating temperature	°C	-85
Suction temperature	°C	-40
Isentropic efficiency		65%
Subcooling	K	5
Evaporator superheat	K	5
Compressor clearance ratio		4%

5

The modelled data is set out in the following table. The GWP values for the binary mixtures shown are calculated on the basis of GWP values of 4 and 12200 for R-1132a and R-116, respectively. By way of reference, the corresponding volumetric capacity for pure R-1132a using the same calculations is 726.

10

Table 2: Refrigeration performance modelling data for R-1132a/R-116 binary system

R1132a (weight %)		4%**	8%**	12%	16%	20%	24%
R116 (weight %)		96.00%**	92.00%**	88.00%	84.00%	80.00%	76.00%
GWP		11712	11224	10736	10249	9761	9273
Evaporator pressure	bar	0.75	0.80	0.85	0.89	0.93	0.96
Condenser pressure	bar	5.82	6.16	6.44	6.68	6.87	7.04
Pressure ratio		7.78	7.68	7.57	7.47	7.39	7.31
Volumetric efficiency		84.2%	84.6%	84.9%	85.3%	85.6%	85.8%
Discharge temperature	°C	-12.1	-10.5	-9.3	-8.2	-7.2	-6.4
Volumetric flowrate	m ³ /hr	62.2	58.9	56.4	54.5	52.9	51.6
Evaporator temp glide	K	0.8	1.3	1.6	1.6	1.4	1.2
Condenser temp glide	K	1.2	1.7	1.8	1.6	1.3	1.0
Volumetric capacity	kJ/m ³	579	611	638	661	681	698
Cooling COP		2.29	2.26	2.24	2.21	2.20	2.19
R1132a (weight %)		28%	32%	36%	40%	44%	48%
R116 (weight %)		72.00%	68.00%	64.00%	60.00%	56.00%	52.00%
GWP		8785	8297	7809	7322	6834	6346
Evaporator pressure	bar	0.99	1.01	1.03	1.04	1.05	1.05
Condenser pressure	bar	7.17	7.27	7.34	7.39	7.41	7.42
Pressure ratio		7.24	7.18	7.14	7.10	7.07	7.05
Volumetric efficiency		86.1%	86.3%	86.5%	86.7%	86.8%	86.9%
Discharge temperature	°C	-5.5	-4.7	-3.9	-3.1	-2.2	-1.3
Volumetric flowrate	m ³ /hr	50.5	49.6	48.9	48.3	47.9	47.6
Evaporator temp glide	K	0.9	0.6	0.4	0.2	0.1	0.0

Condenser temp glide	K	0.7	0.4	0.2	0.1	0.0	0.0
Volumetric capacity	kJ/m ³	713	726	737	746	752	757
Cooling COP		2.18	2.17	2.17	2.17	2.17	2.18
R1132a (weight %)		52%	56%	60%	64%	68%	72%
R116 (weight %)		48.00%	44.00%	40.00%	36.00%	32.00%	28.00%
GWP		5858	5370	4882	4395	3907	3419
Evaporator pressure	bar	1.05	1.05	1.04	1.04	1.03	1.02
Condenser pressure	bar	7.41	7.39	7.36	7.32	7.27	7.22
Pressure ratio		7.05	7.05	7.06	7.07	7.08	7.10
Volumetric efficiency		87.0%	87.1%	87.2%	87.2%	87.3%	87.3%
Discharge temperature	°C	-0.3	0.7	1.7	2.7	3.7	4.7
Volumetric flowrate	m ³ /hr	47.4	47.3	47.3	47.4	47.5	47.6
Evaporator temp glide	K	0.0	0.1	0.1	0.2	0.3	0.3
Condenser temp glide	K	0.0	0.1	0.1	0.2	0.3	0.3
Volumetric capacity	kJ/m ³	760	761	761	760	758	756
Cooling COP		2.18	2.19	2.19	2.20	2.20	2.21
R1132a (weight %)		76%	80%	84%	88%	92%	96%
R116 (weight %)		24.00%	20.00%	16.00%	12.00%	8.00%	4.00%
GWP		2931	2443	1955	1468	980	492
Evaporator pressure	bar	1.01	0.99	0.98	0.97	0.96	0.94
Condenser pressure	bar	7.16	7.10	7.04	6.97	6.90	6.83
Pressure ratio		7.12	7.14	7.16	7.19	7.21	7.24
Volumetric efficiency		87.4%	87.4%	87.4%	87.4%	87.4%	87.4%
Discharge temperature	°C	5.7	6.6	7.5	8.4	9.2	10.0
Volumetric flowrate	m ³ /hr	47.8	48.0	48.3	48.6	48.9	49.2
Evaporator temp glide	K	0.4	0.4	0.4	0.3	0.2	0.1
Condenser temp glide	K	0.4	0.4	0.4	0.3	0.2	0.1
Volumetric capacity	kJ/m ³	753	750	746	741	737	731
Cooling COP		2.22	2.22	2.23	2.24	2.24	2.25

The data show that for compositions between about 32% and 76% R-1132a the evaporation pressure is greater than atmospheric pressure and the cooling capacity is greater than that of R-1132a alone.

5

Binary Mixtures of R-170 and R-1132a

The phase equilibrium behaviour of mixtures of ethane and R-1132a was studied in the temperature range -80 to 0°C using data generated using PHYSPACK-PPB with WERK streamtype and binary interaction parameters optimised to fit Mexichem VLE data. The results are shown in the table below and the bubble point pressure of R-170/R-1132a mixtures at -40 °C is shown in Figure 4.

10

Table 3: Binary VLE data for R-170/R-1132a mixtures

Stream Temperature °C	Stream Molar VF	Liq Mass Fr ETHANE	Vap Mass Fr ETHANE	Bubble Point Pressure bar	Ideal bubble pressure bar
-80	0	0	0	1.21798	1.21798
-80	0	0.05	0.0972247	1.35928	1.25446
-80	0	0.1	0.171521	1.45689	1.28723
-80	0	0.15	0.231542	1.52581	1.31683
-80	0	0.2	0.282277	1.57523	1.34371
-80	0	0.25	0.32683	1.61097	1.36822
-80	0	0.3	0.367258	1.6368	1.39066
-80	0	0.35	0.405006	1.65522	1.41128
-80	0	0.4	0.441142	1.6679	1.4303
-80	0	0.45	0.476504	1.67597	1.4479
-80	0	0.5	0.511787	1.68023	1.46422
-80	0	0.55	0.5476	1.68123	1.47941
-80	0	0.6	0.584512	1.67933	1.49358
-80	0	0.65	0.623085	1.67481	1.50682
-80	0	0.7	0.663903	1.66785	1.51923
-80	0	0.75	0.707603	1.65859	1.53087
-80	0	0.8	0.754905	1.6471	1.54183
-80	0	0.85	0.806652	1.63345	1.55216
-80	0	0.9	0.86386	1.61768	1.5619
-80	0	0.95	0.927781	1.5998	1.57112
-80	0	1	1	1.57985	1.57985
-40	0	0	0	6.75403	6.75403
-40	0	0.05	0.077327	7.26181	6.85829
-40	0	0.1	0.141724	7.62444	6.95196
-40	0	0.15	0.197337	7.88483	7.03659
-40	0	0.2	0.246867	8.07158	7.11342
-40	0	0.25	0.29217	8.20405	7.18348
-40	0	0.3	0.334581	8.29553	7.24763
-40	0	0.35	0.375101	8.35529	7.30658
-40	0	0.4	0.414517	8.3899	7.36095
-40	0	0.45	0.453476	8.40407	7.41125
-40	0	0.5	0.492531	8.40124	7.45792
-40	0	0.55	0.532183	8.38395	7.50133
-40	0	0.6	0.572899	8.35411	7.54182
-40	0	0.65	0.615145	8.31317	7.57967
-40	0	0.7	0.659393	8.26228	7.61514
-40	0	0.75	0.706148	8.20233	7.64844
-40	0	0.8	0.755966	8.13405	7.67976
-40	0	0.85	0.809469	8.05804	7.70927

-40	0	0.9	0.867381	7.97481	7.73713
-40	0	0.95	0.930551	7.88481	7.76348
-40	0	1	1	7.78842	7.78842
0	0	0	0	22.1119	22.1119
0	0	0.05	0.0634704	23.2491	22.299
0	0	0.1	0.12047	24.0949	22.4671
0	0	0.15	0.17285	24.7165	22.619
0	0	0.2	0.221933	25.1633	22.7568
0	0	0.25	0.268696	25.4729	22.8825
0	0	0.3	0.31388	25.6739	22.9977
0	0	0.35	0.358073	25.7881	23.1035
0	0	0.4	0.401746	25.8327	23.201
0	0	0.45	0.445298	25.8214	23.2913
0	0	0.5	0.489069	25.7646	23.375
0	0	0.55	0.533365	25.671	23.4529
0	0	0.6	0.578466	25.5474	23.5256
0	0	0.65	0.624636	25.3992	23.5935
0	0	0.7	0.672132	25.2311	23.6572
0	0	0.75	0.721212	25.0465	23.7169
0	0	0.8	0.772136	24.8487	23.7731
0	0	0.85	0.825178	24.64	23.8261
0	0	0.9	0.880625	24.4226	23.8761
0	0	0.95	0.938786	24.1981	23.9234
0	0	1	1	23.9681	23.9681

The cycle conditions for the following modelling of R-1132a/R-170 blends were as shown above for the modelling on the R-1132a/R-116 blends. The modelled data is set out in the following table. The table also includes the corresponding modelled data for R508B alone, R-1132a alone and R-116 alone.

Table 4: Refrigeration performance modelling data for R-1132a/R-170 binary system

R170 (weight %)		4%	8%	12%	16%	20%	24%	28%
R1132a (weight %)		96.00%	92.00%	88.00%	84.00%	80.00%	76.00%	72.00%
GWP		4	4	4	4	4	4	4
Evaporator pressure	bar	0.99	1.05	1.10	1.14	1.18	1.21	1.23
Condenser pressure	bar	7.10	7.39	7.62	7.82	7.98	8.11	8.22
Pressure ratio		7.15	7.04	6.95	6.86	6.79	6.72	6.66
Volumetric efficiency		87.8%	88.1%	88.3%	88.6%	88.8%	89.0%	89.2%
Discharge temperature	°C	12.6	14.2	15.6	16.9	18.1	19.3	20.4
Evaporator temp glide	K	0.6	0.9	1.1	1.1	1.0	0.8	0.6
Condenser temp glide	K	0.6	0.9	0.9	0.8	0.7	0.5	0.3
Volumetric capacity	kJ/m ³	778	822	861	895	923	948	968

Cooling COP		2.28	2.30	2.31	2.32	2.33	2.34	2.34
R170 (weight %)		32%	36%	40%	44%	48%	52%	56%
R1132a (weight %)		68.00%	64.00%	60.00%	56.00%	52.00%	48.00%	44.00%
GWP		4	4	4	4	4	3	3
Evaporator pressure	bar	1.25	1.27	1.29	1.29	1.30	1.30	1.30
Condenser pressure	bar	8.30	8.35	8.38	8.40	8.40	8.39	8.37
Pressure ratio		6.61	6.57	6.52	6.49	6.46	6.44	6.42
Volumetric efficiency		89.4%	89.6%	89.7%	89.8%	90.0%	90.1%	90.2%
Discharge temperature	°C	21.5	22.6	23.7	24.8	25.9	27.0	28.1
Evaporator temp glide	K	0.5	0.3	0.2	0.1	0.0	0.0	0.0
Condenser temp glide	K	0.2	0.1	0.0	0.0	0.0	0.0	0.1
Volumetric capacity	kJ/m ³	985	999	1009	1017	1022	1025	1025
Cooling COP		2.35	2.35	2.36	2.36	2.36	2.36	2.36
R170 (weight %)		60%	64%	68%	72%	76%	80%	84%**
R1132a (weight %)		40.00%	36.00%	32.00%	28.00%	24.00%	20.00%	16.00%**
GWP		3	3	3	3	3	3	3
Evaporator pressure	bar	1.30	1.30	1.30	1.29	1.28	1.28	1.27
Condenser pressure	bar	8.34	8.30	8.26	8.21	8.16	8.10	8.04
Pressure ratio		6.40	6.39	6.38	6.37	6.36	6.35	6.35
Volumetric efficiency		90.3%	90.4%	90.4%	90.5%	90.6%	90.7%	90.7%
Discharge temperature	°C	29.2	30.3	31.4	32.5	33.6	34.6	35.6
Evaporator temp glide	K	0.0	0.0	0.1	0.1	0.1	0.1	0.0
Condenser temp glide	K	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Volumetric capacity	kJ/m ³	1024	1022	1018	1014	1008	1002	995
Cooling COP		2.36	2.35	2.35	2.35	2.34	2.34	2.34
R170 (weight %)		88%	92%	96%				
R1132a (weight %)		12.00%	8.00%	4.00%		R508B	R1132a	R116
GWP		3	3	3		13212	4	12200
Evaporator pressure	bar	1.26	1.25	1.24		1.23	0.93	0.69
Condenser pressure	bar	7.98	7.92	7.85		8.73	6.75	5.40
Pressure ratio		6.34	6.34	6.34		7.12	7.26	7.85
Volumetric efficiency		90.8%	90.8%	90.9%		87.7%	87.5%	84.0%
Discharge temperature	°C	36.6	37.6	38.5		11.8	10.8	-14.0
Evaporator temp glide	K	0.1	0.1	0.0		0.1	0.0	0.0
Condenser temp glide	K	0.2	0.2	0.1		0.1	0.0	0.0
Volumetric capacity	kJ/m ³	988	981	973		955	726	542
Cooling COP		2.33	2.33	2.32		2.30	2.26	2.32

Ternary Mixtures of R-744, R-1132a and R-116

Ternary compositions of carbon dioxide (R-744) with R-1132a and R-116 have been identified which exhibit further enhanced refrigeration capacity and reduced flammability compared to R-1132a. These have the advantageous features that solid carbon dioxide formation in the low pressure parts of the refrigeration system can be avoided and that
 5 lower compressor discharge temperatures than those attainable with binary R-744/R-1132a mixtures).

It is known in the thermodynamic literature (Valtz et al. Fluid Phase Equilibria 258 (2007) 179–185, which is incorporated herein by reference) that the binary system of R-744/R-
 10 116 exhibits azeotropy at temperatures at least above -20°C. It has been found, surprisingly, that addition of R-744 to R-1132a and R-116 system significantly enhances the refrigeration capacity of the resulting mixture by more than would be expected if the mixture were an ideal mixture. In particular, regions of composition have been identified where the ternary mixtures exhibits no or very low temperature glide in the two-phase
 15 region and only very small differences in phase composition.

The performance of selected ternary R-1132a/R-116/CO₂ compositions was modelled using the same cycle conditions and thermodynamic model as explained in the previous examples. The VLE behaviour of the three binary mixtures (R-744/R-116, R-744/R-1132a,
 20 R-1132a/R-116) was regressed into the selected thermodynamic model and this was then used to estimate performance. The data of Valtz were incorporated into this regression.

