

Reducing Emissions of PFC Heat Transfer Fluids

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Abstract

Semiconductor manufacturing processes such as etch, plasma vapor deposition (PVD), ion implant and test require dielectric heat transfer liquids to maintain process or component temperatures. Both deionized-water-based liquids (DI water, DI water/glycol) and Perfluorocarbon (PFC) liquids [1] have traditionally been used in these applications. In a growing percentage of applications, PFCs are being used not only because they possess the requisite safety, performance, maintenance and dielectric properties but because they can span the temperature range of the application.

In a Memorandum of Understanding (MOU) with the EPA, various semiconductor manufacturers agreed to reduce their emissions of specific PFC gases, most of which are generated by plasma-aided processes. As these emissions are reduced, the percentage of PFC emissions attributable to PFC heat transfer liquids is growing. As soon as 2002, the global warming contribution of liquid emissions could exceed those of gaseous emissions in some facilities.

This paper discusses two different approaches for reducing PFC heat transfer liquid emissions. The first approach involves an on-site review of each system to identify and eliminate likely leaks and evaporative loss mechanisms. The second approach is the adoption of alternative liquids. Many of the alternatives usable beyond the temperature limitations of aqueous liquids are also flammable, corrosive or regulated for their toxicity. One class of alternatives, Segregated Hydrofluoroethers (HFEs), has no such limitations. These liquids have Global Warming Potentials (GWPs) that are 0.5-5% those of common PFC liquids. Their use requires little or no equipment modification the cost of these materials is similar to and often lower than PFCs.

1. Introduction

1.1 Gaseous PFC Emissions

The global warming effect of gaseous PFC emissions attributable to the semiconductor industry is generally agreed to be <0.4% of that attributable to other greenhouse gases. [2] The industry has nevertheless begun to voluntarily reduce its gaseous emissions of perfluorocompounds which come predominantly from the plasma processes etch and CVD. Its efforts were first evidenced in the 1996 Memorandum of Understanding (MOU) with the EPA. [3] As part of this agreement, several members of the Semiconductor Industry Association (SIA) agreed to reduce their emissions of greenhouse gases. In 1999 the WSC (World Semiconductor Council) established an international semiconductor industry goal to reduce absolute emissions of global warming gases. In 2001, the MOU was renewed with wider participation and more specific emission reduction goals. [4] Industry efforts resulting from these agreements have included: process optimization; abatement, capture and recycle programs; and the adoption of alternative plasma chemistries.

The industry's gaseous emission reduction strategies have been successful. Beu, et al [5] presented results of three Tier 2 methods developed by the WSC to estimate emissions of the MOU gases CF_4 , C_2F_6 , CHF_3 , C_3F_8 , $c-C_4F_8$, NF_3 and SF_6 from etch and PVD/CVD processes. These methods were applied to a typical, high volume 200mm wafer manufacturing facility. These data predict a strong downward trend between 1999 and 2002, a trend consistent with the goals of the MOU and the WSC.

¹ The term PFC, as it is used here, refers to a number of perfluorinated liquids including perfluoroalkanes, perfluoropolyethers and perfluoroamines. These are sold under the tradenames Galden™ and Fluorinert™.

² Determined using radiative forcing data from D. Wuebbles, "The effects of Perfluorocompounds on the Global Environment," Presentation at the Global Semiconductor Industry Conference on Perfluorocompound Emissions Control, Monterey Ca, April 7-8, 1998.

³ E. Dutrow, "A successful year in the Partnership," A Partnership for PFC Reduction, Semicon Southwest 97, Austin Convention Center, Austin Texas, October 13, 1997.

⁴ Semiconductor Firms Sign New MOU to Slash PFC Emissions by 2010, *Chemical Week*, Volume 16(5), March 15, 2001.

⁵ L. Beu, J. Peterson and P. Brown, "Analysis of IPCC Emissions Estimating Methodology," Partnership for PFC Emissions Reduction, Semicon Southwest, Austin, Texas, 16 October, 2000.

