Solstice® ze Refrigerant (HFO-1234ze)

LOW GWP HYDROFLUOROOLEFINS (HFO)

The Environmental Alternative to Traditional Refrigerants
Fourth Generation Refrigerants for the 21st Century

Honeywell has been at the forefront of every major development of fluorocarbon refrigerants technology. As the world seeks new, lower-global-warming-potential solutions, Honeywell delivers again, with its Solstice® brand of hydrofluoroolefins (HFOs), a family of unique products that offer comparable performance to today’s most widely-used stationary and mobile refrigerants, blowing agents and aerosol propellants. However, unlike their more common counterparts, the molecular structure of Solstice products causes them to have short atmospheric lifetimes, which means they have very low global warming potential (GWP) index.

Honeywell’s Solstice brand reflects the products’ break-through environmental properties, including their insulating capabilities for foam and their superior cooling capabilities for automotive air conditioning and stationary refrigerant applications.

Hydrofluoroolefins (HFOs): who is who

The chemical structure of pure fluids such as Solstice® ze, Solstice® yf and Solstice® zd contains a carbon-carbon double bond which is a key feature facilitating the low global warming characteristic. These molecules also have low atmospheric lifetimes.

Solstice® ze is trans-1,3,3,3-tetrafluoroprop-1-ene to which ASHRAE Standard 34 has assigned the nomenclature of R-1234ze(E). The suffix (E) indicates that it is an isomer. The other isomer (suffix (Z)) is cis-1,3,3,3-tetrafluoroprop-1-ene. The physical properties of the (E) and (Z) isomers are different: both are ultra-low GWP molecules with GWP<1, but R-1234ze(Z) has a high boiling point (9.8°C) associated with a higher critical temperature (153.7°C) and a volumetric capacity roughly 50% lower than R-1234ze(E), which makes it not the best option as replacement of 134a. Even if the properties of R-1234ze(Z) could be utilised in specific applications like high temp heat pumps, R-1234ze(E) will show operating conditions and applied costs much more in line with R-134a according to system and compressor sizes.

### Physical properties

<table>
<thead>
<tr>
<th>Solstice® ze (HFO-1234ze)</th>
<th>SI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Name</td>
<td>trans-1,3,3,3-Tetrafluoroprop-1-ene</td>
</tr>
<tr>
<td>Molecular Formula</td>
<td>CF₃CH=CHF</td>
</tr>
<tr>
<td>Appearance</td>
<td>Colourless</td>
</tr>
<tr>
<td>Ozone Depletion Potential (ODP-R11=1)</td>
<td>0</td>
</tr>
<tr>
<td>Global Warming Potential rev 5th IPCC (GWP CO₂=1)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>ASHRAE Std. 34 Safety Classification</td>
<td>A2L</td>
</tr>
<tr>
<td>Flammability Limits – ASTM E681-04 @ 21°C</td>
<td>Non Flammable</td>
</tr>
<tr>
<td>Flammability Limits – ASHRAE 34 @ 100°C</td>
<td>7% – 12% (by volume)</td>
</tr>
<tr>
<td>Units</td>
<td></td>
</tr>
<tr>
<td>Molecular weight</td>
<td>114 g/mol</td>
</tr>
<tr>
<td>Boiling point at 101.3 kPa</td>
<td>-18.95°C</td>
</tr>
<tr>
<td>Freezing point at 101.3 kPa</td>
<td>-156°C</td>
</tr>
<tr>
<td>Critical temperature</td>
<td>109.4°C</td>
</tr>
<tr>
<td>Critical pressure</td>
<td>36.36 bar</td>
</tr>
<tr>
<td>Critical volume</td>
<td>0.00204 m³/kg</td>
</tr>
<tr>
<td>Critical density</td>
<td>489 kg/m³</td>
</tr>
<tr>
<td>Vapour density at boiling point</td>
<td>5.71 kg/m³</td>
</tr>
<tr>
<td>Liquid density</td>
<td>1293 kg/m³</td>
</tr>
<tr>
<td>Liquid heat capacity at 25°C</td>
<td>1.383 kJ/kg °K</td>
</tr>
<tr>
<td>Vapour heat capacity at 25°C</td>
<td>0.9822 kJ/kg °K</td>
</tr>
<tr>
<td>Heat of vaporisation at boiling point</td>
<td>195.4 kJ/kg</td>
</tr>
<tr>
<td>Vapour pressure at 25°C</td>
<td>498.6 kPa</td>
</tr>
<tr>
<td>Liquid thermal conductivity at 25°C</td>
<td>0.0781 W/m °K</td>
</tr>
<tr>
<td>Vapour thermal conductivity at 25°C</td>
<td>0.0136 W/m °K</td>
</tr>
<tr>
<td>Liquid viscosity at 25°C</td>
<td>199.4 μPa sec</td>
</tr>
<tr>
<td>Vapour viscosity at 25°C</td>
<td>12.2 μPa sec</td>
</tr>
<tr>
<td>% Volatiles by volume</td>
<td>100</td>
</tr>
<tr>
<td>Solubility of HFO-1234ze(E) in water</td>
<td>0.037 wt.%</td>
</tr>
</tbody>
</table>