The modelled data is set out in the following tables. The corresponding modelled data for R508B alone, R-1132a alone and R-116 alone is shown above in Table 4. The volumetric
 25 cooling capacity of selected R-1132a/R-116/CO₂ blends is illustrated in Figure 5.

Selected R-1132a/R-116/CO₂ blends of the invention offer an unexpected combination of benefits compared to R-508. These are: reduced compressor discharge temperature; reduced GWP and equivalent or enhanced refrigeration capacity at constant compressor
 30 displacement.

Ternary Mixtures of R-744, R-1132a and R-170

The performance of selected ternary R-1132a/R-170/CO₂ compositions was modelled in
 35 accordance with the cycle conditions and thermodynamic model as explained in the previous examples.

The modelled data is set out in the following tables.

Ternary Mixtures of R-116, R-1132a and R-170

5

The performance of selected ternary R-1132a/R-170/R-116 compositions was modelled in accordance with the cycle conditions and thermodynamic model as explained in the previous examples.

10 The modelled data is set out in the following tables.

Quaternary Mixtures of R-116, R-744, R-1132a and R-170

15 The performance of selected ternary R-1132a/R-170/R-116/R-744 compositions was modelled in accordance with the cycle conditions and thermodynamic model as explained in the previous examples.

20 The modelled data is set out in the following tables. The composition typically have capacity close to that of R508 whilst simultaneously avoiding having too flammable a vapour phase (e.g. less flammable than corresponding ethane/R-1132a/R-116 blends) or too high a CO₂ content compared to corresponding CO₂/R-1132a/R-116 blends (which comparatively high CO₂ content can lead to high compressor temperatures and potential dry ice issues).

Table 5: Refrigeration performance modelling data for R-1132a/R-116/CO₂ ternary system with 4% by weight CO₂

R744 (weight %)		4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	
R1132a (weight %)		4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	32.0%	36.0%	40.0%	44.0%	48.0%
R116 (weight %)		92.00%	88.00%	84.00%	80.00%	76.00%	72.00%	68.00%	64.00%	60.00%	56.00%	52.00%	48.00%
GWP		11224	10736	10249	9761	9273	8785	8297	7809	7321	6834	6346	5858
Evaporator pressure	bar	0.90	0.94	0.98	1.01	1.04	1.06	1.08	1.09	1.10	1.11	1.11	1.10
Condenser pressure	bar	6.98	7.20	7.39	7.54	7.67	7.77	7.84	7.89	7.91	7.91	7.90	7.87
Pressure ratio		7.74	7.63	7.54	7.45	7.38	7.32	7.26	7.21	7.17	7.15	7.13	7.12
Volumetric efficiency		84.6%	85.0%	85.3%	85.6%	85.9%	86.1%	86.3%	86.5%	86.7%	86.8%	87.0%	87.1%
Discharge temperature	°C	-5.9	-5.0	-4.1	-3.4	-2.6	-2.0	-1.3	-0.6	0.2	1.0	1.8	2.8
Evaporator temp glide	K	3.6	3.4	3.0	2.6	2.2	1.7	1.3	1.0	0.7	0.5	0.4	0.4
Condenser temp glide	K	5.7	5.0	4.3	3.6	3.0	2.4	1.9	1.5	1.3	1.1	1.0	0.9
Volumetric capacity	kJ/m3	703	722	738	752	764	775	784	792	798	802	804	805
Cooling COP		2.29	2.26	2.23	2.21	2.20	2.18	2.18	2.17	2.17	2.17	2.18	2.18
R744 (weight %)		4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%**
R1132a (weight %)		52.0%	56.0%	60.0%	64.0%	68.0%	70.0%	76.0%	80.0%	84.0%	88.0%	92.0%	96%**
R116 (weight %)		44.00%	40.00%	36.00%	32.00%	28.00%	26.00%	20.00%	16.00%	12.00%	8.00%	4.00%	0.00%**
GWP		5370	4882	4394	3907	3419	3175	2443	1955	1467	980	492	4
Evaporator pressure	bar	1.10	1.09	1.08	1.07	1.06	1.05	1.03	1.02	1.00	0.99	0.97	0.96
Condenser pressure	bar	7.82	7.77	7.71	7.65	7.58	7.54	7.43	7.35	7.27	7.19	7.11	7.02
Pressure ratio		7.12	7.13	7.14	7.16	7.17	7.18	7.21	7.23	7.25	7.28	7.30	7.33
Volumetric efficiency		87.1%	87.2%	87.3%	87.3%	87.3%	87.4%	87.4%	87.4%	87.4%	87.5%	87.5%	87.5%
Discharge temperature	°C	3.7	4.7	5.7	6.6	7.6	8.0	9.4	10.2	11.1	11.9	12.7	13.4
Evaporator temp glide	K	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.6	0.5	0.4	0.3	0.2
Condenser temp glide	K	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0	0.9	0.8	0.7	0.6
Volumetric capacity	kJ/m3	804	802	799	795	791	789	782	777	772	766	760	753
Cooling COP		2.18	2.19	2.19	2.20	2.21	2.21	2.22	2.23	2.23	2.24	2.25	2.25

Table 6: Refrigeration performance modelling data for R-1132a/R-116/CO₂ ternary system with 8% by weight CO₂

R744 (weight %)		8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
R1132a (weight %)		4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	32.0%	36.0%	40.0%	44.0%
R116 (weight %)		88.0%	84.0%	80.0%	76.0%	72.0%	68.0%	64.0%	60.0%	56.0%	52.0%	48.0%
GWP		10736	10248	9761	9273	8785	8297	7809	7321	6834	6346	5858
Evaporator pressure	bar	1.04	1.07	1.09	1.11	1.13	1.15	1.16	1.16	1.16	1.16	1.15
Condenser pressure	bar	7.85	8.01	8.14	8.24	8.31	8.37	8.39	8.39	8.38	8.34	8.29
Pressure ratio		7.55	7.50	7.45	7.40	7.35	7.30	7.26	7.22	7.20	7.18	7.18
Volumetric efficiency		85.4%	85.6%	85.8%	86.0%	86.2%	86.4%	86.6%	86.8%	86.9%	87.0%	87.1%
Discharge temperature	°C	-1.3	-0.6	0.1	0.7	1.3	2.0	2.6	3.3	4.0	4.9	5.7
Evaporator temp glide	K	5.0	4.3	3.6	2.9	2.3	1.8	1.3	1.0	0.8	0.6	0.6
Condenser temp glide	K	7.0	6.0	5.0	4.2	3.4	2.8	2.3	2.0	1.7	1.5	1.4
Volumetric capacity	kJ/m3	805	812	819	827	833	840	845	848	850	849	848
Cooling COP		2.29	2.25	2.23	2.20	2.19	2.18	2.17	2.17	2.17	2.17	2.18
R744 (weight %)		8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%**
R1132a (weight %)		52.0%	56.0%	60.0%	64.0%	68.0%	70.0%	76.0%	80.0%	84.0%	88.0%	92.0%**
R116 (weight %)		40.0%	36.0%	32.0%	28.0%	24.0%	22.0%	16.0%	12.0%	8.0%	4.0%	0.0%**
GWP		4882	4394	3906	3419	2931	2687	1955	1467	979	492	4
Evaporator pressure	bar	1.13	1.12	1.11	1.09	1.08	1.07	1.05	1.03	1.02	1.00	0.99
Condenser pressure	bar	8.16	8.08	8.00	7.92	7.83	7.79	7.65	7.56	7.47	7.37	7.28
Pressure ratio		7.19	7.20	7.21	7.23	7.25	7.26	7.29	7.31	7.33	7.36	7.38
Volumetric efficiency		87.3%	87.3%	87.3%	87.4%	87.4%	87.4%	87.5%	87.5%	87.5%	87.5%	87.5%
Discharge temperature	°C	7.6	8.6	9.5	10.4	11.3	11.7	13.0	13.8	14.5	15.3	16.0
Evaporator temp glide	K	0.6	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.6	0.5	0.4
Condenser temp glide	K	1.4	1.4	1.4	1.5	1.5	1.5	1.4	1.3	1.3	1.1	1.0
Volumetric capacity	kJ/m3	841	836	831	826	820	817	808	801	794	787	779
Cooling COP		2.18	2.19	2.20	2.20	2.21	2.21	2.22	2.23	2.24	2.24	2.25

Table 7: Refrigeration performance modelling data for R-1132a/R-116/CO₂ ternary system with 12% by weight CO₂

R744 (weight %)		12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%
R1132a (weight %)		4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	32.0%	36.0%	40.0%	44.0%
R116 (weight %)		84.0%	80.0%	76.0%	72.0%	68.0%	64.0%	60.0%	56.0%	52.0%	48.0%	44.0%
GWP		10248	9760	9273	8785	8297	7809	7321	6833	6346	5858	5370
Evaporator pressure	bar	1.15	1.17	1.18	1.20	1.21	1.22	1.22	1.22	1.21	1.20	1.19
Condenser pressure	bar	8.55	8.66	8.75	8.81	8.85	8.86	8.84	8.81	8.75	8.69	8.61
Pressure ratio		7.45	7.43	7.39	7.35	7.32	7.28	7.25	7.23	7.22	7.22	7.23
Volumetric efficiency		85.9%	86.1%	86.3%	86.4%	86.6%	86.8%	86.9%	87.0%	87.1%	87.2%	87.3%
Discharge temperature	°C	2.7	3.3	3.9	4.5	5.0	5.6	6.3	7.0	7.8	8.7	9.6
Evaporator temp glide	K	5.0	4.1	3.4	2.7	2.1	1.6	1.2	0.9	0.8	0.7	0.7
Condenser temp glide	K	6.8	5.7	4.8	3.9	3.3	2.7	2.3	2.0	1.8	1.7	1.7
Volumetric capacity	kJ/m3	879	881	885	888	892	894	895	895	893	889	884
Cooling COP		2.27	2.23	2.21	2.19	2.18	2.17	2.17	2.17	2.17	2.17	2.18
R744 (weight %)		12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%**
R1132a (weight %)		48.0%	52.0%	56.0%	60.0%	64.0%	68.0%	70.0%	76.0%	80.0%	84.0%	88.0%**
R116 (weight %)		40.0%	36.0%	32.0%	28.0%	24.0%	20.0%	18.0%	12.0%	8.0%	4.0%	0.0%**
GWP		4882	4394	3906	3419	2931	2443	2199	1467	979	491	4
Evaporator pressure	bar	1.18	1.16	1.15	1.13	1.12	1.10	1.09	1.06	1.05	1.03	1.01
Condenser pressure	bar	8.52	8.43	8.34	8.24	8.14	8.04	7.98	7.83	7.73	7.63	7.52
Pressure ratio		7.24	7.25	7.26	7.28	7.30	7.32	7.33	7.36	7.38	7.40	7.43
Volumetric efficiency		87.3%	87.4%	87.4%	87.5%	87.5%	87.5%	87.5%	87.5%	87.6%	87.6%	87.6%
Discharge temperature	°C	10.5	11.4	12.3	13.2	14.0	14.9	15.3	16.4	17.2	17.9	18.6
Evaporator temp glide	K	0.7	0.8	0.8	0.9	0.9	0.9	0.9	0.8	0.7	0.6	0.5
Condenser temp glide	K	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.6	1.5	1.4	1.3
Volumetric capacity	kJ/m3	878	872	866	859	852	844	841	829	821	813	805
Cooling COP		2.18	2.19	2.19	2.20	2.20	2.21	2.22	2.23	2.23	2.24	2.25

Table 8: Refrigeration performance modelling data for R-1132a/R-116/CO₂ ternary system with 16% by weight CO₂

R744 (weight %)		16.0%	16.0%	16.0%	16.0%	16.0%	16.0%	16.0%	16.0%	16.0%	16.0%
R1132a (weight %)		4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	32.0%	36.0%	40.0%
R116 (weight %)		80.0%	76.0%	72.0%	68.0%	64.0%	60.0%	56.0%	52.0%	48.0%	44.0%
GWP		9760	9272	8785	8297	7809	7321	6833	6345	5858	5370
Evaporator pressure	bar	1.23	1.25	1.26	1.27	1.27	1.27	1.27	1.26	1.25	1.23
Condenser pressure	bar	9.13	9.21	9.26	9.29	9.29	9.26	9.21	9.14	9.06	8.97
Pressure ratio		7.40	7.38	7.36	7.33	7.30	7.27	7.26	7.25	7.26	7.28
Volumetric efficiency		86.4%	86.5%	86.7%	86.8%	86.9%	87.1%	87.2%	87.3%	87.3%	87.4%
Discharge temperature	°C	6.4	7.0	7.5	8.0	8.6	9.2	9.9	10.7	11.6	12.4
Evaporator temp glide	K	4.4	3.5	2.8	2.1	1.6	1.2	1.0	0.8	0.8	0.8
Condenser temp glide	K	6.0	5.0	4.1	3.4	2.8	2.4	2.1	1.9	1.8	1.8
Volumetric capacity	kJ/m3	937	937	939	940	941	940	938	934	928	921
Cooling COP		2.24	2.21	2.19	2.18	2.17	2.17	2.17	2.17	2.17	2.18
R744 (weight %)		16.0%	16.0%	16.0%	16.0%	16.0%	16.0%	16.0%	16.0%	16.0%	16.0%**
R1132a (weight %)		48.0%	52.0%	56.0%	60.0%	64.0%	68.0%	70.0%	76.0%	80.0%	84.0%**
R116 (weight %)		36.0%	32.0%	28.0%	24.0%	20.0%	16.0%	14.0%	8.0%	4.0%	0.0%**
GWP		4394	3906	3418	2931	2443	1955	1711	979	491	4
Evaporator pressure	bar	1.20	1.18	1.17	1.15	1.13	1.11	1.10	1.08	1.06	1.04
Condenser pressure	bar	8.76	8.65	8.54	8.43	8.32	8.20	8.15	7.98	7.87	7.76
Pressure ratio		7.29	7.30	7.32	7.34	7.36	7.38	7.39	7.42	7.44	7.47
Volumetric efficiency		87.5%	87.5%	87.5%	87.6%	87.6%	87.6%	87.6%	87.6%	87.6%	87.6%
Discharge temperature	°C	14.2	15.1	16.0	16.8	17.6	18.4	18.8	19.8	20.5	21.2
Evaporator temp glide	K	0.8	0.9	0.9	1.0	1.0	0.9	0.9	0.8	0.7	0.5
Condenser temp glide	K	1.8	1.8	1.9	1.9	1.9	1.8	1.8	1.7	1.6	1.5
Volumetric capacity	kJ/m3	906	898	890	882	874	865	861	848	839	830
Cooling COP		2.18	2.19	2.19	2.20	2.21	2.21	2.22	2.23	2.24	2.24

Table 9: Refrigeration performance modelling data for R-1132a/R-116/CO2 ternary system with 20% by weight CO2