1.2 PFC Heat Transfer Fluid Emissions

Perfluorocarbon (PFC) liquids were first used as heat transfer media in the early 50s, primarily to cool sensitive military electronics. PFC liquids were used because they are chemically inert and non-flammable; they have high dielectric strength and electrical resistivity; and they evaporate cleanly. In the '70s and '80s these liquids debuted in the commercial sector where they were used to perform thermal test and reflow soldering operations and to cool supercomputers, lasers, x-ray targets, etc. In the early 1990s, the semiconductor manufacturing industry began using PFC liquids as heat transfer media to control component temperatures in ion implanters, dry etchers, deposition tools, steppers, automatic test equipment (ATE) and other tools. Deionized aqueous liquids (DI water and glycol) were being used in the industry at that time but applications were emerging that required the wider liquid range of PFCs. Today, as operating temperature ranges continue to widen, the functional limits of deionized liquids are being challenged and PFCs are being used in an increasing percentage of applications.

PFC liquids will evaporate when not contained. Given the long atmospheric lifetime of the PFC vapors, the vapors ultimately reach the upper atmosphere. Though published atmospheric data for PFC liquids are somewhat sparse, they indicate that PFC liquids have atmospheric lifetimes and IR cross sections similar to the PFC gases listed in the MOU. If the global warming properties of a PFC material (or the vapor of that liquid) have not been measured, it is standard practice to substitute C_6F_{14} [6] data as a means of estimating the environmental properties of that material. This practice is generally sound, however, there are perfluoropolyether liquids with GWPs as high as 11,500 [7] (the GWP of C_6F_{14} is 9,000 [8]).

On average, a typical high volume fab consumes 500 gallons of virgin PFC liquid during a year [9] when no manufacturing capacity is being added. Assuming C_6F_{14} properties, this equates to 0.0079 million metric tons of carbon equivalent (MMTCE) per fab per year. As these fluids are rarely incinerated or recycled, a fab's

fluid consumption equates roughly with what is emitted to the atmosphere via equipment leaks, evaporation and spills. Table 1 compares this PFC liquid emission to total (gas + liquid) MMTCE emissions using MOU gas emissions published by Beu.

These data show that even today emissions of PFC heat transfer liquids are a significant percentage of a facility's MMTCE emissions.

2. Reducing PFC Liquid Emissions

2.1 PFC Liquid Loss Prevention

A critical on-site review of a heat transfer system installation can often reveal causes of fluid loss. Causes of liquid leaks include inappropriate or damaged connections, inappropriate valves or pumps and others. An often overlooked mechanism is evaporative loss resulting from temperature cycles. [10] An understanding of this mechanism can, in some instances, reduce losses dramatically.

When effective, the loss reduction strategy will immediately reduce liquid costs with a nominal investment of time and little or no cost. It can also reduce service time and prevent false Fluorine alarm triggers, etc. However, the effectiveness varies widely. On average, losses are reduced no more than 20%.

2.2 Alternative Liquids

The most effective strategy for reducing global warming emissions resulting from PFC liquids is replacement of these liquids with low-GWP alternatives. While a variety of alternatives can satisfy the temperature requirements of semiconductor applications, many suffer limitations that make their use impractical. [11] For example, petroleum-based products, silicone oils and citrus-based oils tend to be flammable or unstable. Chlorofluorocarbons are ozone depleting and other chlorinated materials like dichloroethylene, trichloroethylene and methylene chloride are either flammable, unstable or highly regulated.

⁶ In lieu of accurate environmental data for PFCs of higher boiling point, the US EPA recommends use of perfluorohexane data (Inventory of US Greenhouse Gas Emissions and Sinks: 1990-1996, US EPA Doc EPA236-R-98-006, 1998).

⁷ 3M Technical Report, J. G. Owens and L. Tousignant, "Measured IR Cross-Sections and GWPs for FC-3283 and HT-135," June 2001.

⁸ Based on an integration of the radiative forcing effect over a 100 year period or integrated time horizon (ITH). Scientific Assessment of Ozone Depletion: 1998, WMO Global Ozone Monitoring Project, Report No. 44.

⁹ Based on 3M market studies.

¹⁰ Tuma, P.E. and Tousignant, L., Modeling Vapor Leak Rate and System Pressures for Single Phase Heat Transfer Systems that Utilize Fluorinated Heat Transfer Liquids, To be published.

¹¹ Tuma, P.E., "Segregated Hydrofluoroethers: Long Term Alternative Heat Transfer Liquids," Proceedings of the 2000 Earth Technologies Forum, Oct.30-Nov.1, Washington D.C., pp. 266-275.