The HFO-1234ze isomers:
Leaks
If a large release of Solstice® ze vapour occurs, the same measures as with R-134a need to be taken.

Leak detection
Hand-held leak detectors can be used for pinpointing leaks. For monitoring an entire room on a continual basis, leak monitors are available. Leak detection is important for protection of those in proximity of the system, refrigerant conservation, equipment protection and performance, and reduction of emissions. Customers should consult the equipment manufacturer for appropriate detectors.
Materials compatibility

Honeywell does not recommend the use of chlorinated solvents to clean refrigeration systems or components.

**Plastics and elastomers**

Solstice® ze is compatible with most common materials. Since there are many different grades and formulations of these materials, we recommend that compatibility testing be performed on the specific grade of materials under consideration and at the conditions of use when designing new systems.

The table below contains materials compatibility data resulting from tests performed by Honeywell (testing conditions: two weeks liquid immersion at room temperature). This data should be used only as a guide to the compatibility of materials with Solstice® ze. The rankings in the table should be used with caution since they are judgments based on limited samplings. Customers should consult the manufacturer or conduct further independent testing.

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Avg. % change in hardness</th>
<th>Avg. % change in weight</th>
<th>Avg. % change in volume</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>0.21</td>
<td>-0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delrin® Acetal</td>
<td>0.18</td>
<td>0.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acrylic</td>
<td>Extremely distorted</td>
<td></td>
<td></td>
<td>Pitted after 1 week. Expands</td>
</tr>
<tr>
<td>HDPE</td>
<td>0.82</td>
<td>-3.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NYLON 66</td>
<td>-0.26</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polycarbonate*</td>
<td>1.1</td>
<td>0.77</td>
<td></td>
<td>Turbid fluid after 1 week. Residue</td>
</tr>
<tr>
<td>ULTEM® Polyetherimide</td>
<td>-0.04</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kynar® PVDF*</td>
<td>0.21</td>
<td>0</td>
<td>Fluid discoloration</td>
<td></td>
</tr>
<tr>
<td>Teflon®</td>
<td>2.03</td>
<td>2.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyprene*</td>
<td>0.83</td>
<td>0</td>
<td></td>
<td>Turbid fluid. Residue</td>
</tr>
<tr>
<td>HIPS</td>
<td>0.26</td>
<td>-0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVC-TYPE 1</td>
<td>0.002</td>
<td>-0.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PET</td>
<td>-0.01</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBR/CR/NBR</td>
<td>7.28</td>
<td>2</td>
<td>-4.31</td>
<td></td>
</tr>
<tr>
<td>Viton® B COMM. GRADE</td>
<td>-11.29</td>
<td>4.43</td>
<td>5.71</td>
<td></td>
</tr>
<tr>
<td>Buna-Nitrile</td>
<td>8.91</td>
<td>-4.95</td>
<td>-7.18</td>
<td></td>
</tr>
<tr>
<td>EPDM</td>
<td>-1.5</td>
<td>-2</td>
<td>-2.49</td>
<td></td>
</tr>
<tr>
<td>Epichlorohydrin</td>
<td>-3.5</td>
<td>0.73</td>
<td>1.51</td>
<td></td>
</tr>
<tr>
<td>Silicone*</td>
<td>-0.71</td>
<td>-1.57</td>
<td>-1.96</td>
<td>Slight fluid discoloration. Residue</td>
</tr>
<tr>
<td>Natural Rubber (Gum)</td>
<td>2</td>
<td>-0.64</td>
<td>-0.75</td>
<td></td>
</tr>
<tr>
<td>Texin® (Thermoplastic)</td>
<td>-4.35</td>
<td>5.14</td>
<td>4.41</td>
<td></td>
</tr>
<tr>
<td>Polyurethane 390</td>
<td>-2.13</td>
<td>1.27</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td>Neoprene</td>
<td>7.32</td>
<td>-7.7</td>
<td>-11.47</td>
<td></td>
</tr>
<tr>
<td>Kalrez® 6375</td>
<td>-10.36</td>
<td>5.22</td>
<td>33</td>
<td></td>
</tr>
</tbody>
</table>

* Suitable
* Suitable under certain conditions
* Unsuitable

* Although changes in weight, volume and hardness are minimal, fluid discoloration and/or residue suggest the material may not be suitable for some applications.