R744 (weight %)		20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%
R1132a (weight %)		4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	32.0%	36.0%	40.0%
R116 (weight %)		76.0%	72.0%	68.0%	64.0%	60.0%	56.0%	52.0%	48.0%	44.0%	40.0%
GWP		9272	8785	8297	7809	7321	6833	6345	5857	5370	4882
Evaporator pressure	bar	1.31	1.32	1.32	1.33	1.32	1.32	1.31	1.29	1.27	1.26
Condenser pressure	bar	9.63	9.68	9.70	9.69	9.65	9.59	9.51	9.41	9.30	9.19
Pressure ratio		7.38	7.36	7.33	7.31	7.29	7.28	7.28	7.29	7.30	7.31
Volumetric efficiency		86.8%	86.9%	87.0%	87.1%	87.2%	87.3%	87.4%	87.5%	87.5%	87.6%
Discharge temperature	°C	9.9	10.5	11.0	11.5	12.1	12.8	13.6	14.5	15.4	16.2
Evaporator temp glide	K	3.4	2.7	2.0	1.5	1.1	0.9	0.8	0.7	0.7	0.8
Condenser temp glide	K	4.9	4.0	3.3	2.7	2.3	2.0	1.9	1.8	1.7	1.8
Volumetric capacity	kJ/m3	985	986	986	985	983	978	972	965	957	948
Cooling COP		2.21	2.19	2.18	2.17	2.17	2.17	2.17	2.17	2.17	2.17
R744 (weight %)		20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%**
R1132a (weight %)		44.0%	48.0%	52.0%	56.0%	60.0%	64.0%	68.0%	70.0%	76.0%	80.0%**
R116 (weight %)		36.0%	32.0%	28.0%	24.0%	20.0%	16.0%	12.0%	10.0%	4.0%	0.0%**
GWP		4394	3906	3418	2930	2443	1955	1467	1223	491	3
Evaporator pressure	bar	1.24	1.22	1.20	1.18	1.16	1.14	1.12	1.11	1.08	1.06
Condenser pressure	bar	9.07	8.95	8.83	8.70	8.58	8.46	8.34	8.28	8.10	7.98
Pressure ratio		7.33	7.34	7.36	7.38	7.40	7.42	7.44	7.45	7.48	7.50
Volumetric efficiency		87.6%	87.6%	87.6%	87.7%	87.7%	87.7%	87.7%	87.7%	87.7%	87.7%
Discharge temperature	°C	17.1	18.0	18.8	19.6	20.4	21.1	21.8	22.2	23.2	23.8
Evaporator temp glide	K	0.8	0.9	0.9	1.0	1.0	1.0	0.9	0.9	0.7	0.6
Condenser temp glide	K	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.8	1.7	1.6
Volumetric capacity	kJ/m3	939	930	920	911	902	892	883	878	863	853
Cooling COP		2.18	2.18	2.19	2.20	2.20	2.21	2.22	2.22	2.23	2.24

Table 10: Refrigeration performance modelling data for R-1132a/R-116/CO₂ ternary system with 24% by weight CO₂

R744 (weight %)		24.0%	24.0%	24.0%	24.0%	24.0%	24.0%	24.0%	24.0%	24.0%
R1132a (weight %)		4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	32.0%	36.0%
R116 (weight %)		72.0%	68.0%	64.0%	60.0%	56.0%	52.0%	48.0%	44.0%	40.0%
GWP		8784	8297	7809	7321	6833	6345	5857	5370	4882
Evaporator pressure	bar	1.37	1.37	1.37	1.37	1.36	1.35	1.33	1.31	1.29
Condenser pressure	bar	10.06	10.08	10.06	10.01	9.94	9.85	9.74	9.62	9.50
Pressure ratio		7.35	7.34	7.32	7.31	7.31	7.31	7.32	7.33	7.35
Volumetric efficiency		87.1%	87.2%	87.3%	87.4%	87.5%	87.6%	87.6%	87.6%	87.7%
Discharge temperature	°C	13.4	13.9	14.4	15.1	15.8	16.6	17.4	18.3	19.2
Evaporator temp glide	K	2.4	1.8	1.3	1.0	0.8	0.7	0.6	0.7	0.7
Condenser temp glide	K	3.8	3.0	2.5	2.1	1.8	1.7	1.6	1.6	1.6
Volumetric capacity	kJ/m3	1029	1029	1026	1023	1017	1009	1000	990	980
Cooling COP		2.19	2.18	2.17	2.17	2.16	2.16	2.16	2.17	2.17
R744 (weight %)		24.0%	24.0%	24.0%	24.0%	24.0%	24.0%	24.0%	24.0%	24.0%**
R1132a (weight %)		44.0%	48.0%	52.0%	56.0%	60.0%	64.0%	68.0%	70.0%	76.0%**
R116 (weight %)		32.0%	28.0%	24.0%	20.0%	16.0%	12.0%	8.0%	6.0%	0.0%**
GWP		3906	3418	2930	2442	1955	1467	979	735	3
Evaporator pressure	bar	1.25	1.23	1.21	1.19	1.17	1.15	1.13	1.12	1.09
Condenser pressure	bar	9.23	9.10	8.97	8.83	8.70	8.57	8.44	8.38	8.19
Pressure ratio		7.38	7.40	7.41	7.43	7.45	7.47	7.49	7.50	7.54
Volumetric efficiency		87.7%	87.8%	87.8%	87.8%	87.8%	87.8%	87.8%	87.8%	87.8%
Discharge temperature	°C	20.8	21.6	22.4	23.2	23.9	24.5	25.2	25.5	26.4
Evaporator temp glide	K	0.9	0.9	1.0	1.0	1.0	0.9	0.8	0.8	0.6
Condenser temp glide	K	1.8	1.8	1.9	1.9	1.9	1.9	1.8	1.8	1.6
Volumetric capacity	kJ/m3	960	949	939	929	918	908	897	892	876
Cooling COP		2.18	2.19	2.19	2.20	2.21	2.22	2.22	2.23	2.24

Table 11: Refrigeration performance modelling data for R-1132a/R-116/CO₂ ternary system with 30% by weight CO₂

R744 (weight %)		30.0%	30.0%	30.0%	30.0%	30.0%	30.0%	30.0%	30.0%	30.0%
R1132a (weight %)		4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	32.0%	36.0%
R116 (weight %)		66.0%	62.0%	58.0%	54.0%	50.0%	46.0%	42.0%	38.0%	34.0%
GWP		8052	7565	7077	6589	6101	5613	5125	4638	4150
Evaporator pressure	bar	1.44	1.44	1.43	1.41	1.39	1.37	1.35	1.33	1.31
Condenser pressure	bar	10.58	10.54	10.47	10.38	10.26	10.13	9.99	9.85	9.70
Pressure ratio		7.33	7.33	7.34	7.35	7.36	7.38	7.39	7.41	7.43
Volumetric efficiency		87.6%	87.7%	87.7%	87.8%	87.8%	87.8%	87.9%	87.9%	87.9%
Discharge temperature	°C	18.5	19.2	19.9	20.8	21.6	22.5	23.3	24.1	24.9
Evaporator temp glide	K	0.9	0.7	0.5	0.4	0.4	0.5	0.6	0.7	0.7
Condenser temp glide	K	2.2	1.7	1.4	1.3	1.2	1.2	1.3	1.4	1.5
Volumetric capacity	kJ/m3	1087	1082	1074	1065	1054	1042	1031	1019	1007
Cooling COP		2.17	2.16	2.16	2.16	2.16	2.16	2.16	2.17	2.17
R744 (weight %)		30.0%	30.0%	30.0%	30.0%	30.0%	30.0%	30.0%	30.0%	30.0%**
R1132a (weight %)		40.0%	44.0%	48.0%	52.0%	56.0%	60.0%	64.0%	68.0%	70.0%**
R116 (weight %)		30.0%	26.0%	22.0%	18.0%	14.0%	10.0%	6.0%	2.0%	0.0%**
GWP		3662	3174	2686	2198	1711	1223	735	247	3
Evaporator pressure	bar	1.28	1.26	1.24	1.22	1.19	1.17	1.15	1.13	1.12
Condenser pressure	bar	9.55	9.40	9.26	9.11	8.97	8.83	8.69	8.55	8.48
Pressure ratio		7.44	7.46	7.48	7.50	7.51	7.53	7.56	7.58	7.59
Volumetric efficiency		87.9%	87.9%	87.9%	88.0%	88.0%	88.0%	88.0%	88.0%	88.0%
Discharge temperature	°C	25.7	26.4	27.1	27.8	28.4	29.0	29.6	30.2	30.5
Evaporator temp glide	K	0.8	0.9	0.9	0.9	0.9	0.8	0.7	0.6	0.6
Condenser temp glide	K	1.6	1.7	1.7	1.8	1.8	1.7	1.7	1.6	1.5
Volumetric capacity	kJ/m3	995	984	972	961	949	938	926	915	909
Cooling COP		2.18	2.18	2.19	2.20	2.21	2.21	2.22	2.23	2.23

Table 12: Refrigeration performance modelling data for R-1132a/R-170/CO₂ ternary system with 4% by weight CO₂

R744 (weight %)		4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
R170 (weight %)		4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	32.0%	36.0%	40.0%	44.0%	48.0%
R1132a (weight %)		92.00%	88.00%	84.00%	80.00%	76.00%	72.00%	68.00%	64.00%	60.00%	56.00%	52.00%	48.00%
GWP		4	4	4	4	4	4	4	4	4	3	3	3
Evaporator pressure	bar	1.02	1.08	1.13	1.18	1.22	1.25	1.28	1.30	1.32	1.33	1.34	1.35
Condenser pressure	bar	7.38	7.68	7.92	8.13	8.30	8.43	8.54	8.62	8.67	8.71	8.72	8.72
Pressure ratio		7.21	7.09	6.99	6.90	6.83	6.75	6.69	6.63	6.58	6.54	6.50	6.47
Volumetric efficiency		87.8%	88.1%	88.4%	88.6%	88.9%	89.1%	89.3%	89.4%	89.6%	89.8%	89.9%	90.0%
Discharge temperature	°C	15.1	16.7	18.0	19.3	20.5	21.6	22.7	23.7	24.8	25.8	26.9	28.0
Evaporator temp glide	K	0.8	1.2	1.3	1.3	1.2	1.1	0.9	0.8	0.6	0.5	0.5	0.4
Condenser temp glide	K	1.2	1.4	1.5	1.4	1.2	1.1	0.9	0.8	0.8	0.7	0.8	0.8
Volumetric capacity	kJ/m3	806	852	892	926	955	980	1002	1019	1033	1044	1052	1057
Cooling COP		2.27	2.29	2.30	2.31	2.32	2.33	2.33	2.34	2.34	2.34	2.34	2.35
R744 (weight %)		4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%**
R170 (weight %)		52.0%	56.0%	60.0%	64.0%	68.0%	70.0%	76.0%	80.0%	84.0%	88.0%	92.0%	96%**
R1132a (weight %)		44.00%	40.00%	36.00%	32.00%	28.00%	26.00%	20.00%	16.00%	12.00%	8.00%	4.00%	0.00%**
GWP		3	3	3	3	3	3	3	3	3	3	3	3
Evaporator pressure	bar	1.35	1.35	1.35	1.35	1.34	1.34	1.33	1.32	1.32	1.31	1.30	1.29
Condenser pressure	bar	8.71	8.69	8.66	8.62	8.57	8.52	8.47	8.41	8.35	8.29	8.22	8.16
Pressure ratio		6.45	6.42	6.41	6.39	6.38	6.37	6.36	6.35	6.35	6.34	6.34	6.33
Volumetric efficiency		90.2%	90.3%	90.3%	90.4%	90.5%	90.6%	90.7%	90.7%	90.8%	90.8%	90.9%	91.0%
Discharge temperature	°C	29.1	30.2	31.3	32.4	33.5	34.6	35.7	36.7	37.7	38.7	39.7	40.6
Evaporator temp glide	K	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8	0.8	0.9	0.9	0.9
Condenser temp glide	K	0.9	0.9	1.0	1.1	1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.4
Volumetric capacity	kJ/m3	1060	1061	1060	1057	1053	1049	1043	1037	1031	1024	1016	1008
Cooling COP		2.35	2.35	2.34	2.34	2.34	2.34	2.33	2.33	2.33	2.32	2.32	2.31

Table 13: Refrigeration performance modelling data for R-1132a/R-170/CO₂ ternary system with 8% by weight CO₂

R744 (weight %)		8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
R170 (weight %)		4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	32.0%	36.0%	40.0%	44.0%
R1132a (weight %)		88.0%	84.0%	80.0%	76.0%	72.0%	68.0%	64.0%	60.0%	56.0%	52.0%	48.0%
GWP		4	4	4	4	4	4	3	3	3	3	3
Evaporator pressure	bar	1.05	1.12	1.17	1.21	1.25	1.29	1.32	1.34	1.36	1.38	1.39
Condenser pressure	bar	7.65	7.96	8.21	8.42	8.60	8.74	8.85	8.93	8.98	9.02	9.03
Pressure ratio		7.25	7.13	7.03	6.93	6.85	6.78	6.71	6.65	6.60	6.55	6.51
Volumetric efficiency		87.8%	88.1%	88.4%	88.7%	88.9%	89.1%	89.3%	89.5%	89.7%	89.9%	90.0%
Discharge temperature	°C	17.7	19.2	20.5	21.7	22.8	23.9	24.9	25.9	26.9	27.9	29.0
Evaporator temp glide	K	1.0	1.4	1.5	1.5	1.4	1.3	1.1	1.0	0.9	0.8	0.8
Condenser temp glide	K	1.6	1.8	1.9	1.8	1.7	1.5	1.4	1.3	1.3	1.3	1.4
Volumetric capacity	kJ/m3	834	881	921	956	987	1012	1034	1052	1067	1078	1086
Cooling COP		2.27	2.28	2.29	2.30	2.31	2.31	2.32	2.32	2.33	2.33	2.33
R744 (weight %)		8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
R170 (weight %)		52.0%	56.0%	60.0%	64.0%	68.0%	70.0%	76.0%	80.0%	84.0%	88.0%	92.0%
R1132a (weight %)		44.00%	40.00%	36.00%	32.00%	28.00%	26.00%	20.00%	16.00%	12.00%	8.00%	4.00%
GWP		3	3	3	3	3	3	3	3	3	3	3
Evaporator pressure	bar	1.40	1.40	1.40	1.40	1.39	1.39	1.38	1.37	1.36	1.36	1.35
Condenser pressure	bar	9.02	8.99	8.96	8.92	8.87	8.82	8.76	8.70	8.64	8.58	8.51
Pressure ratio		6.45	6.42	6.40	6.39	6.37	6.36	6.35	6.34	6.33	6.33	6.32
Volumetric efficiency		90.2%	90.3%	90.4%	90.5%	90.6%	90.7%	90.8%	90.8%	90.9%	90.9%	91.0%
Discharge temperature	°C	31.1	32.2	33.3	34.4	35.5	36.6	37.6	38.7	39.7	40.7	41.7
Evaporator temp glide	K	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.7
Condenser temp glide	K	1.5	1.7	1.8	1.9	2.1	2.2	2.3	2.4	2.5	2.5	2.6
Volumetric capacity	kJ/m3	1094	1095	1094	1092	1088	1084	1078	1072	1066	1059	1052
Cooling COP		2.33	2.33	2.33	2.33	2.33	2.33	2.32	2.32	2.32	2.31	2.31