2.3 Utility of Segregated Hydrofluoroether (HFE) Heat Transfer Liquids

Though a variety of HFEs have been synthesized, their performance and environmental properties and hence their utility can vary widely. [12] Research has shown that segregated HFE liquids, as a class, have a desirable balance of properties. The term “segregated” refers to HFEs that possess a perfluorocarbon segment separated or “segregated” from a fully hydrocarbon segment by an ether oxygen. Examples include the structures shown in Table I and discussed in this work [13]: $C_3F_7OCH_3$, $C_4F_9OCH_3$, $C_4F_9OC_2H_5$ and $C_3F_7CF(OC_2H_5)CF(CF_3)_2$. These liquids possess a balance of properties that makes them well suited for semiconductor heat transfer applications.

2.3.1 Environmental Properties

Like PFCs, the aforementioned HFEs are non-ozone depleting. Because they are not photolyzed in the lower atmosphere where breakdown products would contribute to atmospheric smog formation, the US EPA and most state agencies have exempted $C_4F_9OCH_3$ and $C_4F_9OC_2H_5$ from the definition of a volatile organic compound (VOC). As the relevant properties of $C_3F_7OCH_3$ and $C_3F_7CF(OC_2H_5)CF(CF_3)_2$ are similar, they too are expected to receive this exemption.

In the troposphere, reactive hydroxyl radicals quickly break down these HFE molecules, resulting in short atmospheric lifetimes and GWPs that are 0.6-5% that of C6F14. The GWPs and atmospheric lifetimes of the segregated hydrofluoroethers, as a class, are significantly lower than the hydrofluoropolyethers (HFPEs) described by Marchionni. [14] This is shown in Figure 1. The segregated HFE chemistry has been commended for this quality [15] through numerous environmental awards. [16,17,18,19]

2.3.2 Useful Temperature Range

The temperature range of the segregated HFEs is shown in Figure 2 along with DI water and a 50% ethylene glycol solution. The lower limit for HFEs and for DI glycol is defined here as the temperature at which the viscosity reaches 30 centiStokes (cSt). There are two upper temperature limits shown for the HFEs. The first of these, which is shown in white, is the boiling point of the fluid. This is the practical limit for semiconductor systems which tend to operate at low or ambient pressure. The second limit, which is shown in grey, is the thermal stability limit. It is more relevant for high pressure systems. The upper limit for DI fluids is dependent upon the desired resistivity which, in turn, dictates the corrosiveness of the fluid. For example, DI water with resistivity of 10 Mohm-cm will function well in stainless steel at 25°C but may cause corrosion at 60°C. DI liquids cannot generally be used above 80°C.

The Semiconductor Industry’s transition from PFC liquids to HFEs has been limited primarily by the boiling points of commercially available segregated HFEs. $C_4F_9OCH_3$ (boiling point 61°C) has been available commercially since 1996 and has been used in Automatic Test Equipment (ATE) since 1997. Before 2000, the highest boiling point HFE, $C_4F_9OC_2H_5$, had a boiling point of 76°C and could not be used above about 70°C. This limitation prevented use of HFE liquids in what have typically been higher temperature applications like etch and PVD.

$C_3F_7CF(OC_2H_5)CF(CF_3)_2$ became commercially available in 2000. Its 130°C boiling point and low temperature properties allow it to span the bulk of applications in the industry. This fluid has already been qualified by major etch and CVD manufacturers and is now an option on some equipment platforms. HFEs that meet the requirements of higher temperature applications like thermal shock (i.e. Military Standard 883) are under development.

¹² Bivens, D.B., and Minor, B.H., “Fluoroethers and other Next-Generation Fluids,” ASHRAE/NIST Refrigerants Conference, October 1997, pp. 122-134.

¹³ $C_4F_9OCH_3$, $C_4F_9OC_2H_5$ and $C_7F_{15}O_2H_5$ sold commercially as 3M™ Novec™ Engineered Fluid HFE-7100, HFE-7200 and HFE-7500, respectively. $C_3F_7OCH_3$ is currently under development by 3M.

¹⁴ G. Marchionni, et al, “Hydrofluoropolyethers,” *Journal of Fluorine Chemistry*, 95, 1999, pp. 41-50.

¹⁵ Correspondence with Anhar Karimjee, SNAP Team Leader, Global Programs Division, US EPA, January 2001.