**Desiccants**

Desiccant driers compatible with Solstice® ze are commercially available. Individual drier manufacturers should be contacted for specific recommendations.

**Lubricants**

POE (polyol ester) oil is recommended for using Solstice® ze.

As most of the ultra-low GWP refrigerants, Solstice® ze is more miscible and more soluble in oil than traditional HFCs or HCFCs. When a higher miscibility is very favourable in systems for returning oil to compressors from the liquid side of the circuit, a higher solubility means that more refrigerant will be trapped in gaseous phase in the oil sump. A direct consequence is the reduction in working viscosity of the lubricating mixture (combination of lubricant and refrigerant) to the compressor bearings. The minimum viscosity criterion to operate under the highest bearing loads varies depending on compressor and bearing technology, so there could be a need for certain technologies and at certain conditions to increase the viscosity of the lubricant for compressors used with Solstice® ze in order to maintain reliable bearing lubrication.

Compressor manufacturers typically qualify specific lubricants for use with their products. Users should check with the equipment manufacturer for the recommended lubricants for their system.
Honeywell recommends reading the Material Safety Data Sheet (MSDS) before using the product. Refrigerant Solstice® ze or trans-1,3,3,3-tetrafluoroprop-1-ene is registered under the European Union’s REACH program (Registration, Evaluation, Authorisation and Restriction of Chemicals).

**Toxicity**

Solstice® ze has undergone extensive toxicity testing and when used in accordance with applicable guidelines and standards, is considered safe for its intended refrigeration and air-conditioning applications.

The Occupational Alliance for Risk Science (OARS) WEEL value for R-1234ze(E) is 800ppm (8-hour time-weighted average). HFC-134a, with a 1,000ppm WEEL value is currently used in centrifugal and screw chillers. The Solstice® ze refrigerant SDS contains the following toxicity information: the 4-hr acute inhalation LC50 (rat) was >207000ppm; no skin irritation was observed in rabbits; no cardiac sensitisation was observed in dogs with exposures up to 120,000 ppm; repeated dose toxicity in rats (13-wk) found mild effects on the heart (NOEL 5,000ppm); in vitro genotoxicity findings include negative Ames Test and negative human lymphocyte chromosome aberration test; in vivo genotoxicity findings in the mouse micronucleus test were negative (inhalation, mammalian bone-marrow cytogenic test with chromosomal analysis).

**Flammability**

According to ASHRAE Standard-2010, Solstice® ze, R-1234ze(E) is classified in safety group A2L, i.e., it is in the lower segment of the mildly flammable refrigerants.

A unique characteristic of this refrigerant is the absence of flammable mixture with air under 30°C of ambience. That’s why it is non flammable for handling and storage.

When utilised in a system, R-1234ze(E) could become flammable with air in case of a leakage and the following chart gives a graphical positioning of R-1234ze(E) versus other refrigerants in the ‘chance of flame occurring’ ranking: R-1234ze(E) needs 10 times more concentration and 250,000 times more energy than hydrocarbons to become flammable, only above 30°C.

In case of a flame occurring with Solstice® ze, the effect of this flame would be extremely mild, as its very low heat of combustion (5 times less than propane) associated to a ultra low burning velocity wouldn’t be enough to propagate a fire.