Table 14: Refrigeration performance modelling data for R-1132a/R-170/CO₂ ternary system with 12% by weight CO₂

R744 (weight %)		12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%
R170 (weight %)		4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	32.0%	36.0%	40.0%	44.0%
R1132a (weight %)		84.0%	80.0%	76.0%	72.0%	68.0%	64.0%	60.0%	56.0%	52.0%	48.0%	44.0%
GWP		4	4	4	3	3	3	3	3	3	3	3
Evaporator pressure	bar	1.08	1.15	1.20	1.25	1.29	1.33	1.36	1.39	1.41	1.42	1.43
Condenser pressure	bar	7.91	8.22	8.49	8.71	8.89	9.03	9.14	9.23	9.28	9.32	9.33
Pressure ratio		7.29	7.17	7.06	6.96	6.87	6.79	6.72	6.66	6.60	6.55	6.51
Volumetric efficiency		87.9%	88.2%	88.5%	88.8%	89.0%	89.2%	89.4%	89.6%	89.8%	89.9%	90.1%
Discharge temperature	°C	20.2	21.6	22.9	24.0	25.1	26.1	27.1	28.1	29.0	30.0	31.0
Evaporator temp glide	K	1.1	1.5	1.7	1.7	1.6	1.4	1.3	1.2	1.1	1.0	1.0
Condenser temp glide	K	1.9	2.1	2.2	2.1	2.0	1.8	1.7	1.7	1.7	1.7	1.8
Volumetric capacity	kJ/m3	860	909	950	986	1017	1043	1066	1084	1099	1111	1119
Cooling COP		2.26	2.27	2.28	2.29	2.30	2.30	2.31	2.31	2.31	2.32	2.32
R744 (weight %)		12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%**
R170 (weight %)		48.0%	52.0%	56.0%	60.0%	64.0%	68.0%	70.0%	76.0%	80.0%	84.0%	88.0%**
R1132a (weight %)		40.0%	36.0%	32.0%	28.0%	24.0%	20.0%	18.0%	12.0%	8.0%	4.0%	0.0%**
GWP		3	3	3	3	3	3	3	3	3	3	3
Evaporator pressure	bar	1.44	1.45	1.45	1.45	1.44	1.44	1.43	1.43	1.42	1.41	1.40
Condenser pressure	bar	9.33	9.31	9.28	9.25	9.20	9.16	9.10	9.04	8.98	8.92	8.86
Pressure ratio		6.47	6.44	6.42	6.40	6.38	6.36	6.35	6.33	6.32	6.31	6.31
Volumetric efficiency		90.2%	90.3%	90.4%	90.5%	90.6%	90.7%	90.8%	90.9%	90.9%	91.0%	91.0%
Discharge temperature	°C	32.1	33.1	34.2	35.3	36.4	37.5	38.5	39.6	40.6	41.6	42.6
Evaporator temp glide	K	1.0	1.1	1.2	1.4	1.5	1.6	1.8	1.9	2.1	2.2	2.3
Condenser temp glide	K	1.9	2.1	2.3	2.4	2.6	2.8	3.0	3.1	3.3	3.4	3.5
Volumetric capacity	kJ/m3	1125	1128	1128	1127	1125	1122	1117	1112	1107	1100	1094
Cooling COP		2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.31	2.31	2.31	2.31

Table 15: Refrigeration performance modelling data for R-1132a/R-170/CO₂ ternary system with 16% by weight CO₂

R744 (weight %)		16.0%	16.0%	16.0%	16.0%	16.0%	16.0%	16.0%	16.0%	16.0%	16.0%
R170 (weight %)		4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	32.0%	36.0%	40.0%
R1132a (weight %)		80.0%	76.0%	72.0%	68.0%	64.0%	60.0%	56.0%	52.0%	48.0%	44.0%
GWP		3	3	3	3	3	3	3	3	3	3
Evaporator pressure	bar	1.11	1.18	1.24	1.29	1.33	1.37	1.40	1.43	1.45	1.47
Condenser pressure	bar	8.15	8.48	8.75	8.98	9.17	9.32	9.43	9.52	9.57	9.61
Pressure ratio		7.33	7.20	7.08	6.98	6.89	6.81	6.73	6.67	6.60	6.55
Volumetric efficiency		88.0%	88.3%	88.6%	88.9%	89.1%	89.3%	89.5%	89.7%	89.9%	90.0%
Discharge temperature	°C	22.8	24.1	25.3	26.4	27.4	28.4	29.3	30.2	31.1	32.0
Evaporator temp glide	K	1.2	1.6	1.8	1.8	1.7	1.6	1.4	1.3	1.2	1.2
Condenser temp glide	K	2.1	2.3	2.4	2.3	2.2	2.1	2.0	1.9	2.0	2.0
Volumetric capacity	kJ/m3	886	936	978	1015	1046	1074	1097	1116	1131	1143
Cooling COP		2.26	2.27	2.27	2.28	2.29	2.29	2.29	2.30	2.30	2.31
R744 (weight %)		16.0%	16.0%	16.0%	16.0%	16.0%	16.0%	16.0%	16.0%	16.0%	16.0%**
R170 (weight %)		48.0%	52.0%	56.0%	60.0%	64.0%	68.0%	70.0%	76.0%	80.0%	84.0%**
R1132a (weight %)		36.0%	32.0%	28.0%	24.0%	20.0%	16.0%	12.0%	8.0%	4.0%	0.0%**
GWP		3	3	3	3	3	3	3	3	3	3
Evaporator pressure	bar	1.49	1.49	1.49	1.49	1.49	1.49	1.48	1.47	1.47	1.46
Condenser pressure	bar	9.62	9.60	9.57	9.53	9.48	9.43	9.37	9.31	9.25	9.19
Pressure ratio		6.47	6.43	6.41	6.38	6.36	6.35	6.33	6.32	6.30	6.29
Volumetric efficiency		90.3%	90.4%	90.5%	90.6%	90.7%	90.8%	90.9%	91.0%	91.0%	91.1%
Discharge temperature	°C	34.0	35.1	36.1	37.2	38.3	39.4	40.4	41.5	42.5	43.5
Evaporator temp glide	K	1.3	1.4	1.5	1.7	1.9	2.1	2.2	2.4	2.6	2.8
Condenser temp glide	K	2.3	2.5	2.7	3.0	3.2	3.4	3.6	3.8	4.0	4.1
Volumetric capacity	kJ/m3	1157	1160	1161	1160	1158	1154	1150	1145	1140	1134
Cooling COP		2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.30	2.30

Table 16: Refrigeration performance modelling data for R-1132a/R-116/R-170 ternary system with 4% by weight R-1132a

R170 (weight %)		4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	32.0%	36.0%	40.0%	44.0%	48.0%
R1132a (weight %)		4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
R116 (weight %)		92.0%	88.0%	84.0%	80.0%	76.0%	72.0%	68.0%	64.0%	60.0%	56.0%	52.0%	48.0%
GWP		11224	10736	10249	9761	9273	8785	8297	7809	7321	6833	6345	5858
Evaporator pressure	bar	0.96	1.13	1.25	1.35	1.42	1.48	1.52	1.54	1.53	1.52	1.50	1.48
Condenser pressure	bar	7.09	7.90	8.49	8.91	9.20	9.38	9.45	9.45	9.40	9.32	9.22	9.12
Pressure ratio		7.36	6.97	6.76	6.62	6.48	6.35	6.22	6.15	6.13	6.13	6.14	6.15
Volumetric efficiency		85.4%	86.5%	87.2%	87.8%	88.3%	88.8%	89.2%	89.6%	89.8%	89.9%	90.1%	90.2%
Discharge temperature	°C	-6.1	-2.4	0.6	3.0	5.0	6.7	8.2	10.1	12.5	15.0	17.5	19.8
Evaporator temp glide	K	4.4	5.5	5.0	3.8	2.5	1.3	0.4	0.0	0.1	0.4	0.7	1.0
Condenser temp glide	K	4.8	4.7	3.5	2.2	1.1	0.3	0.0	0.0	0.2	0.5	0.8	1.1
Volumetric capacity	kJ/m3	762	898	990	1057	1112	1156	1189	1204	1203	1193	1180	1166
Cooling COP		2.40	2.46	2.47	2.47	2.48	2.49	2.51	2.51	2.51	2.49	2.48	2.47
R170 (weight %)		52.0%	56.0%	60.0%	64.0%	68.0%	72.0%	76.0%	80.0%	84.0%	88.0%	92.0%	
R1132a (weight %)		4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	
R116 (weight %)		44.0%	40.0%	36.0%	32.0%	28.0%	24.0%	20.0%	16.0%	12.0%	8.0%	4.0%	
GWP		5370	4882	4394	3906	3418	2930	2442	1955	1467	979	491	
Evaporator pressure	bar	1.46	1.44	1.43	1.41	1.39	1.36	1.34	1.32	1.30	1.28	1.26	
Condenser pressure	bar	9.02	8.91	8.81	8.70	8.60	8.49	8.39	8.28	8.18	8.07	7.96	
Pressure ratio		6.16	6.17	6.18	6.19	6.21	6.22	6.24	6.26	6.28	6.30	6.32	
Volumetric efficiency		90.3%	90.4%	90.5%	90.5%	90.6%	90.7%	90.7%	90.8%	90.8%	90.8%	90.9%	
Discharge temperature	°C	21.9	23.9	25.8	27.5	29.2	30.8	32.3	33.7	35.0	36.3	37.5	
Evaporator temp glide	K	1.2	1.4	1.5	1.6	1.6	1.5	1.3	1.1	0.9	0.6	0.4	
Condenser temp glide	K	1.3	1.5	1.6	1.7	1.7	1.6	1.5	1.3	1.1	0.8	0.5	
Volumetric capacity	kJ/m3	1152	1137	1122	1107	1091	1075	1058	1041	1023	1006	989	
Cooling COP		2.46	2.45	2.43	2.42	2.41	2.40	2.39	2.37	2.36	2.35	2.34	

Table 17: Refrigeration performance modelling data for R-1132a/R-116/R-170 ternary system with 8% by weight R-1132a

R170 (weight %)		4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	32.0%	36.0%	40.0%	44.0%
R1132a (weight %)		8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
R116 (weight %)		88.0%	84.0%	80.0%	76.0%	72.0%	68.0%	64.0%	60.0%	56.0%	52.0%	48.0%
GWP		10736	10249	9761	9273	8785	8297	7809	7321	6833	6346	5858
Evaporator pressure	bar	1.01	1.16	1.28	1.37	1.43	1.49	1.52	1.53	1.52	1.51	1.49
Condenser pressure	bar	7.31	8.07	8.61	8.99	9.25	9.40	9.45	9.43	9.37	9.29	9.19
Pressure ratio		7.27	6.93	6.74	6.59	6.45	6.32	6.21	6.16	6.15	6.15	6.16
Volumetric efficiency		85.7%	86.7%	87.4%	87.9%	88.5%	88.9%	89.3%	89.6%	89.8%	89.9%	90.1%
Discharge temperature	°C	-5.2	-1.7	1.1	3.4	5.3	7.0	8.7	10.8	13.2	15.7	18.1
Evaporator temp glide	K	4.2	4.9	4.3	3.1	1.9	0.9	0.2	0.0	0.2	0.5	0.8
Condenser temp glide	K	4.3	4.0	2.9	1.7	0.8	0.2	0.0	0.1	0.3	0.6	0.9
Volumetric capacity	kJ/m3	782	908	996	1062	1115	1157	1185	1196	1192	1183	1171
Cooling COP		2.37	2.42	2.44	2.45	2.46	2.48	2.49	2.50	2.49	2.48	2.47
R170 (weight %)		48.0%	52.0%	56.0%	60.0%	64.0%	68.0%	72.0%	76.0%	80.0%	84.0%	88.0%
R1132a (weight %)		8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
R116 (weight %)		44.0%	40.0%	36.0%	32.0%	28.0%	24.0%	20.0%	16.0%	12.0%	8.0%	4.0%
GWP		5370	4882	4394	3906	3418	2930	2442	1955	1467	979	491
Evaporator pressure	bar	1.47	1.45	1.44	1.42	1.40	1.37	1.35	1.33	1.31	1.29	1.27
Condenser pressure	bar	9.09	8.99	8.88	8.77	8.67	8.56	8.46	8.35	8.24	8.14	8.03
Pressure ratio		6.17	6.18	6.19	6.20	6.21	6.23	6.25	6.26	6.29	6.31	6.32
Volumetric efficiency		90.2%	90.3%	90.4%	90.5%	90.5%	90.6%	90.6%	90.7%	90.7%	90.8%	90.8%
Discharge temperature	°C	20.3	22.4	24.3	26.2	27.9	29.5	31.1	32.6	33.9	35.2	36.5
Evaporator temp glide	K	1.0	1.2	1.4	1.4	1.4	1.4	1.3	1.1	0.9	0.6	0.4
Condenser temp glide	K	1.1	1.3	1.4	1.5	1.5	1.5	1.4	1.3	1.1	0.8	0.5
Volumetric capacity	kJ/m3	1157	1143	1129	1114	1098	1082	1065	1048	1031	1014	997
Cooling COP		2.46	2.45	2.44	2.42	2.41	2.40	2.39	2.38	2.36	2.35	2.34

Table 18: Refrigeration performance modelling data for R-1132a/R-116/R-170 ternary system with 12-20% by weight R-1132a