¹⁶ 1997 American Chemical Society “Heroes of Chemistry Award” in the category of Chemistry and the Environment for development of segregated hydrofluoroethers as alternatives to ozone-depleting materials.

¹⁷ In April 1999 $C_4F_9OC_2H_5$ was designated a “Clean air Solvent” by the South Coast Air Quality Management District.

¹⁸ $C_4F_9OCH_3$ and $C_4F_9OC_2H_5$ are approved for “use without restriction” under the US EPA’s Significant New Alternatives Program (SNAP) which regulates the use of new materials in such chlorofluorocarbon (CFC) replacement applications as solvent, refrigeration, heat transfer, and others.

¹⁹ The United Nations Environment Programme (UNEP) Technology and Economic Assessment Panel has recognized HFEs as meaningful low-GWP replacements for ozone depleting substances, HFCs and PFCs.

For the extreme low temperature requirements that are emerging in some copper PVD and test applications, $C_3F_7OCH_3$ is available and has been used to $-116^{\circ}C$.

Many PFC liquids are distillation fractions which are composed of a variety of molecules of differing molecular weight. When such a fluid is lost from a system by evaporation the average molecular weight of the remaining fluid rises resulting in higher viscosity and reduced low temperature performance. This is not true of the segregated HFEs discussed in this work.

2.3.3 System Compatibility

While many of the industry's strategies for reducing gaseous PFC emissions are relatively straightforward, others have required significant development effort and capital investment. In contrast, the conversion of a well-designed PFC heat transfer system to operate with HFEs often requires no retrofit at all. To determine whether an HFE can be "dropped into" an existing PFC system, the following must be reviewed:

- 1) Like PFC liquids, segregated HFEs are inert to common metals and hard polymers [20] and are even being used in direct contact cooling of electronics. HFEs do, however, have some solvency for many of the additives and plasticizers commonly added to elastomers. Heavily plasticized elastomers may shrink or become brittle while relatively pure elastomeric polymers perform well. For this reason, no sweeping statements can be made about the compatibility of the various types. Attention must be paid to the particular formulation.
 - a) O-rings and seals should be made of Fluoroelastomers previously used successfully in a PFC system or hydrocarbon-based elastomers (i.e. butyl, nitrile, EPDM, silicone, etc.) specifically tested or otherwise known to be low in extractable material. 3M maintains databases of compatible materials and also provide free testing services.
 - b) TFE, PFA or thermoplastic hoses that have been used in PFC systems generally perform well with HFEs. Elastomeric or "rubbery" tubing/hoses should be low in extractable material.

HFE fluids can generally be dropped into existing systems that conform to the criteria mentioned above provided the HFE's electrical properties are adequate.

2.3.4 Electrical Properties

At ~ 40 kV for a 0.1 inch gap, the dielectric strength of the segregated HFEs is similar to that of a PFC. The electrical resistivity of these HFEs is typically 108 ohm-cm while PFC liquids are typically 1015ohm-cm. This reduction is the result of hydrogen present on the HFE molecules and, as such, is a natural consequence of their reduced GWP. The reduced resistivity of HFEs is very rarely an issue as DI water, whose resistivity rarely exceeds 107ohm-cm, is commonly used when its other properties permit. The dielectric constant of a PFC liquid is usually less than 2 while HFE liquids have dielectric constants as high as 8. Lastly, because HFEs absorb in the microwave portion of the electromagnetic spectrum, they are not suited for cooling in some plasma generation applications.

2.3.5 Performance

The physical properties of HFE fluids are generally superior to PFC fluids of similar boiling point. This is shown in Table 2. HFEs generally have slightly higher specific heat and lower viscosity and density than PFCs of similar boiling point. These characteristics are advantageous in most heat transfer applications as they bring about reduced pumping power, better heat transfer performance and a wider useful temperature range. The utility of HFEs has been demonstrated in a variety of applications. [21,22]

2.3.6 Stability

When used below their boiling point, the HFE fluids shown in Figure 1, like PFCs, should not require replacement. Their operational lifetimes above the boiling point and below the thermal stability limit (grey region in Figure 2) depend largely upon the amount of time spent at that temperature and the amount of water present. A lifetime of many years is expected if the system is kept dry.