**Flammability characteristics**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Flammability Limit, Vol. % in air</td>
<td>None</td>
<td>(21°C, ASTM E681-01)</td>
</tr>
<tr>
<td>Lower Flammability Limit, Vol. % in air</td>
<td>None</td>
<td>(21°C, ASTM E681-01)</td>
</tr>
<tr>
<td>Upper Flammability Limit, Vol. % in air</td>
<td>5.7</td>
<td>(60°C, ASTM E681-01)</td>
</tr>
<tr>
<td>Lower Flammability Limit, Vol. % in air</td>
<td>11.3</td>
<td>(60°C, ASTM E681-01)</td>
</tr>
<tr>
<td>Minimum Ignition Energy, mJ at 20°C and 1 atm</td>
<td>No ignition</td>
<td>(Chilworth Technology)</td>
</tr>
<tr>
<td>Minimum Ignition Energy, mJ at 54°C and 1 atm</td>
<td>&gt;61,000 &lt;64,000</td>
<td>(Chilworth Technology)</td>
</tr>
<tr>
<td>Autoignition Temperature, °C</td>
<td>368</td>
<td>(EC Physico/Chemical Test A15, Measured by Chilworth Technology, UK)</td>
</tr>
<tr>
<td>Heat of Combustion, MJ/kg per ASHRAE Standard 34</td>
<td>10.7</td>
<td>(Stoichiometric composition 7.73% in air)</td>
</tr>
<tr>
<td>Fundamental burning velocity, cm/s (per ISO 817, Measured by AIST, Japan)</td>
<td>0 (no flame propagation)</td>
<td></td>
</tr>
</tbody>
</table>
Applications

Honeywell's new Solstice® ze refrigerant (HFO-1234ze) is the best medium pressure, low GWP refrigerant on the market when considering the balance of all properties. It is an energy-efficient alternative to traditional refrigerants in different medium temperature uses and has been selected by a number of equipment manufacturers for applications with a capacity range from several kW to 20MW and charges varying from 300g to 13mT:

- Air-cooled and water-cooled chillers
- District heating and cooling
- Heat pumps
- Refrigerators
- Vending machines
- Beverage dispensers
- Air dryers
- CO₂ cascade systems, etc.

Multi-awarded by the industry, Solstice® ze meets the criteria that are most important to refrigerant users: Performance, Cost Effectiveness, Environmental Impact and Safety.

Performance

Field tests of air-cooled chillers in similar systems comparing Solstice® ze with propane (R-290) show significantly lower energy consumption. In addition, compared to traditional refrigerants, the properties and operating characteristics of Solstice® ze are a very good match, but without the environmental penalty of high GWP HFCs.

Once the design of the application has been optimised to match capacity of HFC-134a, the advantage of Solstice® ze is higher energy efficiency or Coefficient of Performance (COP) than 134a across a range of applications and conditions. According to compressors experts, performance with HFOs can be further improved with optimisation of compressor design. Reciprocating, scroll, screw and centrifugal compressors can be used.

Other features of Solstice® ze:

- As Solstice® ze is a pure molecule it can be used in flooded systems
- The thermodynamic properties of Solstice® ze may benefit from a liquid-line/suction-line heat exchanger or other cycle modifications

Cost-effectiveness

Fast Implementation

Solstice® ze exhibits similar performance to medium-pressure refrigerants like 134a, so only minor considerations are required to use Solstice® ze.

Longer life of compressors

Solstice® ze Refrigerant lower discharge pressure results in less mechanical stress, thus extending the life of the compressor.

Energy Efficiency

Solstice® ze is more energy efficient in hot regions than competitive LGWP alternatives for this type of equipment.

Global Solution

Solstice® ze refrigerant provides efficient cooling in all global climate zones and is commercially available. Honeywell has invested in adding commercial-scale production capability of HFO-1234ze.

Environmental impact

Solstice® ze has a GWP of <1, exceeding existing climate protection goals.

- Helps with eco-design directives
- Reduces direct CO₂ emissions by 99.6 percent
- Reduces indirect CO₂ emissions due to the lower energy consumption
- Atmospheric life is only 18 days, much lower than the 13 years of 134a.

Safety

Solstice® ze Refrigerant is significantly safer in use than alternatives such as hydrocarbons and ammonia, which are either extremely flammable or highly toxic.

Atmospheric Decomposition of Solstice 1234ze

HFO-1234ze(E) breaks down into the same by-products of other commonly used fluorinated compounds at levels much lower than naturally present. F atoms degrade into HF which is then rained out and mineralised with no additional effect on Ozone or on Climate*.

* "We conclude that the products of the atmospheric oxidation of trans-CF₃CH=CHF will have negligible environmental impact." M.S. Javadat et. al.; Atmospheric Chemistry of Trans-CF₃CH=CHF in Atmospheric Chemistry & Physics Discussions,Vol8, pp 1089-1088, 2008
### Comparison 134a alternatives