R170 (weight %)		4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	4.0%	8.0%	12.0%	16.0%
R1132a (weight %)		12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	16.0%	16.0%	16.0%	16.0%
R116 (weight %)		84.0%	80.0%	76.0%	72.0%	68.0%	64.0%	60.0%	80.0%	76.0%	72.0%	68.0%
GWP		10249	9761	9273	8785	8297	7809	7321	9761	9273	8785	8297
Evaporator pressure	bar	1.04	1.19	1.30	1.38	1.44	1.49	1.52	1.07	1.21	1.31	1.39
Condenser pressure	bar	7.49	8.20	8.70	9.05	9.27	9.39	9.43	7.65	8.30	8.76	9.08
Pressure ratio		7.20	6.90	6.70	6.56	6.42	6.30	6.21	7.13	6.86	6.67	6.53
Volumetric efficiency		86.0%	86.9%	87.5%	88.1%	88.6%	89.0%	89.4%	86.2%	87.1%	87.7%	88.2%
Discharge temperature	°C	-4.4	-1.1	1.6	3.8	5.6	7.4	9.3	-3.7	-0.5	2.0	4.2
Evaporator temp glide	K	3.9	4.3	3.6	2.5	1.5	0.6	0.1	3.4	3.6	3.0	2.0
Condenser temp glide	K	3.7	3.3	2.3	1.3	0.5	0.1	0.0	3.1	2.7	1.8	1.0
Volumetric capacity	kJ/m3	798	916	1001	1065	1117	1155	1178	811	923	1004	1067
Cooling COP		2.34	2.39	2.42	2.43	2.45	2.47	2.48	2.31	2.37	2.40	2.42
R170 (weight %)		20.0%	24.0%	28.0%	4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	
R1132a (weight %)		16.0%	16.0%	16.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%	
R116 (weight %)		64.0%	60.0%	56.0%	76.0%	72.0%	68.0%	64.0%	60.0%	56.0%	52.0%	
GWP		7809	7321	6833	9273	8785	8297	7809	7321	6834	6346	
Evaporator pressure	bar	1.45	1.49	1.51	1.10	1.23	1.32	1.40	1.45	1.48	1.50	
Condenser pressure	bar	9.27	9.37	9.39	7.77	8.38	8.80	9.08	9.25	9.33	9.34	
Pressure ratio		6.40	6.29	6.22	7.07	6.82	6.65	6.50	6.38	6.29	6.24	
Volumetric efficiency		88.7%	89.1%	89.4%	86.5%	87.2%	87.8%	88.3%	88.8%	89.1%	89.4%	
Discharge temperature	°C	6.0	7.9	9.9	-3.1	0.0	2.5	4.6	6.5	8.5	10.7	
Evaporator temp glide	K	1.1	0.4	0.1	2.9	3.0	2.4	1.6	0.8	0.3	0.2	
Condenser temp glide	K	0.4	0.1	0.1	2.5	2.2	1.4	0.8	0.3	0.1	0.1	
Volumetric capacity	kJ/m3	1115	1150	1168	822	928	1007	1067	1111	1141	1156	
Cooling COP		2.44	2.46	2.47	2.29	2.35	2.38	2.41	2.43	2.45	2.45	

Table 19: Refrigeration performance modelling data for R-1132a/R-116/R-170 ternary system with 30-60% by weight R-1132a

R170 (weight %)		4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	4.0%	8.0%	12.0%	16.0%
R1132a (weight %)		30%	30%	30%	30%	30%	30%	30%	40%	40%	40%	40%
R116 (weight %)		66.0%	62.0%	58.0%	54.0%	50.0%	46.0%	42.0%	56.0%	52.0%	48.0%	44.0%
GWP		8053	7565	7078	6590	6102	5614	5126	6834	6346	5858	5370
Evaporator pressure	bar	1.14	1.25	1.33	1.39	1.43	1.45	1.45	1.16	1.25	1.31	1.36
Condenser pressure	bar	7.96	8.46	8.79	9.01	9.13	9.18	9.17	7.99	8.40	8.67	8.84
Pressure ratio		6.96	6.75	6.60	6.48	6.40	6.34	6.31	6.89	6.73	6.61	6.52
Volumetric efficiency		86.9%	87.6%	88.1%	88.6%	88.9%	89.2%	89.4%	87.3%	87.8%	88.3%	88.6%
Discharge temperature	°C	-1.5	1.4	3.8	6.0	8.2	10.5	12.7	0.3	3.1	5.7	8.0
Evaporator temp glide	K	1.7	1.8	1.5	1.0	0.6	0.5	0.4	1.0	1.2	1.1	1.0
Condenser temp glide	K	1.4	1.3	0.9	0.5	0.3	0.3	0.3	0.9	1.0	0.8	0.6
Volumetric capacity	kJ/m3	842	935	1004	1055	1090	1111	1122	851	930	989	1030
Cooling COP		2.26	2.32	2.36	2.38	2.40	2.41	2.42	2.25	2.30	2.34	2.36
R170 (weight %)		20.0%	24.0%	28.0%	4.0%	8.0%	12.0%	16.0%	20.0%	24.0%	28.0%	
R1132a (weight %)		40%	40%	40%	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%	
R116 (weight %)		40.0%	36.0%	32.0%	36.0%	32.0%	28.0%	24.0%	20.0%	16.0%	12.0%	
GWP		4882	4394	3906	4395	3907	3419	2931	2443	1955	1467	
Evaporator pressure	bar	1.38	1.40	1.40	1.12	1.19	1.23	1.26	1.28	1.29	1.30	
Condenser pressure	bar	8.94	8.98	8.97	7.79	8.08	8.28	8.41	8.48	8.51	8.51	
Pressure ratio		6.46	6.42	6.39	6.92	6.81	6.73	6.66	6.62	6.58	6.56	
Volumetric efficiency		88.9%	89.2%	89.4%	87.6%	88.0%	88.4%	88.7%	88.9%	89.1%	89.3%	
Discharge temperature	°C	10.3	12.6	14.7	4.9	7.6	10.1	12.4	14.5	16.5	18.4	
Evaporator temp glide	K	0.8	0.7	0.7	0.9	1.3	1.4	1.3	1.2	1.0	0.8	
Condenser temp glide	K	0.5	0.5	0.5	0.9	1.1	1.1	1.0	0.9	0.7	0.6	
Volumetric capacity	kJ/m3	1058	1076	1085	837	895	938	968	990	1004	1012	
Cooling COP		2.38	2.39	2.39	2.25	2.29	2.32	2.33	2.35	2.35	2.36	

Table 20: Refrigeration performance modelling data for R-1132a/R-116/R-170/R-744 quaternary system with 4-12% by weight R-744

R170 (weight %)		4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	8.0%	8.0%	8.0%
R744 (weight %)		4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	8.0%	8.0%	8.0%
R1132a (weight %)		20.0%	30.0%	40.0%	50.0%	60.0%	70.0%	80.0%	90.0%	20.0%	30.0%	40.0%
R116 (weight %)		76.0%	66.0%	56.0%	46.0%	36.0%	26.0%	16.0%	6.0%	72.0%	62.0%	52.0%
GWP		9273	8053	6834	5614	4395	3175	1955	736	8785	7566	6346
Evaporator pressure	bar	1.19	1.22	1.22	1.20	1.16	1.13	1.09	1.05	1.39	1.38	1.35
Condenser pressure	bar	8.45	8.52	8.46	8.33	8.14	7.93	7.72	7.49	9.50	9.40	9.21
Pressure ratio		7.08	6.99	6.95	6.95	6.99	7.04	7.10	7.17	6.84	6.81	6.82
Volumetric efficiency		86.7%	87.1%	87.4%	87.6%	87.7%	87.7%	87.8%	87.8%	87.6%	87.8%	88.0%
Discharge temperature	°C	0.6	2.0	3.6	5.7	7.9	10.1	12.1	13.9	6.1	7.3	8.9
Evaporator temp glide	K	3.5	2.1	1.4	1.2	1.2	1.3	1.2	1.0	3.6	2.3	1.8
Condenser temp glide	K	3.8	2.4	1.8	1.6	1.6	1.6	1.5	1.3	3.7	2.6	2.2
Volumetric capacity	kJ/m3	904	909	905	893	875	856	837	816	1064	1046	1021
Cooling COP		2.31	2.27	2.26	2.25	2.25	2.25	2.26	2.27	2.35	2.32	2.30
R170 (weight %)		8.0%	8.0%	8.0%	8.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%
R744 (weight %)		8.0%	8.0%	8.0%	8.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%
R1132a (weight %)		50.0%	60.0%	70.0%	80.0%	20.0%	30.0%	40.0%	50.0%	60.0%	70.0%	80.0%
R116 (weight %)		42.0%	32.0%	22.0%	12.0%	68.0%	58.0%	48.0%	38.0%	28.0%	18.0%	8.0%
GWP		5126	3907	2687	1468	8297	7078	5858	4638	3419	2199	980
Evaporator pressure	bar	1.31	1.26	1.21	1.16	1.53	1.50	1.44	1.39	1.33	1.27	1.22
Condenser pressure	bar	8.97	8.71	8.45	8.18	10.24	10.01	9.73	9.43	9.13	8.83	8.55
Pressure ratio		6.87	6.93	6.99	7.06	6.68	6.69	6.74	6.81	6.88	6.95	7.02
Volumetric efficiency		88.1%	88.1%	88.1%	88.1%	88.3%	88.4%	88.5%	88.5%	88.5%	88.4%	88.4%
Discharge temperature	°C	10.9	12.9	14.9	16.6	10.4	11.7	13.5	15.4	17.2	18.9	20.5
Evaporator temp glide	K	1.7	1.8	1.8	1.6	3.0	2.1	1.9	2.0	2.0	2.0	1.8
Condenser temp glide	K	2.2	2.2	2.2	2.1	3.1	2.5	2.3	2.4	2.4	2.4	2.3
Volumetric capacity	kJ/m3	991	961	931	903	1180	1144	1103	1062	1024	988	954
Cooling COP		2.29	2.28	2.28	2.28	2.37	2.34	2.32	2.30	2.29	2.29	2.28

Table 21: Refrigeration performance modelling data for R-1132a/R-116/R-170/R-744 quaternary system with 8-24% by weight R-744

R170 (weight %)		4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	8.0%	8.0%	8.0%
R744 (weight %)		8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	16.0%	16.0%	16.0%
R1132a (weight %)		20.0%	30.0%	40.0%	50.0%	60.0%	70.0%	80.0%	90.0%	20.0%	30.0%	40.0%
R116 (weight %)		76.0%	66.0%	56.0%	46.0%	36.0%	26.0%	16.0%	6.0%	72.0%	62.0%	52.0%
GWP		9273	8053	6834	5614	4395	3175	1955	736	8785	7566	6346
Evaporator pressure	bar	1.27	1.28	1.27	1.24	1.20	1.16	1.11	1.07	1.49	1.46	1.42
Condenser pressure	bar	8.97	8.96	8.84	8.66	8.44	8.21	7.97	7.73	10.22	10.02	9.75
Pressure ratio		7.07	7.01	6.98	7.00	7.05	7.10	7.15	7.22	6.85	6.85	6.89
Volumetric efficiency		86.9%	87.2%	87.5%	87.6%	87.7%	87.8%	87.8%	87.8%	87.9%	88.1%	88.2%
Discharge temperature	°C	3.7	4.9	6.5	8.5	10.6	12.6	14.5	16.2	10.9	12.1	13.7
Evaporator temp glide	K	3.6	2.2	1.5	1.4	1.4	1.4	1.4	1.1	3.2	2.3	2.0
Condenser temp glide	K	4.2	2.8	2.2	2.0	2.0	2.0	1.9	1.7	3.6	2.8	2.5
Volumetric capacity	kJ/m3	970	963	950	930	908	885	863	840	1152	1120	1082
Cooling COP		2.32	2.28	2.26	2.25	2.25	2.25	2.26	2.26	2.35	2.32	2.29
R170 (weight %)		8.0%	8.0%	8.0%	8.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%
R744 (weight %)		16.0%	16.0%	16.0%	16.0%	24.0%	24.0%	24.0%	24.0%	24.0%	24.0%	24.0%
R1132a (weight %)		50.0%	60.0%	70.0%	80.0%	20.0%	30.0%	40.0%	50.0%	60.0%	70.0%	80.0%
R116 (weight %)		42.0%	32.0%	22.0%	12.0%	68.0%	58.0%	48.0%	38.0%	28.0%	18.0%	8.0%
GWP		5126	3907	2687	1468	8297	7078	5858	4639	3419	2199	980
Evaporator pressure	bar	1.36	1.31	1.25	1.20	1.64	1.58	1.51	1.45	1.39	1.33	1.27
Condenser pressure	bar	9.46	9.16	8.87	8.59	11.02	10.70	10.35	10.01	9.68	9.36	9.05
Pressure ratio		6.95	7.01	7.07	7.14	6.72	6.77	6.84	6.91	6.98	7.05	7.11
Volumetric efficiency		88.2%	88.2%	88.2%	88.2%	88.6%	88.6%	88.6%	88.6%	88.6%	88.6%	88.5%
Discharge temperature	°C	15.6	17.4	19.1	20.7	16.4	17.9	19.6	21.3	22.9	24.3	25.7
Evaporator temp glide	K	1.9	2.0	1.9	1.8	2.4	2.1	2.1	2.1	2.2	2.1	2.0
Condenser temp glide	K	2.5	2.6	2.6	2.5	2.7	2.4	2.5	2.6	2.7	2.7	2.6
Volumetric capacity	kJ/m3	1045	1009	976	944	1270	1219	1168	1122	1079	1040	1004
Cooling COP		2.28	2.27	2.27	2.27	2.35	2.32	2.30	2.28	2.27	2.27	2.26

Table 22: Refrigeration performance modelling data for R-1132a/R-116/R-170/R-744 quaternary system with 12-36% b/w R-744

R170 (weight %)		4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	8.0%	8.0%	8.0%
R744 (weight %)		12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	24.0%	24.0%	24.0%
R1132a (weight %)		20.0%	30.0%	40.0%	50.0%	60.0%	70.0%	80.0%	90.0%	20.0%	30.0%	40.0%
R116 (weight %)		76.0%	66.0%	56.0%	46.0%	36.0%	26.0%	16.0%	6.0%	72.0%	62.0%	52.0%
GWP		9273	8053	6834	5614	4395	3175	1955	736	8785	7566	6346
Evaporator pressure	bar	1.33	1.33	1.31	1.27	1.23	1.18	1.14	1.09	1.56	1.51	1.46
Condenser pressure	bar	9.40	9.32	9.16	8.94	8.69	8.44	8.19	7.94	10.71	10.45	10.14
Pressure ratio		7.06	7.02	7.02	7.05	7.09	7.14	7.20	7.26	6.87	6.90	6.95
Volumetric efficiency		87.1%	87.4%	87.6%	87.7%	87.8%	87.8%	87.8%	87.8%	88.2%	88.3%	88.3%
Discharge temperature	°C	6.4	7.6	9.2	11.1	13.1	15.0	16.7	18.3	14.9	16.3	17.9
Evaporator temp glide	K	3.4	2.2	1.6	1.5	1.5	1.5	1.4	1.2	2.6	2.1	2.0
Condenser temp glide	K	4.1	3.0	2.4	2.3	2.2	2.2	2.1	1.9	3.1	2.6	2.5
Volumetric capacity	kJ/m3	1023	1008	988	962	936	911	886	861	1211	1169	1125
Cooling COP		2.32	2.28	2.26	2.25	2.25	2.25	2.25	2.26	2.34	2.31	2.29
R170 (weight %)		8.0%	8.0%	8.0%	8.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%	12.0%
R744 (weight %)		24.0%	24.0%	24.0%	24.0%	36.0%	36.0%	36.0%	36.0%	36.0%	36.0%	36.0%
R1132a (weight %)		50.0%	60.0%	70.0%	80.0%	20.0%	30.0%	40.0%	50.0%	60.0%	70.0%	80.0%
R116 (weight %)		42.0%	32.0%	22.0%	12.0%	68.0%	58.0%	48.0%	38.0%	28.0%	18.0%	8.0%
GWP		5126	3907	2687	1468	8298	7078	5858	4639	3419	2200	980
Evaporator pressure	bar	1.40	1.34	1.29	1.24	1.69	1.62	1.55	1.48	1.42	1.36	1.31
Condenser pressure	bar	9.82	9.51	9.20	8.91	11.46	11.10	10.74	10.38	10.04	9.72	9.41
Pressure ratio		7.02	7.08	7.13	7.19	6.79	6.86	6.93	7.00	7.06	7.12	7.18
Volumetric efficiency		88.3%	88.3%	88.3%	88.3%	88.8%	88.8%	88.8%	88.7%	88.7%	88.7%	88.6%
Discharge temperature	°C	19.6	21.3	22.8	24.2	21.7	23.3	24.8	26.3	27.7	28.9	30.1
Evaporator temp glide	K	2.0	2.0	2.0	1.9	2.0	2.0	2.1	2.2	2.2	2.1	2.0
Condenser temp glide	K	2.6	2.7	2.7	2.6	2.1	2.1	2.3	2.5	2.6	2.7	2.6
Volumetric capacity	kJ/m3	1083	1045	1010	977	1316	1259	1206	1159	1116	1077	1040
Cooling COP		2.27	2.26	2.26	2.26	2.33	2.30	2.28	2.27	2.26	2.25	2.25

Flammability data

The flammability behaviour of binary mixtures of R1132a with non-flammable R116 or R744 (carbon dioxide) was studied using a 12 litre glass flask apparatus, conforming to the apparatus and test method described in ASHRAE Standard 34 for evaluation of flammability of refrigerants. Binary mixtures of varying composition were tested using the Standard 34 test method at 60°C with a constant humidity (corresponding to 50% relative humidity at 25°C) to determine the maximum quantity of R-1132a that could be added to each non-flammable component without resulting in a flammable mixture.