In some applications, it is possible to exceed the limitations indicated in Figure 1. Often the pump is turned off while a relatively brief high temperature operation is performed on some sub-portion of the system. An example is a PVD system in which the chuck is periodically "baked out" to remove residue that accumulates during processing. If the system is plumbed properly, it is possible to maintain only a small amount of superheated HFE vapor within the chuck during this operation.

²⁰ Tuma, P.E., "Using Segregated HFEs as Heat Transfer Fluids - Avoiding problems in system design," *Chemical Processing*, February 2001, pp. 47-50.

²¹ Tuma, P.E., "Hydrofluoroethers as Low-Temperature Heat-Transfer Liquids in the Pharmaceutical Industry," *Pharmaceutical Technology*, March 2000, pp.104-116.

²² Tuma, P.E. and Tousignant, L., "New "Green" Heat Transfer Liquids," *Solid State Technology*, June 2000, pp.175-182.

Not only is the amount of fluid represented by this vapor a small percentage of the overall system charge, but the kinetics of thermal decomposition are different in this vapor than in liquid heated under pressure to the same temperature. It has been shown experimentally, for example, that $C_4F_9OCH_3$ can be used in some PVD applications safely and without corrosion even at a bakeout temperature of 275°C. [23]

2.3.7 Safety and Health

Because heat transfer systems are contained, worker exposure to HFE fluids once they're installed in a system are exceedingly low. Significant exposures are limited to filling and draining operations. Industrial hygiene experiments have been conducted with $C_4F_9OCH_3$ and $C_3F_7CF(OC_2H_5)CF(CF_3)_2$ for typical filling scenarios including 10 ft² spills. Worker exposures, as measured by FTIR, show acute exposures well below the guideline for an 8-hour work day. [24]

These materials are both very low in acute toxicity. Table 2 summarizes toxicological data for $C_4F_9OCH_3$ and $C_4F_9OC_2H_5$. The American Industrial Hygiene Association (AIHA) has set an 8-hour worker exposure guideline of 750 parts per million (ppm) for $C_4F_9OCH_3$ based on the results of a 90-day inhalation study. This material is not a cardiac sensitizer at >100,000 ppm and is non irritating to the skin and eyes.

Toxicity tests conducted by Sekiya and Misaki [25] with $C_3F_7OCH_3$ resulted in an acute oral LD₅₀ of >2000 mg/kg. Inhalation tests conducted 6 hours per day for 7 days showed a NOEL of >7.0 g/m³ (850 ppmv). The compound tested negative in the Ames mutagenicity test and was not a skin irritant. 3M has corroborated that $C_3F_7OCH_3$ is low in both acute and sub-acute toxicity. A 28-day inhalation study was conducted at 1000, 10,000 and 30,000 ppm. The No Adverse Effect Level (NOAEL) in this study was 1000 ppm. This data suggests there is a large margin of safety for use of this HFE in relatively non-emissive heat transfer systems.

Toxicity tests conducted to date with $C_3F_7CF(OC_2H_5)CF(CF_3)_2$ indicate this compound exhibits a very low order of toxicity. For instance, the acute oral LD₅₀ for this compound is greater than 2000

mg/kg. $C_3F_7CF(OC_2H_5)CF(CF_3)_2$ is not classified as either an eye or skin irritant. The molecule tested negative in two mutagenicity screens, the Ames assay and the chromosomal aberration assay. In a 28-day feeding study, no adverse health effects were observed at a dosing level of 1000 mg/kg body weight.

None of the HFEs described herein has an open-cup or closed-cup flash point. They are therefore assigned NFPA (National Fire Protection Association) flammability indices of zero.

For all of these reasons, these four materials are not regulated for transport nor are they considered hazardous air pollutants.

3. Conclusions

- A fab's PFC heat transfer liquid emissions are a significant and growing portion of its total PFC emissions.
- Use of commercially available segregated HFE liquids can reduce global warming emissions attributable to PFC liquids by 95% to over 99.5%.
- The performance properties of these segregated HFEs are generally superior to existing PFC liquids. The electrical properties are an exception and may preclude HFE use in some applications.
- Conversion of a PFC system to operate with a segregated HFE is often a "drop-in" procedure or may simply require an O-ring or hose replacement.
- These segregated HFEs are nonflammable; they have favorable toxicological properties; they are not regulated for transport or use; and they cost about the same as PFCs.