<table>
<thead>
<tr>
<th></th>
<th>134a</th>
<th>1234ze</th>
<th>CO₂</th>
<th>R-600</th>
<th>R-290</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASHRAE class</td>
<td>A1</td>
<td>A2L</td>
<td>A1</td>
<td>A3</td>
<td>A3</td>
</tr>
<tr>
<td>GWP (rev 5th IPCC)</td>
<td>1300</td>
<td>&lt;1</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>LFL (vol% in air)*</td>
<td>N/A</td>
<td>7% **</td>
<td>N/A</td>
<td>1.80%</td>
<td>2.10%</td>
</tr>
<tr>
<td>UFL (vol% in air)*</td>
<td>N/A</td>
<td>12% **</td>
<td>N/A</td>
<td>8.40%</td>
<td>9.50%</td>
</tr>
<tr>
<td>Heat of Combustion (kJ/g)</td>
<td>4.2</td>
<td>10.7</td>
<td>N/A</td>
<td>45.6</td>
<td>46.3</td>
</tr>
<tr>
<td>Burning Velocity (cm/s)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>41</td>
<td>46</td>
</tr>
<tr>
<td>Minimum Ignition Energy (mJ)</td>
<td>N/A</td>
<td>61000 to 64000 ***</td>
<td>N/A</td>
<td>~0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>PED (97/23/EC) class</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Flammability for handling and storage</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Commercial availability</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Ease of adoption</td>
<td>Baseline</td>
<td>Moderate – Easy when systems can be designed</td>
<td>Difficult – Very sophisticated systems</td>
<td>Difficult – Flammability issues limit charge amounts</td>
<td>Difficult – Flammability issues limit charge amounts</td>
</tr>
<tr>
<td>Cost of adoption</td>
<td>Baseline</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

*Flame limits- ASTM E681-04 at 21°C; **(at 100ºC); *** (at 54°C)

### Degradation products of various fluorinated compounds

<table>
<thead>
<tr>
<th>Fluorinated compound</th>
<th>In use</th>
<th>In atmosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>134a</td>
<td>None known (hypothetically CF₂ = CHF)</td>
<td>TFA, CO₂, Acid gases (HF) (\rightarrow) Minerals like Caf₂</td>
</tr>
<tr>
<td>1234ze</td>
<td>None known (hypothetically CF₃-C = CH)</td>
<td>CO₂, Acid gases (HF) (\rightarrow) Minerals like Caf₂</td>
</tr>
</tbody>
</table>

### Future-proof

Solstice® ze is not subject to quota phase down in Fgas Regulation and given its ultra-low GWP<1, lower than the reference value of 1 for CO₂, is not subject to taxes or fees in those countries where those schemes apply.

### Package Sizes

Solstice® ze refrigerant is available in 890 kg rolldrum and ISO bulk. For other packing sizes please contact Honeywell distribution network.

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**Solstice® ze Refrigerant F-Gas Ready**

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**Future-proof**

Solstice® ze is not subject to quota phase down in Fgas Regulation and given its ultra-low GWP<1, lower than the reference value of 1 for CO₂, is not subject to taxes or fees in those countries where those schemes apply.
Simulation software
Honeywell's refrigerant modelling software is a free-download software program that eliminates the guesswork involved in selecting a refrigerant by allowing refrigeration engineers to run simulations based on actual data. The tool runs property calculations of refrigerants, conducts thermodynamic evaluations of air conditioning and refrigeration cycles, and provides a first principle thermodynamic comparison of new alternative refrigerants for retrofit applications or new system designs.

The software models systems from simplified basic cycles to large, complex refrigeration systems. The results can be exported to Microsoft Excel, where the data can be manipulated in a variety of ways. The software also creates typical Mollier diagrams (Pressure-Enthalpy, Temperature-Entropy). You can download the Genetron Refrigerants Modelling Software at https://www.honeywell-refrigerants.com/europe/genetron-refrigerants-modeling-software-download/

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Information and contact
For information and support on new applications, contact your local Honeywell representative, visit www.honeywell-refrigerants.com/europe or send us an email at fluorines.europe@honeywell.com

References
• IPCC WG AR – Chapter 8: Anthropogenic and Natural Radiative Forcing, February 2014
• Danfoss Turbocor Mostra presentation: The TG310 compressor with ultra-low GWP refrigerant HFO-1234ze, March 2014
• IOR (Institute of Refrigeration): R-1234ze for variable speed centrifugal chillers, April 2013
• Atmospheric Chemistry of Trans-CF3CH=CHF in Atmospheric Chemistry & Physics Discussions, Vol8, pp 1069-1088, 2008

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Viton® is a registered trademark of DuPont Dow Elastomers
Teix® is a registered trademark of Bayer AG
Kalrez® is a registered trademark of the E. I. DuPont Company

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The quality of our products
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