It was found that the maximum quantity of R-1132a that could be added to R-116 without making the mixture flammable was 48% by volume, which corresponds to a composition of 30.5% by weight R-1132a, 69.5% by weight R-116. It was further determined that the maximum quantity of R-1132a that could be added to R-744 without generating a flammable mixture was 15% by volume.

These flammability data are depicted pictorially in Figure 6, showing a triangular composition diagram for ternary mixtures of R-744, R-1132a and R-116, with the units of composition being volume fraction. A dashed line is shown connecting the non-flammable binary compositions having the maximum quantity of R-1132a. Ternary compositions lying above and to the right of this line are anticipated to be non-flammable and are preferred compositions of the invention.

Performance Data – Binary R-1132a/R-116 Blends

The performance of selected binary compositions of R-1132a/R-116 was studied using a biomedical storage freezer appliance. This appliance was a Panasonic model MDF-U76VC freezer, comprising a cascade refrigeration system with a lower temperature stage operating on R-508B and an upper temperature stage rejecting heat to external ambient air using R-404A refrigerant. Its performance specification for the achieved internal storage compartment air temperature is -86°C or lower when operated in an ambient air temperature of 30°C. The test was carried out as a drop-in test in which the R-508B refrigerant in the low temperature stage was replaced by binary compositions of the invention and the system was operated in a climate room to guarantee an ambient temperature of 30°C. The storage compartment air temperature, motor power consumption, refrigeration compressor operating temperature and pressure and

refrigerant evaporating and condensing temperatures were all recorded. A reference test was carried out with R-508B refrigerant to provide comparative data. A further reference test was carried out using pure R-1132a in the lower stage to provide further comparative data.

5

The results recorded are shown in the following table. It was found that although R1132a alone could not meet the internal air temperature target, addition of R116 improved the performance of the refrigerant. This was demonstrated by the achieved cabinet air temperatures. The presence of the R1132a/R116 azeotrope was demonstrated by the air temperature going through a minimum as the azeotropic composition of ca. 50% w/w R1132a was approached. A composition of 51.1% R1132a/49.9% R116 was found to deliver an acceptable air temperature compared to that achieved with R-508B but at a lower compressor exit temperature. The latter is desirable to protect the compressor and avoid thermal degradation of its lubricating oil.

15

Table 23: Refrigeration performance data for selected R-1132a/R-116 blends

R-116 content (% w/w)	Compressor exit temperature (°C)	Cabinet air temperature (°C)	Power (W)
0**	83.5	-85.3	1132
16.9	83.6	-87.7	1145
29.8	83.7	-88.4	1151
35.7	84.1	-88.6	1157
40.4	84.1	-88.7	1162
45.3	84.7	-88.5	1189
49.7	84.7	-88.5	1189
R508B comparison	85.4	-89.5	1158

Performance Data – Ternary R-744/R-1132a/R-116 Blends

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In the same equipment as used for binary composition testing were tested several ternary compositions of R-744/R-1132a/R-116 at the same operating conditions. These were selected as non-flammable compositions on the basis of the flammability data reported above. Selected results are reproduced below.

Table 24: Refrigeration performance data for selected R-1132a/R-116/CO₂ blends

Ambient Temperature 30°C	R508B	Mixture A	Mixture B	Mixture C	Mixture D
R-1132a (% w/w)		33.6%	31.1%	30.0%	29.1%
R-116 (% w/w)		66.4%	61.5%	59.4%	57.5%
R-744 (% w/w)		0.0%	7.4%	10.6%	13.4%
Compressor exit temperature (°C)	81.6	80.2	80.8	82.0	81.1
Cabinet air temperature (°C)	-88.2	-83.4	-87.2	-88.3	-89.2
Power Input(W)	1070	1040	1060	1080	1080

The ternary compositions delivered performance close to R508B. It was found that at the highest concentration of R-744 tested (13.4% w/w) slight instability in operation was observed, attributed to dry ice formation in the expansion device. Since this is an undesirable feature, it is concluded that for compositions where the mass ratio of R1132a to R116 is selected to ensure that this mixture is non-flammable, the R744 content is preferably less than about 13% w/w of the total.

Next were tested ternary compositions wherein the R-1132a/R-116 composition was close to the azeotropic composition and which are expected to be mildly flammable. Results from selected tests are shown in the table below.

Table 25: Refrigeration performance data for further selected R-1132a/R-116/CO₂ blends

Ambient Temperature 30°C	R508B	Mixture E	Mixture F	Mixture G	Mixture H	Mixture J
R-1132a (%w/w)		50.2%	45.4%	44.1%	42.7%	41.5%
R-116(%w/w)		49.8%	45.1%	43.8%	42.4%	41.3%
R-744(%w/w)		0.0%	9.6%	12.2%	14.9%	17.2%
Compressor exit temperature (°C)	81.6	83.2	81.4	82.1	82.1	82.7
Cabinet air temperature (°C)	-88.2	-87.60	-90.0	-90.1	-90.4	-90.3
Power Input(W)	1070	1080	1100	1100	1100	1100

It is believed that at lower concentrations of R-116 a further increase in R-744 content may be achieved without formation of dry ice, and thus certain preferred ternary R-744/R-1132a/R-116 compositions are those wherein the refrigeration performance can deliver a
5 final air temperature within 3K of that achievable with R-508B without the formation of dry ice in the systems' expansion device or evaporator inlet pipe.

To investigate the potential maximum amount of R-744 that could be added a study was carried out by adding progressively increasing quantities of R744 to mixtures of R1132a
10 and R116 in a constant volume stirred vessel at a temperature of -66 °C (selected as being below the triple point of R-744) and measuring the vapour pressure of the resulting ternary mixtures after mixing and equilibration of the system. Two binary composition ratios of R-1132a/R-116 were used (28 mol% and 75 mol% R1132a). It was found that with both
15 these tests that the maximum quantity of R-744 that could be added before the vapour pressure no longer increased on further addition of R-744, which indicated formation of solid phase R-744, was about 0.5 mol fraction in the ternary mixture. Thus additionally preferred ternary compositions are those wherein the mol fraction of R-744 in the ternary composition is less than 0.5 with more preferred compositional limits as explained above.

20 The invention is defined by the following claims

Claims

1. A composition comprising:
 - (i) from 10 to 99 % by weight of the composition 1,1-difluoroethene (R-1132a);
 - 5 (ii) a second component which is from 1 to 90 % by weight of the composition hexafluoroethane (R-116), and optionally ethane (R-170); and optionally
 - (iii) carbon dioxide (CO₂, R-744); or
 a composition comprising:
 - (i) from 20 to 99 % by weight of the composition 1,1-difluoroethene (R-1132a);
 - 10 (ii) a second component which is from 1 to 80 % by weight of the composition ethane (R-170), and optionally hexafluoroethane (R-116); and optionally
 - (iii) carbon dioxide (CO₂, R-744).
2. A composition according to claim 1 comprising from 14 to 99 % by weight of R-1132a

15 and from 1 to 86 % by weight of R-116; or comprising from 35 to 99 % by weight of R-1132a and from 1 to 65 % by weight of R-116.
3. A composition according to claim 1 or 2 wherein the composition is azeotropic or

near-azeotropic; optionally comprising from 45 to 60 % by weight of R-1132a and

20 from 40 to 55 % by weight of R-116; or optionally comprising from 40 to 60 % by weight of ethane and from 40 to 60 % by weight of R-1132a.
4. A composition according to claim 1 or 2 comprising up to 30 % by weight of R-1132a

and at least 70 % by weight of R-116.
- 25 5. A composition comprising from 2 to 98 % by weight of R-1132a, from 2 to 98 % by weight of R-116 and from 2 to 60 % by weight CO₂; or comprising from 4 to 96 % by weight of R-1132a, from 4 to 96 % by weight of R-116 and from 4 to 50 % by weight CO₂.
- 30 6. A composition according to any of claims 1 to 5 comprising up to 35 % by weight of R-1132a, at least 55 % by weight of R-116 and up to 13 % by weight CO₂.
7. A composition according to claim 1 comprising from 1 to 50 % by weight of ethane

35 and from 50 to 99 % by weight of R-1132a; or comprising from 1 to 25 % by weight of ethane and from 75 to 99 % by weight of R-1132a.

8. A composition according to any of claims 1 to 4 or 7 further comprising CO₂.
- 5 9. A composition comprising R-1132a, ethane and up to 70 % by weight CO₂; or comprising from 2 to 98 % by weight of R-1132a, from 2 to 98 % by weight of ethane and from 2 to 60 % by weight CO₂; or comprising from 4 to 96 % by weight of R-1132a, from 4 to 96 % by weight of ethane and from 4 to 50 % by weight CO₂.
- 10 10. A composition according to claim 9 wherein the CO₂ is present in an amount of from 6 to 40 % by weight, preferably up to 20 % by weight or 15 % by weight.
11. A composition comprising R-1132a, R-116 and ethane; or comprising from 4 to 70 % by weight R-1132a, from 4 to 96 % by weight R-116 and from 4 to 92 % by weight ethane; or comprising from 4 to 70 % by weight R-1132a, from 4 to 88 % by weight R-116 and from 8 to 92 % by weight ethane; and optionally comprising CO₂.
- 15 12. A composition according to claim 11, wherein the sum of ethane and CO₂ present is less than 50 % by weight of the composition.
- 20 13. A composition according to claim 11 or 12, wherein the composition contains at least as much CO₂ as ethane, preferably at least twice as much CO₂ as ethane.
14. A composition according to any of claims 11 to 13 comprising from 2 to 20 % by weight ethane, from 2 to 45 % by weight CO₂, from 15 to 85 % by weight R-1132a and from 5 to 80 % by weight R-116; or comprising from 4 to 12 % by weight ethane, from 4 to 40 % by weight CO₂, from 20 to 80 % by weight R-1132a and from 8 to 76 % by weight R-116.
- 25 15. A composition according to any of the preceding claims further comprising pentafluoroethane (R-125).
- 30 16. A composition according to any of the preceding claims further comprising a hydrocarbon, wherein the hydrocarbon is in addition to any ethane present in the composition.
- 35

17. A composition according to any of claims 1 to 14 consisting essentially of R-1132a, R-116, and/or R-170, and optionally CO₂.
- 5 18. A composition according to any of the preceding claims, wherein the composition is less flammable than R-1132a alone; optionally wherein the composition has:
 - (a) a higher flammable limit;
 - (b) a higher ignition energy; and/or
 - (c) a lower flame velocity
 compared to R-1132a alone.
- 10 19. A composition according to any of the preceding claims, wherein the composition is non-flammable at ambient temperature, preferably wherein the composition is non-flammable at 60 °C.
- 15 20. A composition according to any of the preceding claims, which has a critical temperature of greater than 0 °C, or greater than 10 °C.
- 20 21. A composition comprising a lubricant and a composition according to any of the preceding claims, optionally wherein the lubricant is selected from mineral oil, silicone oil, polyalkyl benzenes (PABs), polyol esters (POEs), polyalkylene glycols (PAGs), polyalkylene glycol esters (PAG esters), polyvinyl ethers (PVEs), poly(alpha-olefins) and combinations thereof, or wherein the lubricant is selected from PAGs or POEs.
- 25 22. A composition comprising a stabiliser and a composition according to any of the preceding claims, optionally wherein the stabiliser is selected from diene-based compounds, phosphates, phenol compounds and epoxides, and mixtures thereof.
- 30 23. A composition comprising a flame retardant and a composition according to any of the preceding claims, optionally wherein the flame retardant is selected from the group consisting of tri-(2-chloroethyl)-phosphate, (chloropropyl) phosphate, tri-(2,3-dibromopropyl)-phosphate, tri-(1,3-dichloropropyl)-phosphate, diammonium phosphate, various halogenated aromatic compounds, antimony oxide, aluminium trihydrate, polyvinyl chloride, a fluorinated iodocarbon, a fluorinated bromocarbon,

35 trifluoro iodomethane, perfluoroalkyl amines, bromo-fluoroalkyl amines and mixtures thereof.

24. A heat transfer device containing a composition as defined in any one of claims 1 to 23, optionally wherein the heat transfer device is a refrigeration device, optionally wherein the heat transfer device comprises an ultra-low temperature refrigeration system or a cascade system.
25. A sprayable composition comprising material to be sprayed and a propellant comprising a composition as defined in any of claims 1 to 23.
26. A method for cooling an article which comprises condensing a composition as defined in any of claims 1 to 23 and thereafter evaporating the composition in the vicinity of the article to be cooled.
27. A method for heating an article which comprises condensing a composition as defined in any one of claims 1 to 23 in the vicinity of the article to be heated and thereafter evaporating the composition.
28. A method for extracting a substance from biomass comprising contacting biomass with a solvent comprising a composition as defined in any of claims 1 to 23, and separating the substance from the solvent.
29. A method of cleaning an article comprising contacting the article with a solvent comprising a composition as defined in any of claims 1 to 23.
30. A method of extracting a material from an aqueous solution or from a particulate solid matrix comprising contacting the aqueous solution or the particulate solid matrix with a solvent comprising a composition as defined in any of claims 1 to 23, and separating the material from the solvent.
31. A mechanical power generation device containing a composition as defined in any of claims 1 to 23, optionally wherein the device is adapted to use a Rankine Cycle or modification thereof to generate work from heat.
32. A method of retrofitting a heat transfer device comprising the step of removing an existing heat transfer composition, and introducing a composition as defined in any

one of claims 1 to 23, optionally wherein the heat transfer device is a refrigeration device, or an ultra-low temperature refrigeration system.