²³ P. Tuma and L. Tousignant, Experimental Study of the Decomposition of HFE-7100 Vapor in a Billet of TI-6AL-4V During Bakeout at 275°C, 3M internal report, August 2000.

²⁴ T. Gutzkow, Comprehensive Industrial Hygiene Test Report, 3M Internal report, Lab request EL1184, February 14, 2000.

²⁵ A. Sekiya and S. Misaki, "The potential of hydrofluoroethers to replace CFCs, HCFCs and PFCs," *Journal of Fluorine Chemistry*, 101, 2000, pp. 215-221.

Figure 1

GWPs (100-year ITH) of segregated HFEs compared to other HFEs and to PFCs.

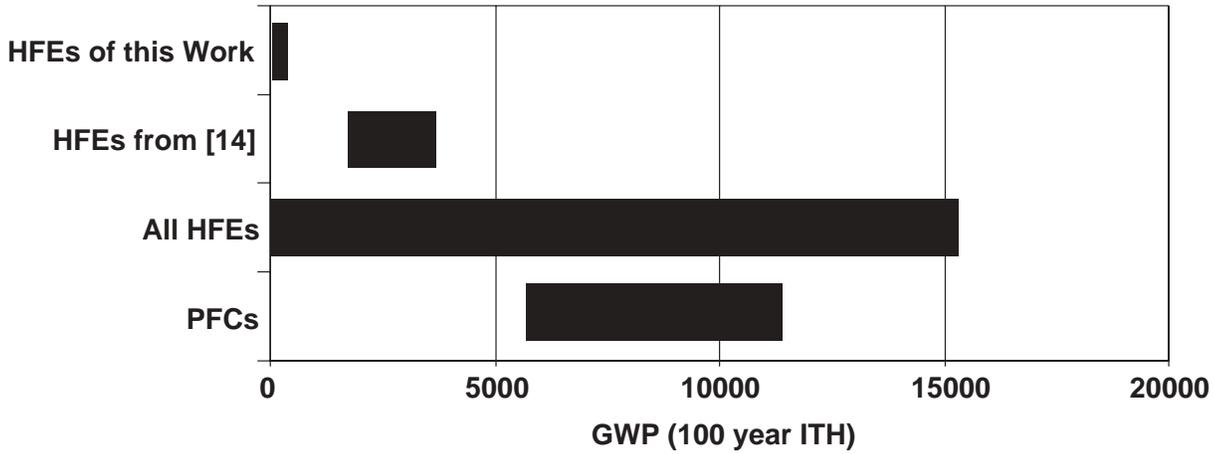


Figure 2

Operating Temperature of Segregated HFE Liquids

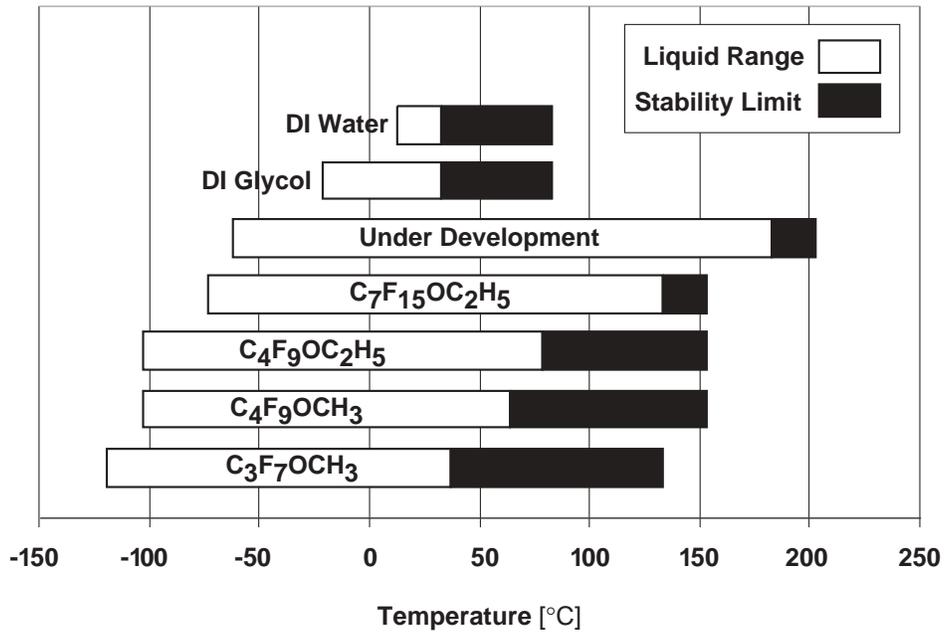


Table 1

Compares PFC liquid emissions to total (gas + liquid) MMTCE emissions using MOU gas emissions published by Beu.