- 5 33. A method for reducing the environmental impact arising from the operation of a product comprising an existing compound or composition, the method comprising replacing at least partially the existing compound or composition with a composition as defined in any one of claims 1 to 23, wherein the existing compound or composition is a heat transfer composition, optionally wherein the heat transfer composition is a refrigerant selected from R-508A, R-508B, R23 and R13B1.
- 10 34. A method of claim 33 carried out on a product from the fields of air-conditioning, refrigeration, heat transfer, aerosols or sprayable propellants, gaseous dielectrics, flame suppression, solvents, cleaners, topical anesthetics and expansion applications, optionally wherein the product is selected from a heat transfer device, 15 a sprayable composition, a solvent and a mechanical power generation device, optionally wherein the heat transfer device is an ultra-low temperature refrigeration system.

SAMMENSÆTNINGER

Patentkrav

1. Sammensætning, der omfatter:
 - (i) fra 10 til 99 vægtprocent af sammensætningen 1,1-difluorethen (R-1132a),
 - (ii) en anden bestanddel, der udgør fra 1 til 90 vægtprocent af sammensætningen hexafluorethan (R-116) og eventuelt ethan (R-170), og eventuelt
 - (iii) carbondioxid (CO₂, R-744) elleren sammensætning, der omfatter:
 - (i) fra 20 til 99 vægtprocent af sammensætningen 1,1-difluorethen (R-1132a),
 - (ii) en anden bestanddel, der udgør fra 1 til 80 vægtprocent af sammensætningen ethan (R-170) og eventuelt hexafluorethan (R-116), og eventuelt
 - (iii) carbondioxid (CO₂, R-744).
2. Sammensætning ifølge krav 1, der omfatter fra 14 til 99 vægtprocent R-1132a og fra 1 til 86 vægtprocent R-116, eller som omfatter fra 35 til 99 vægtprocent R-1132a og fra 1 til 65 vægtprocent R-116.
3. Sammensætning ifølge krav 1 eller 2, hvor sammensætningen er azeotrop eller nær azeotrop og eventuelt omfatter fra 45 til 60 vægtprocent R-1132a og fra 40 til 55 vægtprocent R-116 eller eventuelt omfatter fra 40 til 60 vægtprocent ethan og fra 40 til 60 vægtprocent R-1132a.
4. Sammensætning ifølge krav 1 eller 2, der omfatter op til 30 vægtprocent R-1132a og mindst 70 vægtprocent R-116.
5. Sammensætning, der omfatter fra 2 til 98 vægtprocent R-1132a, fra 2 til 98 vægtprocent R-116 og fra 2 til 60 vægtprocent CO₂, eller som omfatter fra 4 til 96 vægtprocent R-1132a, fra 4 til 96 vægtprocent R-116 og fra 4 til 50 vægtprocent CO₂.
6. Sammensætning ifølge et hvilket som helst af kravene 1 til 5, der omfatter op til 35 vægtprocent R-1132a, mindst 55 vægtprocent R-116 og op til 13 vægtprocent CO₂.
7. Sammensætning ifølge krav 1, der omfatter fra 1 til 50 vægtprocent ethan og fra 50 til 99 vægtprocent R-1132a, eller som omfatter fra 1 til 25 vægtprocent ethan og fra 75 til 99 vægtprocent R-1132a.

8. Sammensætning ifølge et hvilket som helst af kravene 1 til 4 eller 7, der endvidere omfatter CO₂.
9. Sammensætning, der omfatter R-1132a, ethan og op til 70 vægtprocent CO₂, eller som omfatter fra 2 til 98 vægtprocent R-1132a, fra 2 til 98 vægtprocent ethan og fra 2 til 60 vægtprocent CO₂, eller som omfatter fra 4 til 96 vægtprocent R-1132a, fra 4 til 96 vægtprocent ethan og fra 4 til 50 vægtprocent CO₂.
10. Sammensætning ifølge krav 9, hvor CO₂'en er til stede i en mængde på fra 6 til 40 vægtprocent, fortrinsvis op til 20 vægtprocent eller 15 vægtprocent.
11. Sammensætning, der omfatter R-1132a, R-116 og ethan, eller som omfatter fra 4 til 70 vægtprocent R-1132a, fra 4 til 96 vægtprocent R-116 og fra 4 til 92 vægtprocent ethan, eller som omfatter fra 4 til 70 vægtprocent R-1132a, fra 4 til 88 vægtprocent R-116 og fra 8 til 92 vægtprocent ethan, og som eventuelt omfatter CO₂.
12. Sammensætning ifølge krav 11, hvor summen af ethan og CO₂ til stede er mindre end 50 vægtprocent af sammensætningen.
13. Sammensætning ifølge krav 11 eller 12, hvilken sammensætning indeholder mindst lige så meget CO₂ som ethan, fortrinsvis mindst dobbelt så meget CO₂ som ethan.
14. Sammensætning ifølge et hvilket som helst af kravene 11 til 13, der omfatter fra 2 til 20 vægtprocent ethan, fra 2 til 45 vægtprocent CO₂, fra 15 til 85 vægtprocent R-1132a og fra 5 til 80 vægtprocent R-116, eller som omfatter fra 4 til 12 vægtprocent ethan, fra 4 til 40 vægtprocent CO₂, fra 20 til 80 vægtprocent R-1132a og fra 8 til 76 vægtprocent R-116.
15. Sammensætning ifølge et hvilket som helst af de foregående krav, der endvidere omfatter pentafluorethan (R-125).
16. Sammensætning ifølge et hvilket som helst af de foregående krav, der endvidere omfatter et carbonhydrid, hvilket carbonhydrid er i tillæg til eventuelt ethan, som er til stede i sammensætningen.
17. Sammensætning ifølge et hvilket som helst af kravene 1 til 14, der i det væsentlige består af R-1132a, R-116 og/eller R-170 og eventuelt CO₂.
18. Sammensætning ifølge et hvilket som helst af de foregående krav, hvilken sammensætning er mindre brændbar end R-1132a alene, eventuelt hvor sammensætningen har:

- (a) en højere brændbarhedsgrænse,
- (b) en højere tændenergi, og/eller
- (c) en lavere flammehastighed

sammenlignet med R-1132a alene.

19. Sammensætning ifølge et hvilket som helst af de foregående krav, hvilken sammensætning er ikke-brændbar ved omgivelsestemperatur, fortrinsvis hvor sammensætningen er ikke-brændbar ved 60 °C.
20. Sammensætning ifølge et hvilket som helst af de foregående krav, der har en kritisk temperatur på over 0 °C eller over 10 °C.
21. Sammensætning, der omfatter et smøremiddel og en sammensætning ifølge et hvilket som helst af de foregående krav, eventuelt hvor smøremidlet er valgt blandt mineralolie, silikoneolie, polyalkylbenzener (PAB'er), polyolestere (POE'er), polyalkylen-glycoler (PAG'er), polyalkylenglycolestere (PAG-estere), polyvinylethere (PVE'er), poly(alfaolefiner) og kombinationer deraf, eller hvor smøremidlet er valgt blandt PAG'er eller POE'er.
22. Sammensætning, der omfatter en stabilisator og en sammensætning ifølge et hvilket som helst af de foregående krav, eventuelt hvor stabilisatoren er valgt blandt dien-baserede forbindelser, phosphater, phenolforbindelser og epoxider, og blandinger deraf.
23. Sammensætning, der omfatter et brandhæmmende middel og en sammensætning ifølge et hvilket som helst af de foregående krav, eventuelt hvor det brandhæmmende middel er valgt fra gruppen bestående af tri-(2-chlorethyl)phosphat, (chlorpropyl)phosphat, tri-(2,3-dibrompropyl)-phosphat, tri-(1,3-dichlorpropyl)-phosphat, diammoniumphosphat, forskellige halogenerede aromatiske forbindelser, antimonoxid, aluminiumtrihydrat, polyvinylchlorid, et fluoreret iodcarbon, et fluoreret bromcarbon, trifluoriodmethan, perfluoralkylaminer, bromfluoralkylaminer og blandinger deraf.
24. Varmeoverførselsindretning, der indeholder en sammensætning som defineret i et hvilket som helst af kravene 1 til 23, eventuelt hvor varmeoverførselsindretningen er en køleindretning, eventuelt hvor varmeoverførselsindretningen omfatter et ultralavtemperatur kølesystem eller et kaskadesystem.
25. Sprøjtbar sammensætning, der omfatter materiale, som skal sprøjtes, og et drivmiddel,

- der omfatter en sammensætning som defineret i et hvilket som helst af kravene 1 til 23.
26. Fremgangsmåde til afkøling af en genstand, hvilken fremgangsmåde omfatter kondensering af en sammensætning som defineret i et hvilket som helst af kravene 1 til 23 og derefter fordampning af sammensætningen i nærheden af den genstand, der skal afkøles.
 27. Fremgangsmåde til opvarmning af en genstand, hvilken fremgangsmåde omfatter kondensering af en sammensætning som defineret i et hvilket som helst af kravene 1 til 23 i nærheden af den genstand, der skal opvarmes, og derefter fordampning af sammensætningen.
 28. Fremgangsmåde til ekstraktion af et stof fra biomasse, hvilken fremgangsmåde omfatter etablering af kontakt mellem biomasse og et opløsningsmiddel, der omfatter en sammensætning som defineret i et hvilket som helst af kravene 1 til 23, og adskillelse af stoffet fra opløsningsmidlet.
 29. Fremgangsmåde til rengøring af en genstand, hvilken fremgangsmåde omfatter etablering af kontakt mellem genstanden og et opløsningsmiddel, der omfatter en sammensætning som defineret i et hvilket som helst af kravene 1 til 23.
 30. Fremgangsmåde til ekstraktion af et materiale fra en vandig opløsning eller fra en partikelholdig fast matrix, hvilken fremgangsmåde omfatter etablering af kontakt mellem den vandige opløsning eller den partikelholdige faste matrix og et opløsningsmiddel, der omfatter en sammensætning som defineret i et af hvilket som helst af kravene 1 til 23, og adskillelse af materialet fra opløsningsmidlet.
 31. Mekanisk energigenereringsindretning, der indeholder en sammensætning som defineret i et hvilket som helst af kravene 1 til 23, eventuelt hvor indretningen er indrettet til at anvende en Rankine-cyklus eller modifikation deraf til at generere arbejde fra varme.
 32. Fremgangsmåde til ombygning af en varmeoverførselsindretning, hvilken fremgangsmåde omfatter et trin til fjernelse af en eksisterende varmeoverførsels-sammensætning og indføring af en sammensætning som defineret i et hvilket som helst af kravene 1 til 23, eventuelt hvor varmeoverførselsindretningen er en køleindretning eller et ultralavtemperatur kølesystem.
 33. Fremgangsmåde til reduktion af miljøpåvirkningen som følge af driften af et produkt, der

omfatter en eksisterende forbindelse eller sammensætning, hvilken fremgangsmåde omfatter udskiftning i det mindste delvist af den eksisterende forbindelse eller sammensætning med en sammensætning som defineret i et hvilket som helst af kravene 1 til 23, hvor den eksisterende forbindelse eller sammensætning er en varmeoverførsels-sammensætning, eventuelt hvor varmeoverførselssammensætningen er et kølemiddel valgt blandt R-508A, R-508B, R23 og R13B1.

34. Fremgangsmåde ifølge krav 33 udført på et produkt fra områderne luftkonditionering, køling, varmeoverførsel, aerosoler eller sprøjtbare drivmidler, gasformige dielektrika, flammehæmning, opløsningsmidler, rengøringsmidler, topiske bedøvelsesmidler og ekspansionsmidler, eventuelt hvor produktet er valgt fra en varmeoverførselsindretning, en sprøjtbare sammensætning, et opløsningsmiddel og en mekanisk energigenereringsindretning, eventuelt hvor varmeoverførselsindretningen er et ultralavtemperatur kølesystem.