	Total MMTCE Gaseous	PFC liquid % of Total
1999 Tier 2a	0.03904	16.8
1999 Tier 2b	0.03401	18.8
1999 Tier 2c	0.03468	18.5
2002 Tier 2a	0.00642	55.2
2002 Tier 2b	0.01105	41.7
2002 Tier 2c	0.00756	51.1

Table 2

Physical Properties of segregated HFEs compared to common PFCs.

Property	Low Temperature						Medium Temperature		
	HFE HFE-7000 ¹ C ₃ F ₇ OCH ₃	Fluorinert FC-87 ¹	HFE HFE-7100 ¹ C ₄ F ₉ OCH ₃	Fluorinert FC-72 ¹	HFE HFE-7200 ¹ C ₄ F ₉ OC ₂ H ₅	Galden HT-70 ²	HFE HFE-7500 ¹ C ₇ F ₁₅ OC ₂ H ₅	Fluorinert FC-3283 ¹	Galden HT-135 ²
Atmospheric Lifetime [yrs]	4.7	4100	4.1	3200	0.8	3200	2.5	2000	N/A
GWP (100 year 1TH)	400	8900	320	9000	55	9000 ³	210	8600	N/A
Boiling Point [°C]	34	30	61	56	76	70	128	128	135
Pour Point [°C]	-122.5	-115	-138	-90	-135	<-110	-100	-50	<-100
Useful low Temperature [°C] ⁴	-122.5	-115	-106	-90	-106	-93	-75	-50	-67
Density [kg/m ³]	1400	1650	1420	1680	1510	1680	1614	1820	1730
Coefficient of Expansion [1/°C]	0.00219	0.0015	0.0016	0.0016	0.0018	0.0011	0.00129	0.0014	0.0011
Specific Heat [J/kg-K]	1300	1100	1220	1100	1180	960	1128	1050	960
Thermal Conductivity [W/m-K]	0.075	0.056	0.068	0.057	0.069	0.07	0.065	0.066	0.07
Viscosity [cSt] at 25°C at -40°C	0.32 0.78	0.28 0.76	0.37 1.1	0.38 1.17	0.44 1.26	0.5 1.79	0.77 3.55	0.75 4.26	1.00 6.33
Dielectric Strength [kV, 0.1 inch gap]	~40	~40	~40	~40	~40	40	~40	~40	40
Dielectric Constant	7.4	1.7	7.3	1.75	7.4	2.1	5.8	NA	2.1
Electrical Resistivity [ohm-cm]	1.E+08	1.E+15	1.E+08	1.E+15	1.E+08	1.E+15	1.E+08	1.E+15	1.E+15

N/A = Not available

¹ Properties for Fluorinert™ and Novec™ materials were taken from 3M Product Literature.² Properties for Galden HT-70 and HT-135 were taken from Ausimont product literature “Galden® Heat Transfer Fluids.”³ The US EPA recommends the use of C₆F₁₄ data for perfluorocarbons where measured data are not available (Inventory of US Greenhouse Gas Emissions and Sinks: 1990-1996, US EPA Doc EPA236-R-98-006, 1998).⁴ The useful low temperature was defined as the higher of the freezing temperature and the temperature at which the fluid kinematic viscosity reached 30 cSt.**Table 3**Toxicological data for C₄F₉OCH₃ and C₄F₉OC₂H₅.

	C ₄ F ₉ OCH ₃	C ₄ F ₉ OC ₂ H ₅
Acute Lethal Conc., 4 hr LC50, ppmv	> 100,000	>92,000
Oral Toxicity	Practically non-toxic (>5 g/kg)	Practically non-toxic (>5 g/kg)
Mutagenicity	Negative	Negative
Cardiac Sensitization Threshold, ppmv	>100,000	>20,000
Ocular Irritant	No	Mimimally Irritating
Dermal Irritant	No	No
Exposure Guideline 8 hr TWA, ppmv	750	200
Exposure Ceiling, ppmv	None	None

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