DRAWINGS

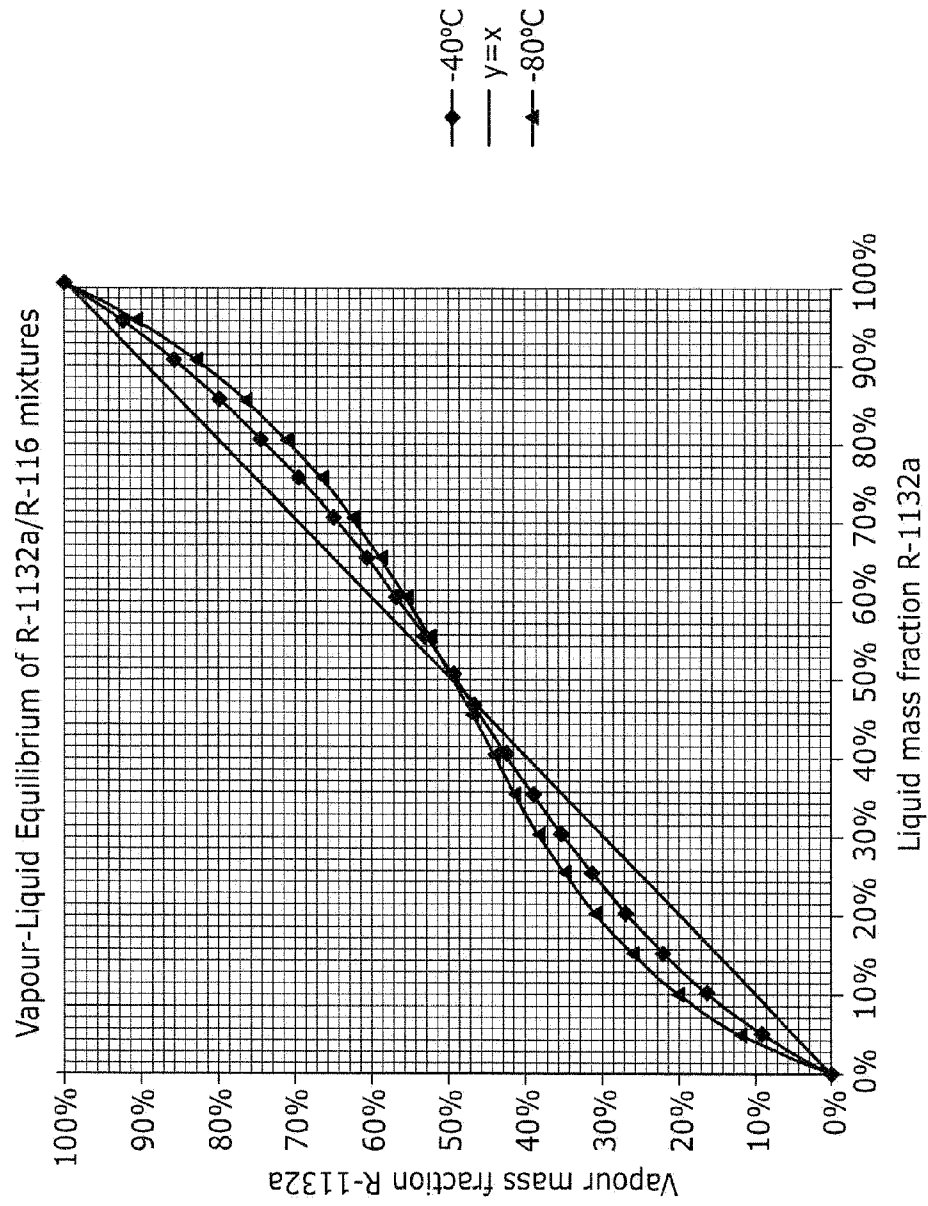


Figure 1: Phase equilibrium behaviour of R-1132/R-116 mixtures showing azeotropy

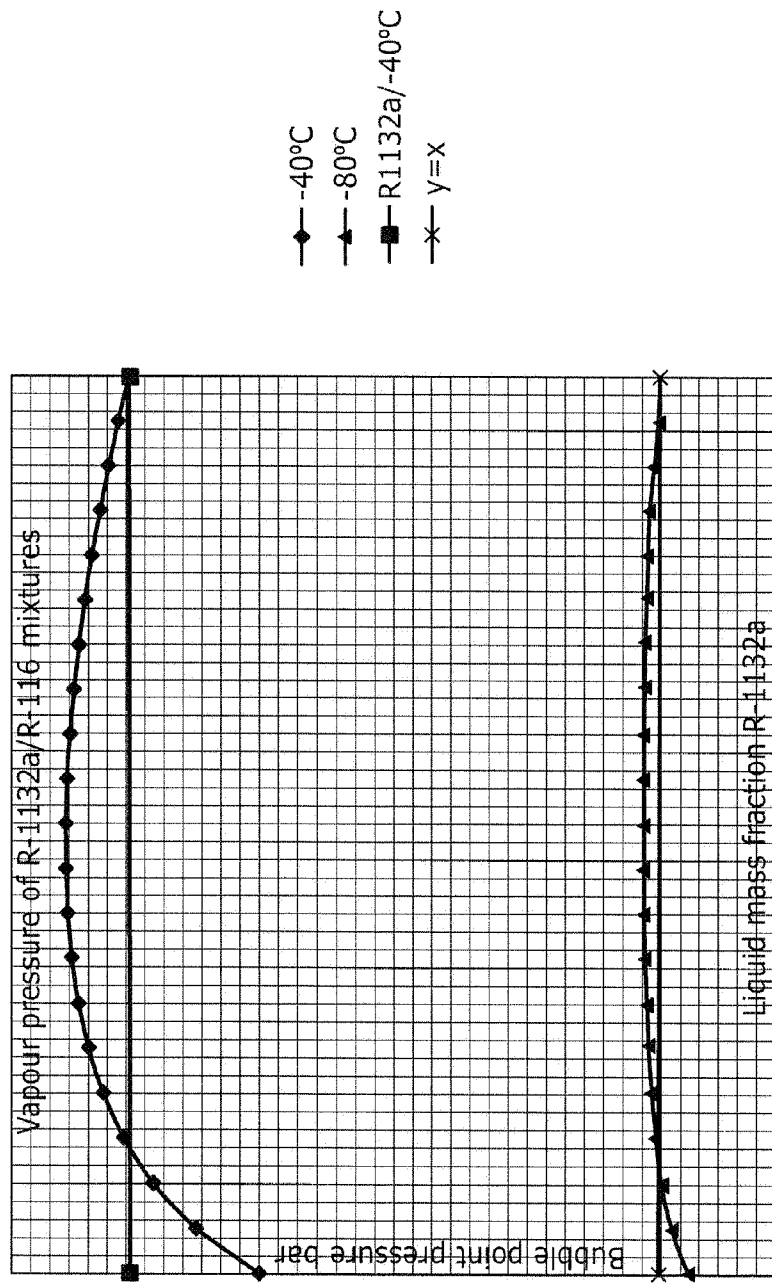


Figure 2: Vapour pressure of R-1132a/R-116 mixtures

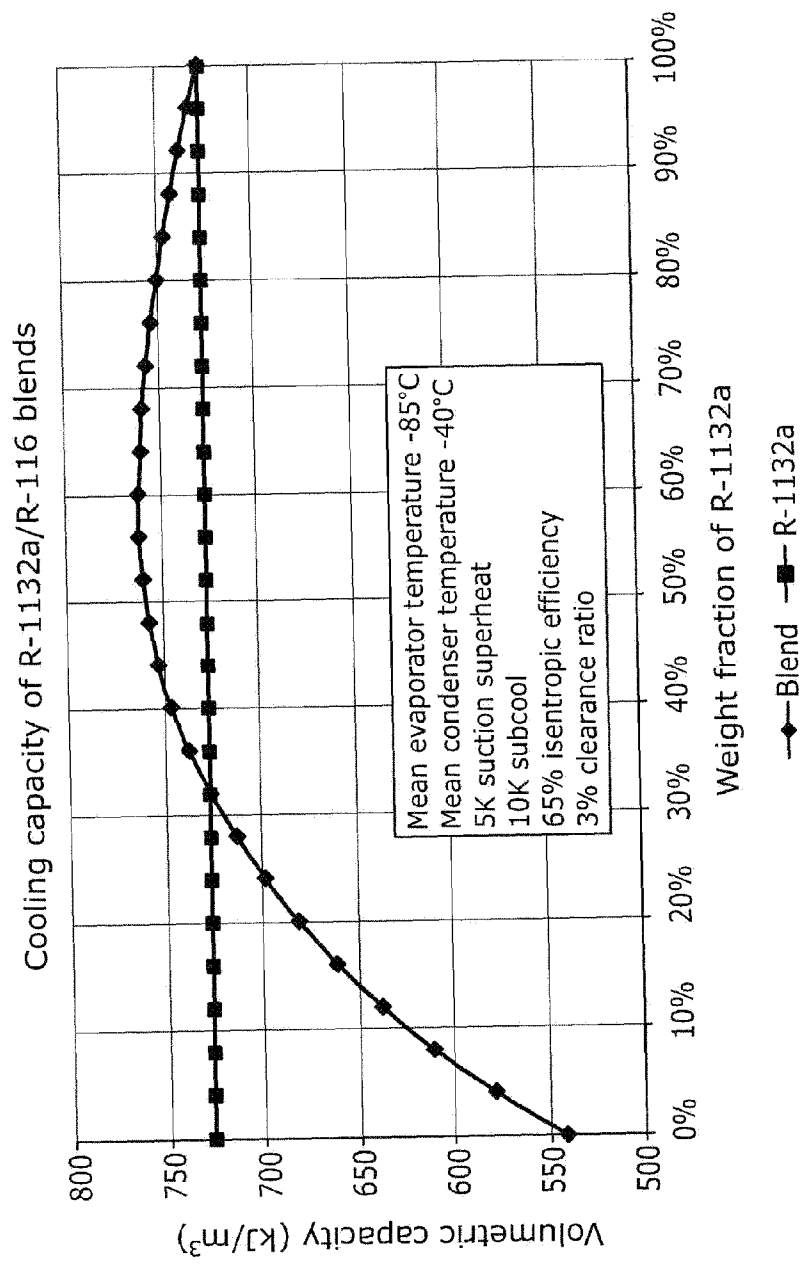


Figure 3: Calculated refrigeration cycle performance for R-1132a/R-116 mixtures

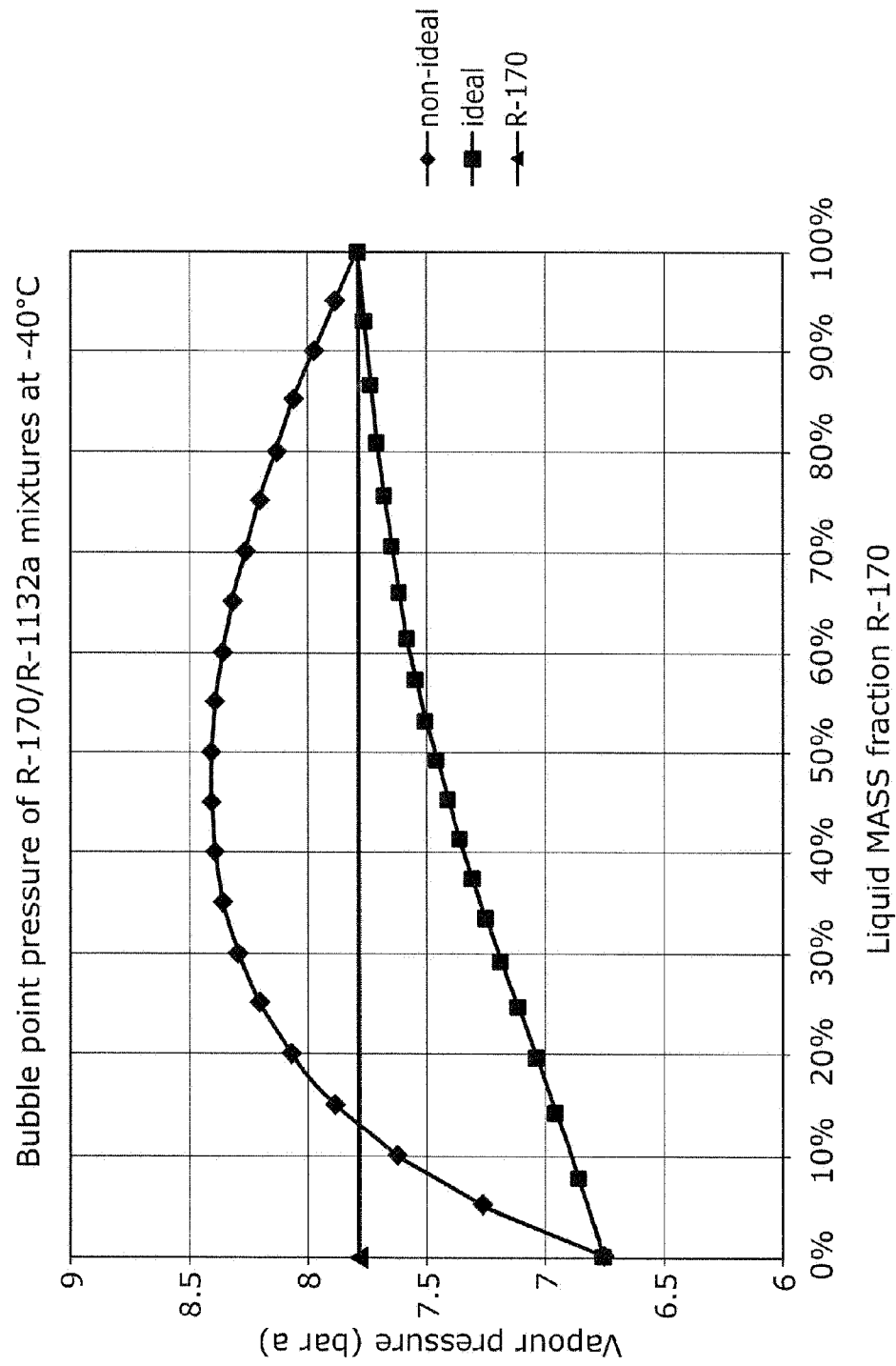


Figure 4

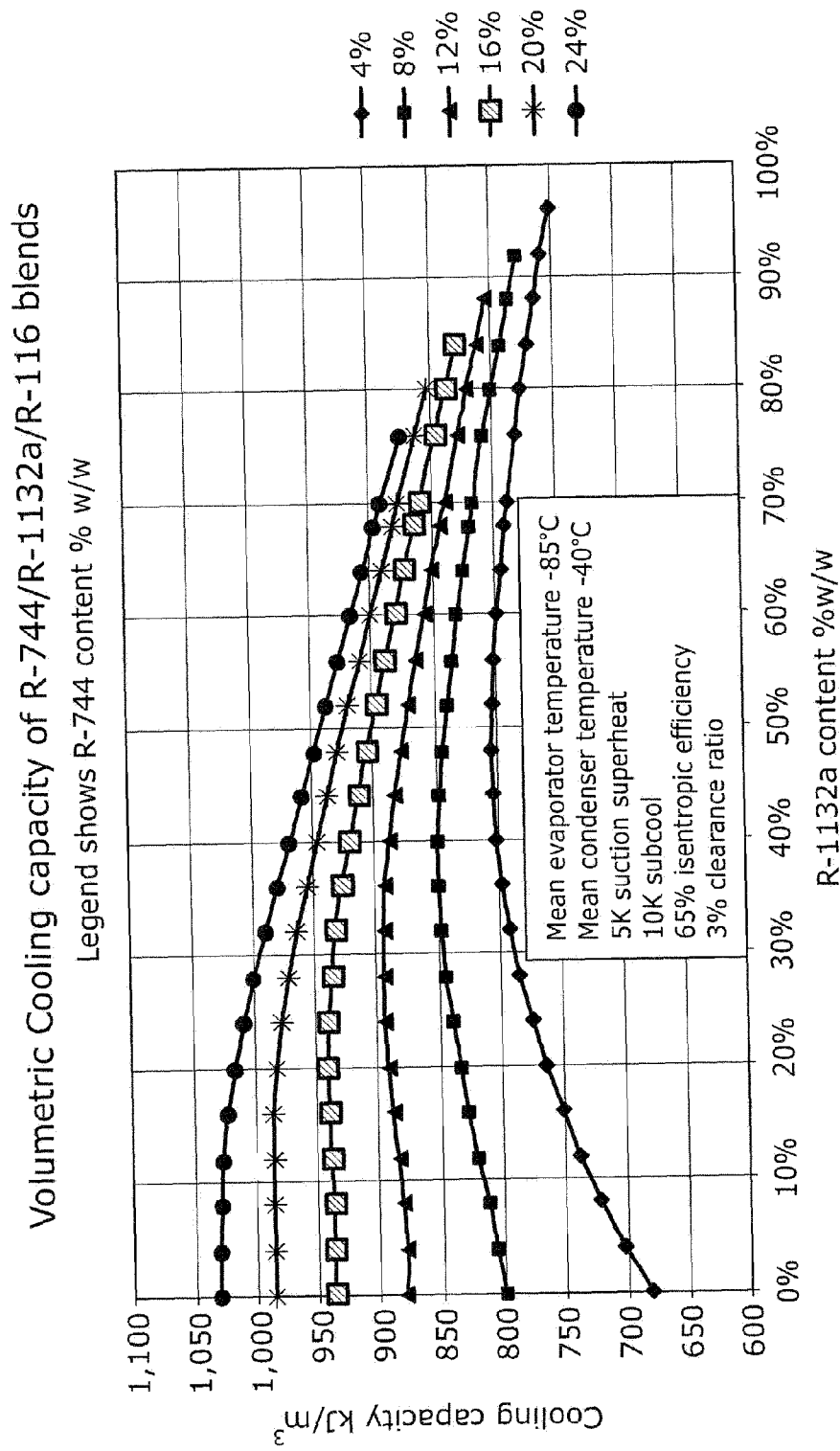


Figure 5: Calculated refrigeration cycle performance for R-1132a/R-116/R-744 mixtures

Flammability Diagram for R-744/R-1132a/R-116 at 60°C
Compositions shown are MOLAR (% v/v)

